BULLETIN

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INFORMATION FOR STUDENTS

1968 / 1969

INFORMATION FOR STUDENTS 1968-1969

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA · CALIFORNIA

SEPTEMBER 1968

CONTENTS

ACADEMIC CALENDAR

1968-69

1968 — FIRST TERM

September 26	Registration of entering freshmen—8:00 a.m. to 10 a.m.
September 26-28	Student Camp.
September 30	General Registration—8:30 a.m. to 3:30 p.m.
September 30	Undergraduate Academic Standards and Honors Committee—3:00 p.m.
October 1	Beginning of instruction—8:00 a.m.
October 18	Last day for adding courses.
October 19	Examinations for the removal of conditions and incompletes.
October 26	Parents' Day.
November 4-8	Mid-Term Week.
November 8	Last day for admission to candidacy for Masters' and Engineers' degrees.
November 9	MID-TERM.
November 11	Mid-Term deficiency notices due—9:00 a.m.
November 12	Freshman-Sophomore MUDEO.
November 15	Last day for dropping courses.
November 18-22	Pre-registration for second term, 1968-69.
Nov. 28-Dec. 1	Thanksgiving recess.
November 28, 29	Thanksgiving holidays for employees.
December 14-20	Final Examinations—first term, 1968-69.
December 21	End of first term, 1968-69.
Dec. 22-Jan. 5	Christmas vacation.
December 23	Instructors' final grade reports due—9:00 a.m.
December 25	Christmas holiday for employees.

1969 — SECOND TERM

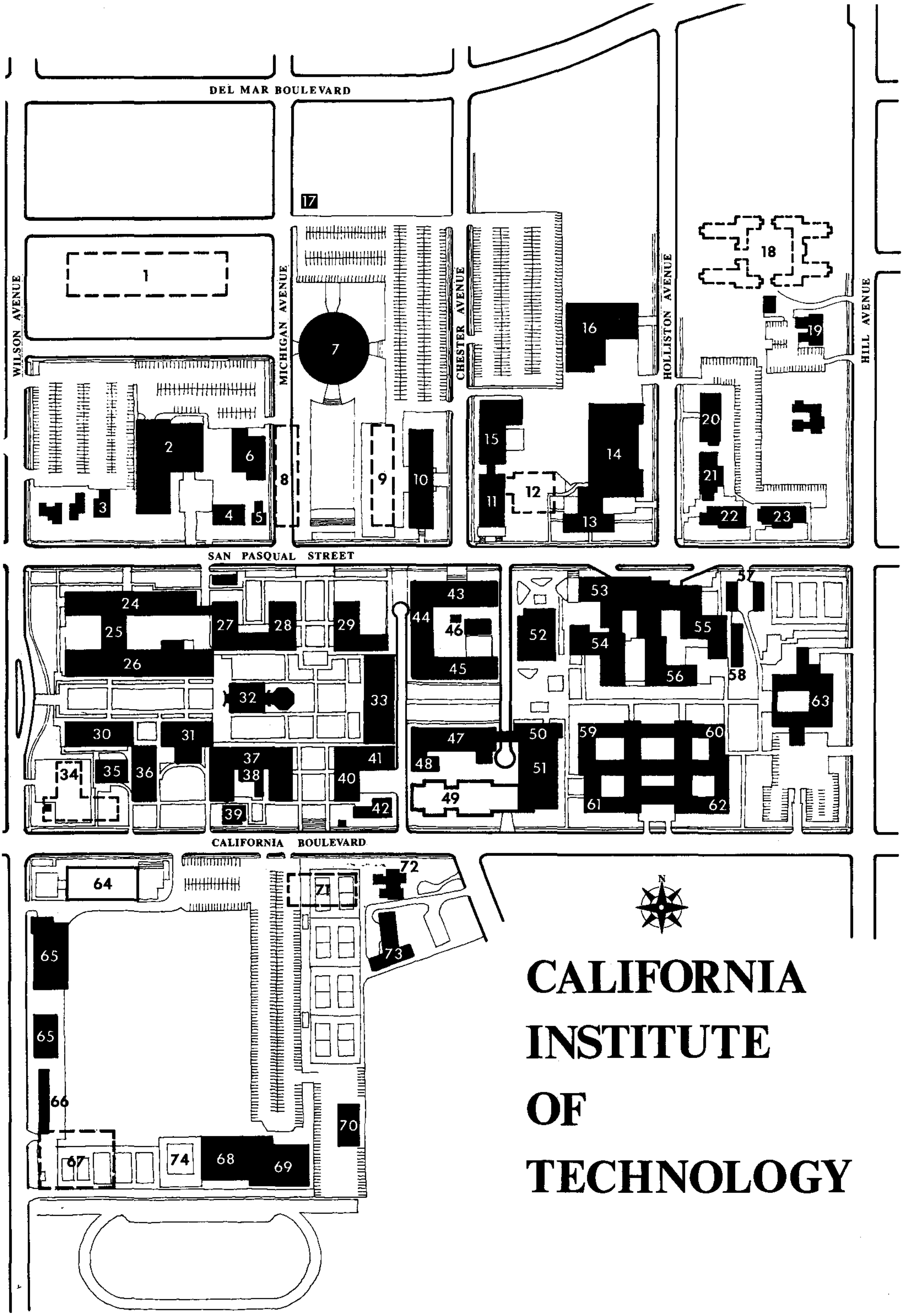
January 1	New Year's Day holiday for employees.
January 3	Undergraduate Academic Standards and Honors Committee—9:00 a.m.
January 6	General Registration—8:30 a.m. to 3:30 p.m.
January 7	Beginning of instruction—8:00 a.m.
January 24	Last day for adding courses.
January 25	Examinations for the removal of conditions and incompletes.
February 3-7	Mid-Term Week.
February 8	MID-TERM.
February 10	Mid-Term deficiency notices due—9:00 a.m.
February 14	Last day for dropping courses.
February 22	Students' Day.
February 24-28	Pre-registration for third term 1968-69.
March 15-21	Final examinations—second term, 1968-69.
March 21	Last day for obtaining admission to candidacy for the degree of Doctor of Philosophy.
March 22	End of second term, 1968-69.
March 23-30	Spring Recess.
March 24	Instructor's final grade reports due—9:00 a.m.
March 28	Undergraduate Academic Standards and Honors Committee—9:00 a.m.

1969 — THIRD TERM

March 31	General Registration—8:30 a.m. to 3:30 p.m.
April 1	Beginning of instruction—8:00 a.m.
April 18	Last day for adding courses.

1969	THIRD TERM (continued)
April 19	Examinations for the removal of conditions and incompletes.
April 28-May 2	Mid-Term Week.
May 3	MID-TERM.
May 5	Mid-Term deficiency notices due—9:00 a.m.
May 9	Last day for dropping courses.
May 16, 17	Examinations for admission to upper classes, September 1969.
May 19	Registration for summer research (graduate students).
May 19-23	Pre-registration for first term, 1969-70, and registration for undergraduate summer research.
May 29	Last day for final oral examinations and presenting of theses for the degree of Doctor of Philosophy.
May 29	Last day for presenting theses for Engineer's degree.
May 30	Memorial Day holiday.
May 30	Memorial Day holiday for employees.
May 31-June 6	Final examinations for senior and graduate students, third term, 1968-69.
June 7-13	Final examinations for undergraduate students, third term, 1968-69.
June 9	Instructor's final grade reports due for senior and graduate students—9:00 a.m.
June 11	Curriculum Committee—10:00 a.m.
June 11	Faculty Meeting—2:00 p.m.
June 12	Class Day.
June 13	Commencement—4:30 p.m.
June 14	End of third term, 1968-69.
June 16	Instructors' final grade reports due for undergraduate students—9:00 a.m.
June 20	Undergraduate Academic Standards and Honors Committee—9:00 a.m.
July 4, 5	Independence Day holidays for employees.
September 1	Labor Day holiday for employees.

1969	FIRST TERM 1969-70
September 25	Registration of entering freshmen—8:00 a.m. to 10:00 a.m.
September 25-27	Student Camp.
September 29	General Registration—8:30 a.m. to 3:30 p.m.
September 30	Beginning of instruction—8:00 a.m.



CALIFORNIA INSTITUTE OF TECHNOLOGY

CAMPUS DIRECTORY

INFORMATION DESK

ROOM 21, THROOP HALL, BUILDING NO. 33

25. Alles Laboratory (Molecular Biology)
74. Alumni Swimming Pool
72. Arden House (Residence of Master of Student Houses)
31. Arms Laboratory (Geological Sciences)
1. Astrophysics (Future)
63. Athenaeum (Faculty Club)
7. Beckman Auditorium
8. Behavioral Biology (Future)
62. Blacker House (Undergraduate Residence)
52. Bookstore (Student Center)
11. Booth Computing Center
12. Booth Addition (Future)
22. Braun House (Graduate Residence)
37. Bridge Laboratory (Physics)
69. Brown Gymnasium
66. Building T1 (Air Force ROTC)
58. Building T4
70. Building T6 (Development Offices)
64. Business Services (Administration)
4. Campbell Laboratory (Plant Research)
16. Central Engineering Services
65. Central Plant
53. Chandler Dining Hall
44. Chemical Engineering Laboratory
24. Church Laboratory (Chemical Biology)
38. Cosmic Ray Laboratory
27. Crellin Laboratory (Chemistry)
35. Culbertson Hall (Auditorium)
71. Cyclotron (Future)
29. Dabney Hall (Humanities and Social Sciences)
61. Dabney House (Undergraduate Residence)
5. Dolk Laboratory (Plant Physiology)
6. Earhart Laboratory (Plant Research)
50. Firestone Laboratory (Flight Sciences)
59. Fleming House (Undergraduate Residence)
28. Gates Laboratory (Chemistry)
34. Geophysics Laboratory (Future)
18. Graduate Houses (Future)
42. Graphic Arts and Safety Office
47. Guggenheim Laboratory (Aeronautics)
49. High Energy Physics
9. Humanities Building (Future)
19. Industrial Relations Center
39. Isotope Handling Laboratory
48. Karman Laboratory
10. Keck Laboratory
20. Keck House
41. Kellogg Radiation Laboratory
26. Kerckhoff Laboratory (Biological Sciences)
3. Language Laboratory
56. Lloyd House (Undergraduate Residence)
58. Locker Rooms
23. Marks House (Graduate Residence)
32. Millikan Library
21. Mosher-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)
67. Physical Education Building (Future)
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
51. Synchrotron
45. Thomas Laboratory (Civil & Mechanical Engineering)
17. Ticket Agency
33. Throop (Administration)
52. Winnett Student Center
52. Y.M.C.A.
73. Young Health Center

OFF-CAMPUS UNITS

Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena

Kerckhoff Marine Laboratory
Corona Del Mar, California

Radio Astronomy Observatory
Owens Valley, California

Palomar Observatory
Mayer Observatory (Future)
Palomar Mountain
San Diego County, California

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

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Floyd B. Humphrey, Ph.D. .... *Electrical Engineering*
Wilfred D. Iwan, Ph.D. .... *Applied Mechanics*
Paul C. Jennings, Ph.D. .... *Applied Mechanics*
Toshi Kubota, Ph.D. .... *Aeronautics*
Hardy C. Martel, Ph.D. .... *Electrical Engineering*
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Fredric Raichlen, Sc.D. .... *Civil Engineering*
Jerome L. Shapiro, Ph.D. .... *Applied Science*
Rangasami Sridhar, Ph.D. .... *Electrical Engineering*
Bradford Sturtevant, Ph.D. .... *Aeronautics*
David F. Welch, I.D. .... *Engineering Design*

*In residence 1967-68

SENIOR RESEARCH FELLOWS

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Lewis G. Bishop, Ph.D. .... *Applied Science*
James E. Broadwell, Ph.D. .... *Aeronautics*
L. Edward Fraenkel,* M.Sc. .... *Saul Kaplun Fellow in Applied Mathematics*
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Arnold H. Kadish, M.D. .... *Engineering*
Jia-Ding Lin, Sc.D. .... *Engineering Science*
Peter C. Lockemann, Dr. Ing. .... *Engineering*
Rokuro Muki,* Ph.D. .... *Applied Mechanics*
Evert J. Post,* Ph.D. .... *Electrical Engineering*
Eric Varley,* Ph.D. .... *Applied Mathematics*
Milosz P. Wnuk,* Ph.D. .... *Aeronautics*
Robin A. Wooding, Ph.D. .... *Hydraulics*

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Boris Auksmann, Ph.D. .... *Engineering Design*
Wilhelm Behrens, Ph.D. .... *Aeronautics*
Robert S. Harp, Ph.D. .... *Electrical Engineering*
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RESEARCH FELLOWS

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Nagendra Singh, M.S.
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Ira Robert Snyder, B.S.
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William Arthur Stinger, B.S.E.
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Brian Hyman Tabak, B.Eng.
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Thane McColloh, Ph.D. .... *Geology*

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*On leave of absence 1968-69
**On leave of absence, first term

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Rochus E. Vogt, Ph.D. . . . . *Physics*

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Ricardo Gomez, Ph.D. . . . . *Physics*
Kristofer Kolltveit, cand.real. . . . . *Physics*
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David Boyd, Ph.D. . . . . *Mathematics*
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Edward C. Stone, Jr., Ph.D. . . . . *Physics*
David B. Wales, Ph.D. . . . . *Mathematics*

*On leave of absence, second term, 1968-69
**On leave of absence, 1968-69

VISITING ASSISTANT PROFESSOR

Allan J. Ellis, Ph.D. .... *Mathematics*

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Richard B. Read, Ph.D.
Bruce H. Rule, B.S.
George A. Seielstad, Ph.D.
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William D. Arnett, Ph.D. .... *Physics*
Daniel Ashery, Ph.D. .... *Physics*
Glenn L. Berge, Ph.D. .... *Radio Astronomy*
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John L. Fanselow, Ph.D. .... *Physics*
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Roberto Fanti, Ph.D. .... *Radio Astronomy*
Edward B. Fomalont, Ph.D. .... *Radio Astronomy*
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[1]Ford Foundation Research Fellow, 1968-69
[2]Harry Bateman Research Fellow, 1968-69
[3]Richard Chace Tolman Research Fellow, 1968-69

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Department of Athletics and Physical Education

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James H. Nerrie, B.S.
Edward T. Preisler, B.A.
Lawlor M. Reck, M.A.

TEAM PHYSICIAN

John E. Lusche, M.D.

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Paul G. Barthel, M.A.

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Delmar Calvert, B.M.
Harold G. Cassriel, B.S.
Ronald W. Kehoe
John L. Lamb
Tsutomu Ohshima, B.A.
Hudson L. Scott, M.S.
Raymond Wallace

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R. Stewart Harrison, M.D. .... *Assistant Director and Consultant in Radiology*
Daniel C. Siegel, M.D. .... *Consulting Psychiatrist*
N. Y. Matossian, M.D. .... *Attending Physician*
Robert L. Boardman, M.D., ... *Attending Physician*
Kenneth W. Eells, Ph.D. .... *Institute Psychologist*
Alice A. Shea, R.N. .... *Nursing Director*

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Olaf Frodsham, M.A. .... *Director of Choral Music*
Priscilla C. Remeta, M.A. .... *Assistant Director of Choral Music*

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A.B., Cornell College (Iowa), 1922; A.M., University of Wisconsin, 1924; Ph.D., 1926. California Institute, 1946-. (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-. (Karman)

John T. Adams, Ph.D., *Research Fellow in Chemistry*
B.S., Arkansas State University, 1964; Ph.D., 1968. California Institute, 1968-69.

David George Agresti, Ph.D., *Visiting Associate in Materials Science*
B.S., The Ohio State University, 1959; M.S., California Institute, 1962; Ph.D., 1967. Assistant Professor of Physics, California State College, Los Angeles, 1967-. Research Fellow in Physics, California Institute, 1967; Visiting Associate in Materials Science, 1968.

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-. (Church)

Marc L. Alleaume, D.Sc., *Research Fellow in Chemistry*
B.S., University of Poitiers, 1953; D.Sc., University of Bordeaux, 1967. California Institute, 1967-68.

Nadine Alleaume, D. Sc., *Research Fellow in Applied Science*
B.S., University of Bordeaux, 1950; D.Sc., 1960. California Institute, 1967-68.

Clarence Roderic Allen, Ph.D., *Professor of Geology and Geophysics; Acting Chairman, Division of Geological Sciences*
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 Chairman, 1967-. (Arms)

Yosef Aloni, Ph.D., *Research Fellow in Biology*
M.Sc., Tel-Aviv University, 1963; Ph.D., Weizmann Institute, 1968. California Institute, 1968-69.

Carl David Anderson, Ph.D., Sc.D., LL.D., Nobel Laureate, *Professor of Physics; Chairman, Division of Physics, Mathematics and Astronomy*
B.S., California Institute, 1927; Ph.D., 1930. Research Fellow, 1930-33; Assistant Professor, 1933-37; Associate Professor, 1937-39; Professor, 1939-; Division Chairman, 1962-. (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, 1968-69. (Mudd)

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)

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)

**Part-time

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, 1968-69. (Firestone)

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.)

Richard Lee Armstrong, Ph.D., *Visiting Associate in Geology*
B.S., Yale University, 1959; Ph.D., 1964. Assistant Professor of Geology, 1964-. California Institute, 1969.

William David Arnett, Ph.D., *Research Fellow in Physics*
B.S., University of Kentucky, 1961; M.S., Yale University, 1963; Ph.D., 1966. California Institute, 1967-. (Kellogg)

Halton Christian Arp, Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
A.B., Harvard College, 1949; Ph.D., California Institute, 1953. Mt. Wilson Observatory, 1957-. (Mt. Wilson Office)

Ulla Asgaard, M.Sc., *Visiting Associate in Paleoecology*
M.Sc., University of Copenhagen, 1962. Staff member, Geological Institute, Copenhagen, 1964-. California Institute, 1967-68.

Michael Ashburner, Ph.D., *Research Fellow in Biology*
B.A., Churchill College, University of Cambridge, 1964; M.A., Ph.D., 1968. California Institute, 1968. (Alles)

Daniel Ashery, Ph.D., *Research Fellow in Physics*
M.Sc., Hebrew University of Jerusalem, 1963; Ph.D., Weizmann Institute of Science, Rehovoth, 1966. California Institute, 1967-. (Kellogg)

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)

Boris Auksmann, Ph.D., *Assistant Professor of Engineering Design*
B.S., University of British Columbia, 1955; M.S., California Institute, 1958; M.E., 1959; Ph.D., 1964. Assistant Professor, 1964-. (Thomas)

Harvey Allan Averch, Ph.D., *Lecturer in Economics*
A.B., University of Colorado, 1957; Ph.D., University of North Carolina, 1962. Research Economist, The Rand Corporation, 1961-. California Institute, 1967.

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, Mount Wilson and Palomar Observatories*
B.S., California Institute, 1934; Ph.D., University of California, 1938; Sc.D., University of Newcastle-upon-Tyne, 1965. Staff Member, Mt. Wilson Observatory, 1946-. Assistant Director, 1956-63; Associate Director, 1963-64; Director, 1964-. (Mt. Wilson Office)

Robert Fox Bacher, Ph.D., Sc.D., *Professor of Physics; Provost*
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-. (Throop)

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)

Andranik Bagdasarian, Ph.D., *Research Fellow in Chemistry*
Phar.D., University of Tehran, 1961; Ph.D., University of Louisville, 1967. California Institute, 1967-68.

John Norris Bahcall,*** Ph.D., *Associate Professor of Theoretical Physics*
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)

**Part-time

***Leave of absence, second term, 1968-69

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, 1968-69. (Thomas)

Donald John Barclay, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Strathclyde, Scotland, 1964; Ph.D., 1967. California Institute, 1967-. (Gates)

Barry Clark Barish, Ph.D., *Assistant Professor of Physics*
B.A., University of California, 1957; Ph.D., 1962. Research Fellow, California Institute, 1963-66; Assistant Professor, 1966-. (Synchrotron)

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)

William Robert Bauer, Ph.D., *Research Fellow in Chemistry*
B.S., California Institute, 1961; B.A., Oxford University, 1963; Ph.D., California Institute, 1968. Research Fellow, 1968. (Church)

Jesse Lee Beauchamp, Ph.D., *Arthur Amos Noyes Research Instructor in Chemistry*
B.S., California Institute, 1964; Ph.D., Harvard University, 1967. California Institute, 1967-. (Crellin)

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)

Antal Karoly Bejczy, Cand.Real., *Research Fellow in Engineering*
Cand.Real., University of Oslo, 1963. Scientific Associate, Institute of Physics, University of Oslo, 1966-. California Institute, 1966-. (Steele)

Isaac Bekhor, Ph.D., *Research Fellow in Biology*
B.S., University of California (Los Angeles), 1961; Ph.D., University of Southern California, 1966. California Institute, 1966-. (Kerckhoff)

Raymond Dudley Bennett, Ph.D., *Research Fellow in Biology*
B.S., University of Connecticut, 1953; M.S., Purdue University, 1955; Ph.D., 1958. Research Chemist, National Institutes of Health, 1963-. California Institute, 1964-. (Kerckhoff)

John Frederick Benton, Ph.D., *Associate 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-. (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., *Research Fellow in Radio Astronomy*
B.A., Luther College, 1960; M.S., California Institute, 1962; Ph.D., 1965. Research Fellow, 1965-. (Robinson)

Robert G. Bergman, Ph.D., *Arthur Amos Noyes Research Instructor in Chemistry*
B.A., Carleton College, 1963; Ph.D., University of Wisconsin, 1966. California Institute, 1967-. (Crellin)

Richard Bersohn, Ph.D., *Visiting Professor of Chemical Physics*
B.S., Massachusetts Institute of Technology, 1943; Ph.D., Harvard University, 1949. Professor of Theoretical Chemistry, Columbia University, 1961-. California Institute, 1969.

Arvind Bhatnagar, Ph.D., *Research Fellow in Astronomy*
B.Sc., Government College, Agra, 1956; M.Sc., 1958; Ph.D., 1965. California Institute, 1968-69.

Lawrence Christian Biedenharn, Ph.D., *Visiting Associate in Physics*
B.S., Massachusetts Institute of Technology, 1944; Ph.D., 1949. Professor of Physics, Duke University, 1961-. California Institute, 1968.

Hans R. Bilger, Ph.D., *Senior Research Fellow in Electrical Engineering*
Ph.D., University of Basel, 1961. Associate Professor, Oklahoma State University, 1968-. California Institute, 1967; 1968.

Halka Bilinski, Ph.D., *Research Fellow in Environmental Health Engineering*
B.Sc., University of Zagreb, 1961; M.Sc., 1963; Ph.D., 1964. Scientist, Institute Ruder Boskovic, Zagreb, 1967-. California Institute, 1967-68.

**Part-time

David Morison Binnie, Ph.D., *Senior Research Fellow in Physics*
B.S., Manchester University, 1952; Ph.D., 1956. Senior Lecturer, Imperial College, London, 1967-. Research Fellow, California Institute, 1965-66; Senior Research Fellow, 1967.

Graeme Austin Bird, Ph.D., *Visiting Professor of Aeronautics*
B.S., M.E., Ph.D., University of Sydney. Professor and Head, Department of Aeronautical Engineering, University of Sydney, 1965-. California Institute, 1969.

Lewis Graham Bishop, Ph.D., *Senior Research Fellow in Applied Science*
Sc.B., Brown University, 1955; M.S., Rensselaer Polytechnic Institute, 1959; Ph.D., University of California (Los Angeles), 1965. Research Fellow, California Institute, 1965-67; Senior Research Fellow, 1967-. (Booth)

George Wallace Bluman, Ph.D., *Research Fellow in Applied Mathematics*
B.Sc., University of British Columbia, 1964; Ph.D., California Institute, 1968. Research Fellow, 1968.

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)

Donald Dale Bogard, Ph.D., *Research Fellow in Geochemistry*
B.S., University of Arkansas, 1962; M.S., 1964; Ph.D., 1966. California Institute, 1966-. (Arms)

John David Bohlin, Ph.D., *Research Fellow in Astronomy*
A.B., Wabash College, 1961; Ph.D., University of Colorado, 1968. California Institute, 1967-. (Robinson)

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., *Assistant to the President; 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-. (Throop)

Jon D. B. Bordner, Ph.D., *Research Fellow in Chemistry*
B.S., Case Institute of Technology, 1962; Ph.D., University of California, 1966. California Institute, 1966-. (Church)

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-. (Kerckhoff)

Ira Sprague Bowen, Ph.D., Sc.D., *Distinguished Service Member, Carnegie Institution; Mount Wilson and Palomar 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, Mt. Wilson and Palomar Observatories, 1946-64; Distinguished Service Member, 1964-. (Mt. Wilson Office)

Paul Bowerman, A.M., *Associate Professor of Modern Languages*
A.B., Dartmouth College, 1920; A.M., University of Michigan, 1936. Instructor, California Institute 1942-45; Assistant Professor, 1945-47; Associate Professor, 1947-. (Dabney)

James David Bowman, Ph.D., *Research Fellow in Physics*
B.S., California Institute, 1961; Ph.D., 1968. Research Fellow, 1967-68.

David Boyd, Ph.D., *Assistant Professor of Mathematics*
B.Sc., Carleton College, 1963; M.A., University of Toronto, 1964; Ph.D., 1966. California Institute, 1967-. (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)

Wolfgang Bremser, Ph.D., *Research Fellow in Chemistry*
Dipl., Unversity of Cologne, 1966; Ph.D., 1968. California Institute, 1968-69.

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 Lab.)

**Part-time

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-. (Kerckhoff)

Norman Herrick Brooks, Ph.D., *Professor of 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)

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 H. Brown, Ph.D., *Research Fellow in Biology*
B.Sc., University of Toronto, 1964; M.Sc., 1966; Ph.D., 1968. California Institute, 1968-69. (Church)

James Neil Brune, Ph.D., *Associate Professor of Geophysics*
B.A., University of Nevada, 1956; Ph.D., Columbia University, 1961. California Institute, 1965-. (Seismo Lab.)

Lucien Munson Brush, Jr., Ph.D., *Visiting Associate in Civil Engineering*
B.S., Princeton University, 1952; Ph.D., Harvard University, 1956. Associate Professor of Civil and Geological Engineering; Head, Lewis F. Moody Laboratory of Hydrodynamics, Princeton University, 1963-. California Institute, 1968-69.

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)

Phiet T. Bui, Ph.D., *Research Fellow in Biology*
B.S., Syracuse University, 1960; Ph.D., Purdue University, 1967. California Institute, 1968-69.

Charles Edwin Bures, Ph.D., *Associate 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-. (Dabney)

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)

Stuart Raymond Butler, Ph.D., *Research Fellow in Biology*
B.A., University of Cambridge, 1963; M.A., 1966; Ph.D., University of London, 1967. California Institute, 1967-68.

Joseph M. Butros, Ph.D., *Visiting Associate in Biology*
B.A., American University of Beirut, 1941; M.A., 1945; Ph.D., Emory University, 1953. Professor of Biology, American University of Beirut, 1961-. Research Fellow, California Institute, 1959-60. Visiting Associate, 1967-68.

Jean Buttet, Ph.D., *Research Fellow in Physics*
Dipl., University of Lausanne, 1960; Ph.D., 1968. California Institute, 1968-69. (Sloan)

Stephen Howard Caine,** *Lecturer in Applied Science*
Computing Analyst, Head, Programming Systems, California Institute, 1964-. Lecturer, 1965-. (Booth)

Josip Caja, Ph.D., *Research Fellow in Chemistry*
B.S., University of Zagreb, 1962; M.Sc., 1964; Ph.D., 1967. California Institute, 1968. (Gates)

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)

Ian Campbell, Ph.D., *Research Associate in Geology*
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-.

**Part-time

Alfonso Campolattaro, Laurea, *Visiting Associate in Physics*
Laurea, University of Naples, 1959. California Institute, 1968.

Mario Castaneda, M.D., *Research Fellow in Biology*
B.S., Universidad Nacional de Mexico, 1952; M.D., Escuela Medico Militar, 1958. California Institute, 1966-. (Kerckhoff)

Alberto Castellani, Dr. Ing., *Visiting Associate in Civil Engineering*
Dr.Ing., Polytechnic Institute of Milan, 1962. Assistant Professor of Civil Engineering, 1964-. California Institute, 1967.

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)

Gerald Paul Ceasar, Ph.D., *Research Fellow in Chemistry*
B.S., Manhattan College, 1962; Ph.D., Columbia University, 1967. California Institute, 1967-68.

Ahmet Okay Celebi, Ph.D., *Research Fellow in Applied Mathematics*
B.S., University of Ankara, 1964; Ph.D., 1967. Assistant Professor of Applied Mathematics, 1967-. California Institute, 1968-69. (Firestone)

Enrique Cerda-Olmedo, Ph.D., *Research Fellow in Biology*
Lic., University of Madrid, 1965; Ph.D., Stanford University, 1967. California Institute, 1967-. (Church)

Hilary Kwoh-Hung Chan, Ph.D., *Research Fellow in Biology*
B.S., St. Louis University, 1964; Ph.D., Kansas State University, 1968. California Institute, 1968-69. (Church)

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)

James L. Charlton, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Western Ontario, 1965; Ph.D., 1968. California Institute, 1968-69.

Robert Frederick Christy, Ph.D., *Professor of Theoretical Physics; Executive Officer for Physics*
B.A., University of British Columbia, 1935; Ph.D., University of California, 1941. Associate Professor, California Institute, 1946-50; Professor, 1950-; Executive Officer, 1968-. (Sloan)

Donald Sherman Clark, Ph.D., *Professor of Physical Metallurgy; Director of Placements*
B.S., California Institute, 1929; M.S., 1930; Ph.D., 1934. Instructor, California Institute, 1934-37; Assistant Professor, 1937-45; Associate Professor, 1945-51; Professor, 1951-. (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)

Mary Eleanor Clark, Ph.D., *Research Fellow in Environmental Health Engineering*
A.B., University of California, 1949; M.A., 1951; Ph.D., 1960. California Institute, 1968-69. (Keck)

Morris G. Cline, Ph.D., *Research Fellow in Biology*
Ph.D., University of Michigan, 1964. California Institute, 1966-. (Kerckhoff)

Dale Randolph Clutter, Ph.D., *Research Fellow in Chemistry*
B.S., Marietta College, 1964; Ph.D., Case Western Reserve University, 1967. California Institute, 1967-. (Noyes)

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)

Edward Arnold Cohen,** Ph.D., *Research Fellow in Chemistry*
B.S., Massachusetts Institute of Technology, 1959; Ph.D., University of Wisconsin, 1966. Resident Research Associate, Jet Propulsion Laboratory, 1967-. California Institute, 1967-. (Jet Propulsion Lab.)

**Part-time

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)

Natalie Schulman Cohen,** Ph.D., *Research Fellow in Biology*
B.A., Cornell University, 1959; M.S., New York University, 1961; Ph.D., 1965. California Institute, 1966-. (Kerckhoff)

Giles Roy Cokelet, Sc.D., *Assistant Professor of Chemical Engineering*
B.S., California Institute, 1957; M.S., 1958; Sc.D., Massachusetts Institute of Technology, 1963. California Institute, 1964-. (Spalding)

Julian David Cole, Ph.D., *Professor of Applied Mathematics*
B.M.E., Cornell University, 1944; M.S., California Institute, 1946; Ph.D., 1949. Research Fellow in Aeronautics, 1949-51; Assistant Professor, 1951-55; Associate Professor, 1955-59; Professor, 1959-67; Professor of Applied Mathematics, 1967-. (Firestone)

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).

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

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)

Dwight Dexter Cook, Ph.D., *Research Fellow in Physics*
B.S., Massachusetts Institute of Technology, 1963; Ph.D., University of Illinois, 1968. California Institute, 1968-69.

Alan Frank George Cope, Ph.D., *Research Fellow in Chemical Engineering*
B.Sc., University College of South Wales, 1964; Ph.D., Imperial College, London, 1967. California Institute, 1967-. (Spalding)

William Harrison Corcoran, Ph.D., *Professor of Chemical Engineering; Executive Officer for Chemical Engineering*
B.S., California Institute, 1941; M.S., 1942; Ph.D., 1948. Associate Professor, 1952-57; Professor, 1957-; Executive Officer, 1967-. (Spalding)

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)

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)

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-. (Spalding)

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)

James Franklin Crow, Ph.D., *Visiting Gosney Professor of Biology*
A.B., Friends College, 1937; Ph.D., University of Texas, 1941. Professor of Genetics, University of Wisconsin, 1954-; Division Chairman, 1967-. California Institute, 1969. (Church)

**Part-time

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)

Michael Edward Dahmus, Ph.D., *Research Fellow in Biology*
B.S., Iowa State University, 1963; Ph.D., California Institute, 1968. Research Fellow, 1968-69. (Kerckhoff)

Barton Eugene Dahneke, Ph.D., *Research Fellow in Environmental Health Engineering*
B.S., Brigham Young University, 1963; M.S., University of Minnesota, 1965; Ph.D., 1967. California Institute, 1967-. (Keck)

Jörgen Damgård, M.Sc., *Research Fellow in Physics*
M.Sc., University of Copenhagen, 1963. Staff Member, Niels Bohr Institute, 1967-. California Institute, 1968-69. (W. Bridge)

Graham K. Darby, Ph.D., *Research Fellow in Biology*
B.Sc., University of Birmingham, England, 1964; Ph.D., 1967. California Institute, 1967-. (Kerckhoff)

Roger Fred Dashen,*** Ph.D., *Professor of Theoretical Physics*
A.B., Harvard College, 1960; Ph.D., California Institute, 1964. Research Fellow, 1964-65; Assistant Professor, 1965-66; Professor, 1966-.

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)

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)

Donald Goodwin Davis, Ph.D., *Visiting Associate in Chemistry*
B.A., Wesleyan University, 1954; Ph.D., Harvard University, 1957. Professor of Analytical Chemistry, Louisiana State University, 1962-; Dean of Graduate School, 1965-. California Institute, 1968. (Gates)

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-. (East Bridge)

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)

Frank P. De Haan, Ph.D., *Visiting Associate in Chemistry*
A.B., Calvin College, 1957; Ph.D., Purdue University, 1961. Associate Professor of Chemistry, Occidental College, 1961-. California Institute, 1968-69.

Max Delbrück, Ph.D., Sc.D., *Professor of Biology*
Ph.D., University of Göttingen, 1931; Sc.D., University of Chicago, 1967. Research Fellow, California Institute, 1937-39; Professor, 1947-. (Alles)

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

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)

Armin Joseph Deutsch, Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
B.S., University of Arizona, 1940; Ph.D., University of Chicago, 1946. Mt. Wilson and Palomar Observatories, 1951-. (Mt. Wilson Office)

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)

***Leave of absence, first and second terms, 1968-69

Dennis Jon Diestler, Ph.D., *Research Fellow in Chemistry*
B.S., Harvey Mudd College, 1964; Ph.D., California Institute, 1968. Assistant Professor, University of Missouri, 1967-. California Institute, 1968.

Herbert Dietmann, Dr.Ing., *Research Fellow in Aeronautics*
Dipl., Technical University of Stuttgart; Dr.Ing., 1964. California Institute, 1968-69. (Firestone)

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)

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)

Richard Andrew Dobbins, Ph.D., *Visiting Associate in Jet Propulsion*
S.B., Harvard College, 1948; M.S., Northeastern University, 1958; Ph.D., Princeton University, 1961. Associate Professor of Engineering, Brown University, 1964-. California Institute, 1966; 1967-68.

Michael Repplier Dohan, M.A., *Instructor in Economics*
B.A., Haverford College, 1961; M.A., Harvard University, 1966. California Institute, 1966-. (Spalding)

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, 1968-69.

Bozena Henisz Dostert,** Ph.D., *Lecturer in English*
M.A., University of Warsaw, 1956; M.S., Georgetown University, 1961; Ph.D., 1965. California Institute, 1969.

Melvin Dresher,** Ph.D., *Lecturer in Applied Mathematics*
B.S., Lehigh University, 1933; Ph.D., Yale University, 1937. Research Mathematician, The Rand Corporation, 1947-. California Institute, 1967-68.

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-. 500 Columbia Street, South Pasadena.

Donald Frank Du Bois,** Ph.D., *Lecturer in Electrical Engineering*
A.B., Cornell University, 1954; Ph.D., California Institute, 1959. Senior Staff Physicist, Hughes Research Laboratories, 1962-. Instructor in Mathematics, California Institute, 1958-59; Lecturer in Electrical Engineering, 1967.

Lee Alvin DuBridge, Ph.D., Sc.D., LL.D.
(See page 41.)

James Johnson Duderstadt, Ph.D., *Research Fellow in Engineering Science*
B.Eng., Yale University, 1964; M.S., California Institute, 1965; Ph.D., 1968. Research Fellow, 1968. (Thomas)

Lawrence B. Dumas, Ph.D., *Research Fellow in Biology*
B.S., Michigan State University, 1963; M.S., University of Wisconsin, 1965; Ph.D., 1967. California Institute, 1967-. (Kerckhoff)

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)

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)

Joseph Emmett Earley, Ph.D., *Visiting Associate in Chemistry*
B.S., Providence College, 1954; Ph.D., Brown University, 1957. Associate Professor of Chemistry, Georgetown University, 1963-. California Institute, 1967-68.

Paul Conant Eaton, A.M., *Associate Professor of English; Dean of Students*
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-. (Throop)

**Part-time

Robert Stuart Edgar, Ph.D., *Professor of Biology*
B.Sc., McGill University, 1953; Ph.D., University of Rochester, 1957. Research Fellow, California Institute, 1957; 1958-60; Assistant Professor, 1960-63; Associate Professor, 1963-66; Professor, 1966-. (Church)

Kenneth Walter Eells, Ph.D., *Institute Psychologist*
A.B., George Washington University, 1937; A.M., University of Chicago, 1942; Ph.D., 1948. California Institute, 1961-. (Health Center)

Gloria Eggart, Ph.D., *Research Fellow in Chemistry*
Dipl., Swiss Federal Institute of Technology, 1965; Ph.D., 1967. California Institute, 1968-69.

Ronald David Ekers, Ph.D., *Research Fellow in Radio Astronomy*
B.S., University of Adelaide, 1962; Ph.D., Australian National University, 1967. California Institute, 1967-. (Robinson)

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)

Allan John Ellis, Ph.D., *Visiting Assistant Professor of Mathematics*
B.S., University of Birmingham, 1961; Ph.D., Oxford University, 1964. Lecturer in Pure Mathematics, University College of Swansea, 1964-. California Institute, 1968-69. (Sloan)

Cornelis Antonius Emeis, Ph.D., *Research Fellow in Chemistry*
M.S., University of Leiden, 1961; Ph.D., 1968. California Institute, 1968-69. (Noyes)

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)

Francisco Eng, M.D., Ph.D., *Research Fellow in Biology*
B.Sc., University of the Philippines, 1957; M.D., 1961; Ph.D., University of Toronto, 1967. California Institute, 1968-69. (Kerckhoff)

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)

Karl-Erik Eriksson, Fil.Dr., *Research Fellow in Biology*
B.S., The University of Uppsala, 1958; Fil.Lic., 1963; Fil.Dr., 1967. California Institute, 1968-69.

Arnold Eskin, Ph.D., *Research Fellow in Biology*
B.A., Vanderbilt University, 1961; Ph.D., University of Texas, 1968. California Institute, 1968-69.

Ottokar Jakob Eugster, Ph.D., *Research Fellow in Geochemistry*
Dipl., University of Berne, 1964; Ph.D., 1967. California Institute, 1967-. (Arms)

Trevor Evans, D.Sc., *Visiting Professor of Mathematics*
B.A., Jesus College, Oxford University, 1946; M.A., 1950; M.Sc., Manchester University, England, 1948; D.Sc., Oxford University, 1959. Professor of Mathematics; Chairman, Mathematics Department, Emory University, 1954-. California Institute, 1968.

Edward Douglas Fackerell, Ph.D., *Research Fellow in Physics*
B.Sc., University of Sydney, 1959; M.Sc., 1960; Ph.D., 1967. Senior Lecturer in Mathematics, Monash University, Victoria, 1968-. California Institute, 1968-69.

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)

Douglas McIntosh Fambrough, Jr., Ph.D., *Instructor in Biology*
A.B., University of North Carolina, 1963; Ph.D., California Institute, 1968. Instructor, 1967-68.

Loh-Nien Fan, Ph.D., *Research Fellow in Civil Engineering*
B.S., National Taiwan University, 1961; M.S., California Institute, 1964; Ph.D., 1967. Research Fellow, 1967-68.

John Lyman Fanselow, Ph.D., *Research Fellow in Physics*
B.A., College of Wooster, 1960; Ph.D., University of Chicago, 1967. California Institute, 1968-69.

Carla Giovannini Fanti, Ph.D., *Research Fellow in Radio Astronomy*
Ph.D., University of Bologna, 1960. Associated Research Fellow, 1964-. California Institute, 1967-. (Robinson)

Roberto Fanti, Ph.D., *Research Fellow in Radio Astronomy*
Ph.D., University of Bologna, 1964. Associated Research Fellow, 1964-. California Institute, 1967-. (Robinson)

Peter Ward Fay, Ph.D., *Associate Professor of History*
B.A., Harvard College, 1947; B.A., Oxford University, 1949; Ph.D., Harvard University, 1954. Assistant Professor, California Institute, 1955-60; Associate Professor, 1960-. (Dabney)

Jerry F. Feldman, Ph.D., *Research Fellow in Biology*
B.A., Swarthmore College, 1963; M.A., Princeton University, 1965; Ph.D., 1967. California Institute, 1967-. (Kerckhoff)

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)

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-. (E. Bridge)

Eva Fifkova, M.D., Ph.D., *Research Fellow in Biology*
M.D., Charles University, Prague, 1957; Ph.D., Czechoslovakian Academy of Sciences, 1963. California Institute, 1968-69. (Kerckhoff)

Edward Berel Fomalont, Ph.D., *Research Fellow in Radio Astronomy*
B.S., University of Pennsylvania, 1961; Ph.D., California Institute, 1966. Research Fellow, 1966-67; 1968-69.

William Alfred Fowler, Ph.D., *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)

Ludwig Edward Fraenkel, M.Sc., *Saul Kaplun Senior Research Fellow in Applied Mathematics*
B.Sc., University of Toronto, 1947; M.Sc., 1948. Lecturer in Applied Mathematics, University of Cambridge, 1964-. Visiting Assistant Professor of Aeronautics, California Institute, 1957-58; Kaplun Senior Research Fellow in Applied Mathematics, 1968.

Joel N. Franklin, Ph.D., *Professor of Applied Science*
B.S., Stanford University, 1950; Ph.D., 1953. Associate Professor of Applied Mechanics, California Institute, 1957-65; Professor of Applied Science, 1965-. (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. 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-. (Sloan)

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)

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)

Hans Friedrichsen, Ph.D., *Research Fellow in Geochemistry*
M.A., University of Kiel, 1963; Ph.D., University of Marburg, 1966. California Institute, 1967-. (Arms)

Daniel Froelich, D.Sc., *Research Fellow in Chemical Engineering*
M.S., University of Strasbourg, 1960; D.Sc., 1966. California Institute, 1967-. (Spalding)

**Part-time

Benno Fuchssteiner, Dr.rer.nat., *Research Fellow in Mathematics*
Dipl., Technical University of Darmstadt, 1965; Dr.rer.nat., 1967. California Institute, 1967-68.

Hideyuki Fujisawa, Ph.D., *Research Fellow in Geophysics*
B.S., University of Toyko, 1962; M.S., 1964; Ph.D., 1967. Staff Member, Earthquake Research Institute, Toyko, 1967-. California Institute, 1968-69. (Seismo Lab.)

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)

Frederick D. Funk, Ph.D., *Research Fellow in Biology*
B.S., Pennsylvania State University, 1962; M.S., 1964; Ph.D., 1966. California Institute, 1967-. (Kerckhoff)

Peter Gaehtgens, M.D., *Research Fellow in Engineering Science*
M.D., University of Cologne, 1964. Assistant, Physiological Institute, University of Cologne, 1966-. California Institute, 1967-. (Thomas)

Ruth Gallily, Ph.D., *Research Fellow in Chemistry*
M.Sc., The Hebrew University, Jerusalem, 1952; Ph.D., 1955. California Institute, 1967-. (Church)

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-. (W. Bridge)

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)

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., *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-. (Sloan)

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)

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

Robert Blythe Gilmore, B.S., C.P.A., *Vice President for Business Affairs*
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 Comptroller, 1952-58; Comptroller, 1958-62; Vice President, 1962-. (Throop)

Raymon Melvin Glantz, Ph.D., *Research Fellow in Biology*
B.A., Brooklyn College, 1963; M.S., Syracuse University, 1965; Ph.D., 1966. California Institute, 1967-. (Kerckhoff)

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

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

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

**Part-time

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)

Henry Crawford Goldwire, Jr., Ph.D., *Research Fellow in Physics*
B.A., Rice University, 1963; Ph.D., 1967. California Institute, 1967-. (Kellogg)

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

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)

David Reeves Goosman, Ph.D., *Research Fellow in Physics*
A.B., Reed College, 1962; Ph.D., California Institute, 1967. Research Fellow, 1967-. (Kellogg)

David Frederick Goslee, Ph.D., *Assistant Professor of English*
B.A., Oberlin College, 1962; M.A., Yale University, 1963; Ph.D., 1967. California Institute, 1967-. (Dabney)

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-. (Steele)

Elie Gradsztajn, Ph.D., *Visiting Associate in Nuclear Geophysics*
B.Sc., University of Paris, 1956; M.Sc., 1959; Ph.D., 1965. Head of Research, National Center of Scientific Research, Paris, 1966-. California Institute, 1968.

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)

William Robert Gray, Ph.D., *Senior Research Fellow in Biology*
B.A., St. John's College, University of Cambridge, 1957; M.A., Ph.D., University of Cambridge, 1964. Research Fellow, California Institute, 1964-66; Senior Research Fellow, 1966-. (Church)

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-. (Dabney)

Jesse Leonard Greenstein,*** Ph.D., *Professor of Astrophysics; Staff Member, Mount Wilson and Palomar 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)

Eugene Herbert Gregory, Ph.D., *Assistant Professor of Physics*
B.S., Washington University (St. Louis), 1958; M.S., University of California (Los Angeles), 1961; Ph.D., 1965. California Institute, 1966-. (Sloan)

Thomas Lynn Grettenberg, Ph.D., *Associate Professor of Electrical Engineering*
B.A., Pomona College, 1957; B.S., M.S., Massachusetts Institute of Technology, 1957; Ph.D., Stanford University, 1962. Assistant Professor, California Institute, 1962-67; Associate Professor, 1967-. (Steele)

Klaus Gerhard Grohmann, Ph.D., *Research Fellow in Chemistry*
Dipl., University of Heidelberg, 1959; Ph.D., 1963. California Institute, 1968-69. (Crellin)

John Brandon Grutzner, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Melbourne, Australia, 1962; Ph.D., 1967. California Institute, 1968-69.

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

**Part-time
***Leave of absence, first term, 1968-69

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)

Ralph Stuart Hager, Ph.D., *Research Fellow in Physics*
B.S., University of Minnesota, 1961; Ph.D., California Institute, 1966. Research Fellow, 1966-68.

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

Richard L. Hallberg, Ph.D., *Research Fellow in Biology*
A.B., Carleton College, 1963; Ph.D., Johns Hopkins University, 1968. California Institute, 1968-69. (Church)

Jack Halpern, Ph.D., *Visiting Professor of Chemistry*
B.Sc., McGill University, 1946; Ph.D., 1949. Professor of Chemistry, University of Chicago, 1962-. California Institute, 1968.

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)

Willis Burdette Hammond, Jr., Ph.D., *Research Fellow in Chemistry*
B.A., Northwestern University, 1964; M.A., Columbia University, 1966; Ph.D., 1967. California Institute, 1967-68.

George S. Hand, Jr., Ph.D., *Research Fellow in Biology*
B.S., Southeast Missouri State College, 1958; M.A., Washington University, 1961; Ph.D., University of South Carolina, 1967. California Institute, 1967-. (Kerckhoff)

Theo Franz Hansen, Dipl., *Research Fellow in Applied Science*
Dipl., University of Munich, 1960. Assistant Director, Computing Center, University of Mainz, 1967-. California Institute, 1968.

Robert S. Harp, Ph.D., *Assistant Professor of Electrical Engineering*
B.S., Massachusetts Institute of Technology, 1959; M.S., Stanford University, 1961; Ph.D., 1964. California Institute, 1967-. (Steele)

Gordon Leonard Harris, D.Sc., *Senior Research Fellow in 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-. (Guggenheim)

Leland Harris, Ph.D., *Visiting Associate in Chemistry*
B.S., University of Michigan, 1950; M.S., University of Arizona, 1952; Ph.D., State University of Iowa, 1955. Professor; Chairman, Department of Chemistry, Knox College, 1959-. California Institute, 1968-69.

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, 1968-69.

F. David A. Hartwick, Ph.D., *Research Fellow in Astronomy*
B.Eng., McGill University, 1962; M.A., University of Toronto, 1964; Ph.D., 1966. California Institute, 1967-68.

Joseph Richard Haskins, Ph.D., *Visiting Associate in Physics*
B.S., University of Texas, 1946; Ph.D., The Ohio State University, 1952. Professor of Physics, Gettysburg College, 1965-. California Institute, 1968-69.

Frederic Curt Haupt, Ph.D., *Research Fellow in Chemistry*
B.S., University of Florida, 1963; Ph.D., Harvard University, 1968. California Institute, 1967-. (Crellin)

Taizo Hayashi, Dr.Eng., *Visiting Associate in Civil Engineering*
B.Eng., University of Tokyo, 1942; Dr.Eng., 1953. Professor of Hydraulics, Chuo University, 1954-. California Institute, 1968.

John Eugene Hearst, Ph.D., *Visiting Associate in Biology*
B.E., Yale University, 1957; Ph.D., California Institute, 1961. Associate Professor of Biophysical Chemistry, University of California, 1967-. California Institute, 1968-69.

Robert Thornton Heath, Ph.D., *Research Fellow in Biology*
B.S., University of Michigan, 1963; Ph.D., University of Southern Califorina, 1968. California Institute, 1968. (Kerckhoff)

Erich Heftmann, Ph.D., *Research Associate in Biology*
B.A., New York University, 1942; Ph.D., University of Rochester, 1947. U.S. Department of Agriculture, 1963-. Research Fellow, California Institute, 1959; 1961-64; Research Associate, 1964-. (Dolk)

Robert Willis Hellwarth,** Ph.D., *Senior Research Fellow in Electrical Engineering*
B.Sc., Princeton University, 1952; Ph.D., Oxford University, 1955. Senior Staff Physicist, Hughes Research Laboratories, 1955-. Research Fellow in Physics, California Institute, 1955-56; Lecturer, 1957-64; Senior Research Fellow in Electrical Engineering, 1966-. (Steele)

James William Hendrix, Ph.D., *Visiting Associate in Biology*
B.S., North Carolina State University, 1959; M.S., University of Arkansas, 1960; Ph.D., North Carolina State University, 1963. Associate Professor, University of Kentucky, 1967-. California Institute, 1968-69.

Peter Herczeg, Ph.D., *Research Fellow in Theoretical Physics*
Dipl., Faculty of Technical and Nuclear Physics, Prague, 1962; Ph.D., University of Sussex, 1968. California Institute, 1968-69.

Richard Alan Hertz, Ph.D., *Assistant Professor of Philosophy*
B.A., University of California (Los Angeles), 1962; M.A., University of California (Santa Barbara), 1964; Ph.D., University of Pittsburgh, 1967. California Institute, 1968-.

Clemens August Heusch, Dr.rer.nat., *Associate Professor of Physics*
Dipl., Technische Hochschule, Aachen, 1955; Dr.rer.nat., Technische Hochschule, Munich, 1959. Research Fellow, California Institute, 1963-65; Senior Research Fellow, 1965-67; Associate Professor, 1967-. (Synchrotron)

Emerson Hibbard, Ph.D., *Senior Research Fellow in Biology*
B.S., Cornell University, 1950; M.S., University of Michigan, 1957; Ph.D., 1959. Research Fellow, California Institute, 1963-66; Senior Research Fellow, 1966-. (Alles)

James Edward Hix, Jr., Ph.D., *Research Fellow in Chemistry*
B.A., Vanderbilt University, 1963; Ph.D., 1967. California Institute, 1967-. (Crellin)

Alan John Hodge,*** Ph.D., *Professor of Biology*
B.Sc., University of Western Australia, 1946; Ph.D., Massachusetts Institute of Technology, 1952. California Institute, 1960-. (Alles)

Ross B. Hodgetts, Ph.D., *Research Fellow in Biology*
B.Sc., Queen's University, Canada, 1963; M.S., Yale University, 1965; Ph.D., 1967. California Institute, 1968-69.

Joachim Wilhelm Hoeffs, Ph.D., *Research Fellow in Geochemistry*
Ph.D., University of Göttingen, 1964. California Institute, 1967-68.

David Swenson Hogness, Ph.D., *Visiting Associate in Biology*
B.S., California Institute, 1949; Ph.D., 1953. Professor of Biochemistry, Stanford University, 1966-. California Institute, 1968.

Aladar Hollander, M.E., *Professor of Mechanical Engineering, Emeritus*
M.E., Joseph Royal University, Budapest, 1904. Professor, California Institute, 1944-51; Professor Emeritus, 1951-. (Karman)

Norman Harold Horowitz, Ph.D., *Professor of Biology*
B.S., University of Pittsburgh, 1936; Ph.D., California Institute, 1939. Research Fellow, 1940-42; Senior Research Fellow, 1946; Associate Professor, 1947-53; Professor, 1953-. (Kerckhoff)

Friedrich Hörz, Ph.D., *Research Fellow in Geology*
B.S., University of Tübingen, 1961; Ph.D., 1965. California Institute, 1968-69. (Seismo Lab.)

Yoshiki Hotta, M.D., *Research Fellow in Biology*
M.D., University of Tokyo, 1963. California Institute, 1968-69.

George William Housner, Ph.D., *Professor of Civil Engineering and Applied Mechanics*
B.S., University of Michigan, 1933; M.S., California Institute, 1934; Ph.D., 1941. Assistant Professor, 1945-49; Associate Professor, 1949-53; Professor, 1953-. (Thomas)

Robert Franklin Howard, Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
B.A., Ohio Wesleyan University, 1954; Ph.D., Princeton University, 1957. Carnegie Fellow, Mount Wilson and Palomar Observatories, 1957-59; Staff Member, 1961-. (Mt. Wilson Office)

**Part-time
***Leave of absence, first and second terms, 1968-69

Fred Hoyle, M.A., *Visiting Associate in Physics*
M.A., Fellow, St. John's College, University of Cambridge. Plumian Professor of Astronomy and Experimental Philosophy, University of Cambridge, 1958-. Visiting Professor of Astronomy, California Institute, 1953; 1954; 1956; Addison White Greenway Visiting Professor of Astronomy; Staff Member, Mount Wilson and Palomar Observatories, 1957-62; Visiting Associate, 1963; 1964; 1965; 1966; 1968.

Joel Anthony Huberman, Ph.D., *Research Fellow in Biology*
B.A., Harvard College, 1963; Ph.D., California Institute, 1968. Research Fellow, 1967-68.

Donald Ellis Hudson, Ph.D., *Professor of Mechanical Engineering and Applied Mechanics*
B.S., California Institute, 1938; M.S., 1939; Ph.D., 1942. Instructor, 1941-43; Assistant Professor, 1943-49; Associate Professor, 1949-55; Professor, 1955-. (Thomas)

Edward Wesley Hughes, Ph.D., *Research Associate in Chemistry*
B.Chem., Cornell University, 1924; Ph.D., 1935. Research Fellow, California Institute, 1938-43; Senior Research Fellow, 1945-46; Research Associate, 1946-. (Noyes)

Floyd Bernard Humphrey, Ph.D., *Associate Professor of Electrical Engineering*
B.S., California Institute, 1950; Ph.D., 1956. Senior Research Fellow, 1960-64; Associate Professor, 1964-. (Steele)

Edward Hutchings, Jr., B.A., *Lecturer in Journalism; Director of Institute Publications*
B.A., Dartmouth College, 1933. Editor of Engineering and Science Monthly, California Institute, 1948-. Lecturer, 1952-. (Throop)

Robert A. Huttenback, Ph.D., *Professor of History; Master of Student Houses*
B.A., University of California (Los Angeles), 1951; Ph.D., 1959. Master of Student Houses, California Institute, 1958-; Lecturer in History, 1958-60; Assistant Professor, 1960-63; Associate Professor, 1963-66; Professor, 1966-. (Lloyd House, Dabney)

Ardon R. Hyland, Ph.D., *Research Fellow in Astronomy*
B.S., University of Queensland, 1963; Ph.D., The Australian National University, 1967. California Institute, 1967-. (Robinson)

Marcia Ann Ilton, Ph.D., *Research Fellow in Chemistry*
B.S., University of Michigan, 1964; Ph.D., Stanford University, 1967. California Institute, 1967-68.

Andrew Perry Ingersoll, Ph.D., *Assistant Professor of Planetary Science*
B.A., Amherst College, 1960; A.M., Harvard University, 1961; Ph.D., 1966. California Institute, 1966-. (Mudd)

Robert Ellsworth Ireland, Ph.D., *Professor of Organic Chemistry*
B.A., Amherst College, 1951; M.S., University of Wisconsin, 1953; Ph.D., 1954. California Institute, 1965-. (Crellin)

Wilfred Dean Iwan, Ph.D., *Associate Professor of Applied Mechanics*
B.S., California Institute, 1957; M.S., 1958; Ph.D., 1961. Assistant Professor, 1964-67; Associate Professor, 1967-. (Thomas)

Jon Willis Jacklet, Ph.D., *Research Fellow in Biology*
B.S., University of Oregon, 1962; M.A., 1964; Ph.D., 1966. California Institute, 1967-. (Kerckhoff)

Manfred Fritz Heinrich Jayme, Dr.Ing., *Research Fellow in Chemistry*
Dipl. Ing., Technical University of Darmstadt, 1963; Dr.Ing., 1966. California Institute, 1967-68.

Paul Christian Jennings, Ph.D., *Associate Professor of Applied Mechanics*
B.S., Colorado State University, 1958; M.S., California Institute, 1960; Ph.D., 1963. Research Fellow in Civil Engineering, 1965; Assistant Professor of Applied Mechanics, 1966-68; Associate Professor, 1968-. (Thomas)

Eberhard Karl Jobst, Dr.rer.pol., *Assistant Professor of German*
Dipl.-Hdl., Goethe-Universität, Frankfurt, 1964; Dr.rer.pol., 1968. Instructor, California Institute, 1967-68; Assistant Professor, 1968-. (Dabney)

Nils G. E. Johansson, Fil.kand., *Research Fellow in Electrical Engineering*
Fil.kand., University of Stockholm, 1957. Research Assistant, 1965-. California Institute, 1968.

Raymond Alex Joly, Ph.D., *Research Fellow in Biology*
Dipl., University of Basel, 1964; Ph.D., 1967. California Institute, 1968-69. (Kerckhoff)

Byrd Luther Jones,* Ph.D., *Assistant Professor of History*
B.A., Williams College, 1960; Ph.D., Yale University, 1966. Instructor, California Institute, 1963-66; Assistant Professor, 1966-.

*Leave of absence, 1968-69

Lorella Margaret Jones, Ph.D., *Research Fellow in Theoretical Physics*
B.A., Radcliffe College, 1964; M.S., California Institute, 1966; Ph.D., 1968. Research Fellow, 1967-68.

Louis Winchester Jones, A.B., *Dean of Admissions, Emeritus*
A.B., Princeton University, 1922. Instructor in English, California Institute, 1925-37; Assistant Professor, 1937-43; Registrar, 1942-52; Associate Professor, 1943-68; Dean of Admissions; Director of Undergraduate Scholarships, 1937-68; Dean Emeritus, 1968-.

John Maxwell Jordan, Ph.D., *Research Fellow in Chemistry*
B.S., Central State College (Ohio), 1959; Ph.D., Ohio State University, 1963. California Institute, 1966-. (Church)

William H. Julian, Ph.D., *Research Fellow in Astronomy*
B.S., Massachusetts Institute of Technology, 1961; Ph.D., 1965. California Institute, 1967-. (Robinson)

Arnold Henry Kadish,** M.D., *Senior Research Fellow in Engineering*
B.A., Wayne State University, 1939; M.D., 1943. Director, Physiochemical Automation Laboratory, Los Angeles. California Institute, 1966-. (Steele)

Walter Barclay Kamb, Ph.D., *Professor of Geology and Geophysics*
B.S., California Institute, 1952; Ph.D., 1956. Assistant Professor, 1956-60; Associate Professor, 1960-62; Professor, 1962-. (Mudd)

Henning Kausch-Blecken von Schmeling, Dr.rer.nat., *Research Fellow in Chemical Engineering*
Dipl., University of Göttingen, 1957; Dr.rer.nat., 1960. California Institute, 1967-68.

Ralph William Kavanagh, Ph.D., *Associate Professor of Physics*
B.A., Reed College, 1950; M.A., University of Oregon, 1952; Ph.D., California Institute, 1956. Research Fellow, 1956-58; Senior Research Fellow, 1958-60; Assistant Professor, 1960-65; Associate Professor, 1965-. (Kellogg)

Lois Marie Kay, M.S., *Research Fellow in Chemistry*
B.S., University of California (Los Angeles), 1949; M.S., 1952. Research Fellow, California Institute, 1955-58; 1959-. (Church)

Geoffrey Lorrimer Keighley, Ph.D., *Research Associate in Biology*
B.A., University of Toronto, 1926; M.S., California Institute, 1940; Ph.D., 1944. Instructor, 1943-46; Senior Research Fellow, 1946-64; Research Associate, 1964-. (Kerckhoff)

Herbert Bishop Keller, Ph.D., *Professor of Applied Mathematics*
B.E.E., Georgia Institute of Technology, 1945; M.A., New York University, 1948; Ph.D., 1954. Visiting Professor of Applied Mathematics, California Institute, 1965-66; Professor, 1967-. (Firestone)

Douglas Gilbert Kelly,** Ph.D., *Research Fellow in Mathematics*
A.B., Princeton University, 1961; M.A., Indiana University, 1964; Ph.D., 1967. Resident Research Associate, Jet Propulsion Laboratory, 1967-. California Institute, 1967-68.

Daniel Jerome Kevles, Ph.D., *Associate Professor of History*
A.B., Princeton University, 1960; Ph.D., 1964. Assistant Professor, California Institute, 1964-68; Associate Professor, 1968-. (Dabney)

Hershy Harry Kisilevsky, Ph.D., *Ford Foundation Research Fellow in Mathematics*
B.Sc., McGill University, 1964; Ph.D., Massachusetts Institute of Technology, 1968. California Institute, 1968-69.

Arthur Louis Klein, Ph.D., *Professor of Aeronautics, Emeritus*
B.S., California Institute, 1921; M.S., 1924; Ph.D., 1925. Research Fellow in Physics and in Aeronautics, 1927-29; Assistant Professor of Aeronautics, 1929-34; Associate Professor, 1934-54; Professor, 1954-68; Professor Emeritus, 1968-. (Firestone)

Burton H. Klein, Ph.D., *Professor of Economics*
A.B., Harvard College, 1940; Ph.D., Harvard University, 1948. California Institute, 1967-. (Dabney)

Wolfgang Gustav Knauss, Ph.D., *Assistant Professor of Aeronautics*
B.S., California Institute, 1958; M.S., 1959; Ph.D., 1963. Research Fellow, 1963-65; Assistant Professor, 1965-. (Firestone)

James Kenyon Knowles, Ph.D., *Professor of Applied Mechanics*
B.S., Massachusetts Institute of Technology, 1952; Ph.D., 1957. Assistant Professor, California Institute, 1958-61; Associate Professor, 1961-65; Professor, 1965-. (Thomas)

Robert Milton Koch, Ph.D., *Visiting Associate in Biology*
B.S., Montana State College, 1948; M.S., Iowa State University, 1950; Ph.D., 1953. Professor of Animal Science, University of Nebraska, 1959-. California Institute, 1969.

**Part-time

Keiichi Kodaira, D.Sc., *Research Fellow in Astrophysics*
B.Sc., University of Tokyo, 1959; M.Sc., 1961; D.Sc., University of Kiel, 1964; D.Sc., University of Tokyo, 1967. Research Assistant, Tokyo Astronomical Observatory, 1964-. California Institute, 1967-. (Robinson)

Joseph Blake Koepfli, D.Phil., *Research Associate in Chemistry*
A.B., Stanford University, 1924; M.A., 1925; D.Phil., Oxford University, 1928. California Institute, 1932-. (Church)

Bryan Earl Kohler, Ph.D., *Research Fellow in Chemistry*
B.A., University of Utah, 1962; Ph.D., University of Chicago, 1967. California Institute, 1967-68.

Kristofer Kolltveit, Cand.real., *Senior Research Fellow in Physics*
Cand.real., University of Bergen, 1960. California Institute, 1968. (Kellogg)

Alexander Kosloff,** Ph.D., *Lecturer in Russian*
A.B., University of Moscow, 1937; A.M., University of California (Los Angeles), 1942; Ph.D., University of Southern California, 1954. Associate Professor; Head, Slavic Studies Department, University of Southern California, 1962-. California Institute, 1955-61; 1962-65; 1966-. (Dabney)

Ben Zion Kozlovsky, Ph.D., *Research Fellow in Astrophysics*
M.S., Hebrew University of Jerusalem, 1963; Ph.D., Weizmann Institute (Rehovoth), 1966. Research Fellow in Physics, California Institute, 1966-68; Research Fellow in Astrophysics, 1968-69. (Robinson)

Theo Frank Krans, Ph.D., *Visiting Associate in Paleontology*
B.S., State University of Leiden, 1959; M.S., 1962; Ph.D., 1965. Lecturer in Paleontology, 1964-. California Institute, 1968.

Jerome Kristian, Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
A.B., Shimer College, Illinois, 1953; M.S., University of Chicago, 1956; Ph.D., 1962. Research Fellow in Astronomy, California Institute, 1967-68; Staff Member, 1968-. (Mt. Wilson Office)

Jacqueline Irene Kroschwitz, Ph.D., *Research Fellow in Chemistry*
B.S., Ursinus College, Pennsylvania, 1964; Ph.D., University of Pennsylvania, 1967. California Institute, 1967-68.

Toshi Kubota, Ph.D., *Associate Professor of Aeronautics*
B.E., Tokyo University, 1947; M.S., California Institute, 1952; Ph.D., 1957. Research Fellow, 1957-59; Assistant Professor, 1959-63; Associate Professor, 1963-. (Firestone)

Rudolf Kummer, Dr.rer.nat., *Research Fellow in Chemistry*
Dipl., Technical University of Munich, 1964; Dr.rer.nat., 1966. California Institute, 1967-. (Crellin)

Aron Kuppermann,* Ph.D., *Professor of Chemical Physics*
M.Sc., University of Sao Paulo, 1948; Ph.D., Notre Dame University, 1956. California Institute, 1963-.

Bert La Brucherie, B.E., *Coach*
B.E., University of California (Los Angeles), 1929. California Institute, 1949-. (Gymnasium)

William Noble Lacey, Ph.D., *Professor of Chemical Engineering, Emeritus*
A.B., Stanford University, 1911; Ch.E., 1912; M.S., University of California, 1913; Ph.D., 1915. Instructor, California Institute, 1916-17; Assistant Professor, 1917-19; Associate Professor, 1919-31; Professor, 1931-1962. Dean of Graduate Studies, 1946-56; Dean of the Faculty, 1961-62; Professor Emeritus, 1962-.

Dora Angela Russo Lackner, Laurea, *Research Fellow in Astrophysics*
Laurea, University of Florence, 1960. California Institute, 1967-68.

Paco Axel Lagerstrom, Ph.D., *Professor of Applied Mathematics*
Fil.kand., University of Stockholm, 1935; Fil.lic., 1939; Ph.D., Princeton University, 1942. Research Associate in Aeronautics, California Institute, 1946-47; Assistant Professor, 1947-49; Associate Professor, 1949-52; Professor, 1952-66; Professor of Applied Mathematics, 1967-. (Firestone)

Ting Fong Lai, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Hong Kong, 1954; M.Sc., 1957; Ph.D., St. Hilda's College, Oxford University, 1960. Lecturer, University of Hong Kong, 1966-. California Institute, 1965; 1968-69. (Church)

Marion Theresa Laico, Ph.D., *Research Fellow in Biology*
B.A., Caldwell College, 1960; Ph.D., University of Southern California, 1967. California Institute, 1967-. (Church)

*Leave of absence, 1968-69
**Part-time

David Lawrence Lambert, Ph.D., *Research Fellow in Astrophysics*
B.A., Oxford University, 1960; Ph.D., 1965. California Institute, 1967-. (Robinson)

Robert Franklin Landel,** Ph.D., *Senior Research Fellow in Chemical Engineering*
B.S., University of Buffalo, 1949; M.S., 1950; Ph.D., University of Wisconsin, 1954. Section Chief, Solid Propellant Chemistry, Jet Propulsion Laboratory, 1959-. Senior Research Fellow in Materials Science, California Institute, 1965-67; Senior Research Fellow in Chemical Engineering, 1967-. (Keck)

Anton Lang, Ph.D., *Research Associate in Biology*
Ph.D., University of Berlin, 1939. Director, Plant Research Laboratory, Michigan State University, 1965-. Research Fellow, California Institute, 1950-52; Senior Research Fellow, 1952; Professor, 1959-65; Research Associate, 1966-.

Robert Vose Langmuir, Ph.D., *Professor of Electrical Engineering*
A.B., Harvard University, 1935; Ph.D., California Institute, 1943. Senior Research Fellow, 1948-50; Assistant Professor, 1950-52; Associate Professor, 1952-57; Professor, 1957-. (Steele)

Beach Langston, Ph.D., *Associate Professor of English*
A.B., The Citadel, 1933; M.A., Claremont College, 1934; Ph.D., University of North Carolina, 1940. Assistant Professor, California Institute, 1947-53; Associate Professor, 1953-. (Dabney)

Lt. Colonel Charles J. Larkin, M.A., *Professor of Aerospace Studies*
B.A., George Washington University, 1962; M.A., 1963; M.A., University of Southern California, 1966. California Institute, 1967-. (Building T-1)

Raymond Walter Latham,** Ph.D., *Research Fellow in Electrical Engineering*
B.Eng., McGill University, 1958; M.S., California Institute, 1959; Ph.D., 1967. Staff Member, Northrop Corporation, 1963-. California Institute, 1967-. (Steele)

Richard Lewis Lau, Ph.D., *Bateman Research Fellow in Mathematics*
B.A., Yale University, 1963; M.A., 1965; Ph.D., 1967. California Institute, 1967-. (Sloan)

Thomas Lauritsen, Ph.D., *Professor of Physics*
B.S., California Institute, 1936; Ph.D., 1939; Senior Research Fellow, 1945; Assistant Professor, 1946-50; Associate Professor, 1950-55; Professor, 1955-. (Kellogg)

Muriel Lederman, Ph.D., *Research Fellow in Biology*
A.B., Barnard College, 1960; M.A., Columbia University, 1962; Ph.D., 1968. California Institute, 1968-69.

Lester Lees,*** M.S., *Professor of Aeronautics*
S.B., Massachusetts Institute of Technology, 1940; M.S., 1941. Associate Professor, California Institute, 1953-55; Professor, 1955-. (Firestone)

Robert Benjamin Leighton, Ph.D., *Professor of Physics; Staff Member, Mount Wilson and Palomar Observatories*
B.S., California Institute, 1941; M.S., 1944; Ph.D., 1947. Research Fellow, 1947-49; Assistant Professor, 1949-53; Associate Professor, 1953-59; Professor, 1959-. (Bridge)

James Lequeux, Ph.D., *Visiting Associate in Radio Astronomy*
B.S., University of Paris, 1956; Ph.D., 1962. Associate Scientist, Paris-Meudon Observatory, 1967-. California Institute, 1968-69.

Edward B. Lewis, Ph.D., *Thomas Hunt Morgan Professor of Biology*
B.A., University of Minnesota, 1939; Ph.D., California Institute, 1942. Instructor, 1946-48; Assistant Professor, 1948-49; Associate Professor, 1949-56; Professor, 1956-66; Morgan Professor, 1966-. (Kerckhoff)

Hsueh-Jei Li, Ph.D., *Research Fellow in Biology*
B.S., National Taiwan University, 1964; Ph.D., Yale University, 1968. California Institute, 1968-69.

Robert L. Lichter, Ph.D., *Research Fellow in Chemistry*
A.B., Harvard College, 1962; Ph.D., University of Wisconsin, 1967. California Institute, 1968-69.

Hans Wolfgang Liepmann, Ph.D., *Professor of Aeronautics*
Ph.D., University of Zurich, 1938. Assistant Professor, California Institute, 1939-46; Associate Professor, 1946-49; Professor, 1949-. (Karman)

Chun K. Lim, Ph.D., *Research Fellow in Chemical Engineering*
B.S., University of Missouri, 1960; M.S., The Pennsylvania State University, 1962; Ph.D., 1967. California Institute, 1967-. (Spalding)

Jia Ding Lin, Sc.D., *Senior Research Fellow in Engineering Science*
B.S., National Taiwan University, 1953; M.S., University of Illinois, 1956; Sc.D., Massachusetts Institute of Technology, 1961. Associate Professor of Civil Engineering, University of Connecticut, 1964-. California Institute, 1968-69.

**Part-time
***Leave of absence, second and third terms, 1968-69

Robert I. Lin, Ph.D., *Research Fellow in Chemistry*
B.Sc., National Taiwan University, 1961; M.A., University of California (Los Angeles), 1965; Ph.D., 1968. California Institute, 1968-69.

Frederick Charles Lindvall, Ph.D., D.Sc., Dr.Eng., *Professor of Electrical and Mechanical Engineering; Chairman of the Division of Engineering and Applied Science*
B.S., University of Illinois, 1924; Ph.D., California Institute, 1928; D.Sc., National University of Ireland, 1963; Dr.Eng., Purdue University, 1966. Instructor in Electrical Engineering, California Institute, 1930-31; Assistant Professor, 1931-37; Associate Professor of Electrical and Mechanical Engineering, 1937-42; Professor, 1942-; Division Chairman, 1945-. (Thomas)

Peter Barry Stuart Lissaman, Ph.D., *Assistant Professor of Aeronautics*
B.Sc., Natal University, South Africa, 1951; B.A., University of Cambridge, 1954; M.S., California Institute, 1955; Ph.D., 1966. Assistant Professor, 1962-. (Firestone)

Leslie Thomas Little, Ph.D., *Research Fellow in Radio Astronomy*
B.A., University of Cambridge, 1964; Ph.D., 1968. California Institute, 1968-69.

Peter Christian Lockemann, Dr.Ing., *Senior Research Fellow in Engineering*
Dipl.Ing., Institute of Technology, Munich, 1958; Dr.Ing., 1963. Research Fellow, California Institute, 1963-68; Senior Research Fellow, 1968-. (Steele)

Peter Loeliger, Ph.D., *Research Fellow in Chemistry*
Dipl., Swiss Federal Institute of Technology, Zurich, 1963; Ph.D., 1967. California Institute, 1967-. (Crellin)

Gary Allen Lorden, Ph.D., *Assistant Professor of Mathematics*
B.S., California Institute, 1962; Ph.D., Cornell University, 1966. California Institute, 1968-. (Sloan)

Heinz Adolph Lowenstam, Ph.D., *Professor of Paleoecology*
Ph.D., University of Chicago, 1939. California Institute, 1952-. (Arms)

Peter Herman Lowy, Doctorandum, *Senior Research Fellow in Biology*
Doctorandum, University of Vienna, 1936. Research Fellow, California Institute, 1949-65; Senior Research Fellow, 1965-. (Kerckhoff)

Ronald B. Luftig, Ph.D., *Research Fellow in Biology*
B.S., City College of New York, 1960; M.S., New York University, 1962; Ph.D., University of Chicago, 1967. California Institute, 1967-. (Kerckhoff)

Harold Lurie, Ph.D., *Professor of Engineering Science; Associate Dean of Graduate Studies*
B.Sc., University of Natal, South Africa, 1940; M.Sc., 1946; Ph.D., California Institute, 1950. Lecturer in Aeronautics, 1948-50; Assistant Professor of Applied Mechanics, 1953-56; Associate Professor, 1956-64; Professor of Engineering Science, 1964-; Assistant Dean of Graduate Studies, 1964-66; Associate Dean, 1966-. (Thomas, Throop)

Wilhelmus A. J. Luxemburg, Ph.D., *Professor of Mathematics*
Ph.D., Delft Institute of Technology, 1955. Assistant Professor, California Institute, 1958-60; Associate Professor, 1960-62; Professor, 1962-. (Sloan)

George Eber MacGinitie, M.A., *Professor of Biology, Emeritus*
A.B., Fresno State College, 1925; M.A., Stanford University, 1928. California Institute, 1932-57; Professor Emeritus, 1957-.

William Bernard MacGowan, M.A., *Lecturer in Music*
B.A., University of Michigan, 1949; M.A., 1950. California Institute, 1968. (Dabney)

George Rupert MacMinn, A.B., *Professor of English, Emeritus*
A.B., Brown University, 1905. California Institute, 1918-54; Professor Emeritus, 1954-.

Ralph G. Mancke, Ph.D., *Research Fellow in Chemical Engineering*
B.S., Yale University, 1962; Ph.D., University of Wisconsin, 1967. California Institute, 1967-. (Spalding)

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 E. Mandula, Ph.D., *Research Fellow in Theoretical Physics*
A.B., Columbia University, 1962; A.M., Harvard University, 1964; Ph.D., 1966. California Institute, 1967-. (Sloan)

Edwin Mansfield, Ph.D., *Visiting Professor of Economics*
A.B., Dartmouth College, 1951; M.A., Duke University, 1953; Ph.D., 1955. Professor of Economics, Wharton School, University of Pennsylvania, 1963-. California Institute, 1968.

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)

David George Marsh, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Birmingham, England, 1961; Ph.D., University of Cambridge, 1964. California Institute, 1967. (Church)

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)

David Robert Marshall, Ph.D., *Research Fellow in Chemistry*
B.A., Keble College, Oxford University, 1962; Ph.D., The University of Western Ontario, 1967. California Institute, 1967-. (Crellin)

Hardy Cross Martel, Ph.D., *Associate Professor of Electrical Engineering*
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-. (Steele)

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

Satoshi Matsuda, Ph.D., *Richard Chace Tolman Research Fellow in Theoretical Physics*
B.S., University of Tokyo, 1964; M.Sc., 1966; Ph.D., 1968. California Institute, 1968-69.

Ann Matthysse, Ph.D., *Research Fellow in Biology*
B.A., Radcliffe College, 1961; Ph.D., Harvard University, 1967. California Institute, 1966-. (Kerckhoff)

Livia Pica Mattoccia, Laurea, *Research Fellow in Biology*
Laurea, University of Rome, 1964. Staff Member, International Laboratory of Genetics (Naples), 1965-. California Institute, 1967-. (Church)

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, 1968-69.

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-. (Thomas)

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., *Research Fellow in Planetary Science*
B.S., Pennsylvania State University, 1964; M.S., California Institute, 1966; Ph.D., 1968. Research Fellow, 1968.

Thane H. McCulloh, Ph.D., *Research Associate in Geology*
B.A., Pomona College, 1949; Ph.D., University of California (Los Angeles), 1952. Staff Member, U. S. Geological Survey, 1964-. Assistant Professor, California Institute, 1953-55; Research Associate, 1964-. (Mudd)

Jack Edward McKee, Sc.D., *Professor of Environmental Health 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)

Dan Peter McKenzie, Ph.D., *Visiting Associate in Geophysics*
B.A., University of Cambridge, 1963; Ph.D., 1966. Imperial Chemical Industries Research Fellow, Imperial College, 1968-. Research Fellow, California Institute, 1967; Visiting Associate, 1968. (Seismo Lab.)

Basil Vincent McKoy, Ph.D., *Assistant 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-. (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-.

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)

Tsafrira Rand Meir, Ph.D., *Research Fellow in Chemistry*
M.Sc., Hebrew University of Jerusalem, 1960; Ph.D., 1967. California Institute, 1967-. (Church)

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)

Gerhard W. D. Meissner, Dr.rer.nat., *Research Fellow in Biology*
B.S., Free University of Berlin, 1963; Dr.rer.nat., Technical University of Berlin, 1965. California Institute, 1966-. (Alles)

James Edgar Mercereau,** Ph.D., *Research Associate in Physics*
B.A., Pomona College, 1953; M.S., University of Illinois, 1954; Ph.D., California Institute, 1959. Manager, Cryogenic Devices Department, Ford Motor Company, Newport Beach, 1965-. Assistant Professor, California Institute, 1959-62; Visiting Associate, 1964-65; Research Associate, 1965-. (Sloan)

John R. Merriam, Ph.D., *Research Fellow in Biology*
B.S., University of Wisconsin, 1962; M.S., University of Washington, 1963; Ph.D., 1966. California Institute, 1967-. (Kerckhoff)

Virginia Merriam, Ph.D., *Research Fellow in Biology*
B.S., Elizabethtown College, 1962; Ph.D., University of Washington, 1966. California Institute, 1967-. (Kerckhoff)

William Whipple Michael, B.S., *Professor of Civil Engineering, Emeritus*
B.S., Tufts College, 1909. 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)

Richard Lee Miller, Ph.D., *Research Fellow in Biology*
B.S., University of Chicago, 1962; Ph.D., 1965. Assistant Professor of Biology, Oregon State University, 1966-. California Institute, 1965-66; 1967; 1968.

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)

Mary B. Mitchell, M.A., *Research Fellow in Biology*
B.S., George Washington University, 1941; M.A., Stanford University, 1945. California Institute, 1946-. (Kerckhoff)

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)

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)

Carl Robert Morgan, Ph.D., *Research Fellow in Biology*
B.A., Wartburg College, Iowa, 1950; M.A., University of Nebraska, 1952; Ph.D., University of Minnesota, 1963. Associate Professor, Indiana University Medical Center, 1967-. California Institute, 1968-69.

**Part-time

James Fredrick Morgan, Ph.D., *Research Fellow in Physics*
B.A., St. Mary's College, Winona, Minnesota, 1963; M.S., University of Minnesota, 1966; Ph.D., 1968. California Institute, 1968-69.

James John Morgan, Ph.D., *Associate Professor of Environmental Health Engineering*
B.C.E., Manhattan College, 1954; M.S.E., University of Michigan, 1956; M.A., Harvard University, 1962; Ph.D., 1964. California Institute, 1965-. (Keck)

John Michael Morris, Ph.D., *Research Fellow in Physics*
B.Sc., Melbourne University, 1962; M.Sc., 1964; Ph.D., The Australian National University, 1967. California Institute, 1967-68.

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; 1966; 1967; 1968.

Duane O. Muhleman, *Associate Professor of Planetary Science; Staff Member, Mount Wilson and Palomar Observatories*
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.

Guido Münch, Ph.D., *Professor of Astronomy; Staff Member, Mount Wilson and Palomar 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)

Masayo Murozumi, Ph.D., *Visiting Associate in Geochemistry*
B.Sc., Hokkaido University, 1948; Ph.D., 1961. Professor of Chemistry, Muroran College of Technology, 1962-. Research Fellow, California Institute, 1964-65; 1966; Visiting Associate, 1968.

Bruce Churchill Murray, Ph.D., *Professor of Planetary Science; Staff Associate, Mount Wilson and Palomar Observatories*
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; Staff Associate, 1965-; Professor, 1968-. (Mudd)

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-.

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*
A.B., Pomona College, 1926; Ph.D., California Institute, 1931; Sc.D., Pomona College, 1968. Instructor and Assistant Professor, 1933-40; Associate Professor, 1940-44; Professor, 1944-.

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

Michael Neushul, Jr.,** Ph.D., *Visiting Associate in Environmental Health Engineering*
B.A., University of California (Los Angeles), 1955; Ph.D., 1959. Associate Professor of Botany, University of California (Santa Barbara), 1965-. California Institute, 1968-69.

Gerry Neugebauer, Ph.D., *Associate Professor of Physics; Staff Associate, Mount Wilson and Palomar Observatories*
A.B., Cornell University, 1954; Ph.D., California Institute, 1960. Assistant Professor, 1962-65; Associate Professor; Staff Associate, 1965-. (Bridge)

*Leave of absence, 1968-69
**Part-time

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

Davis Betz Nichols, Ph.D., *Research Fellow in Physics*
B.S., Wheaton College, 1962; Ph.D., University of Kentucky, 1966. California Institute, 1968-69.

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)

Navin Chandra Nigam, Ph.D., *Research Fellow in Civil Engineering*
B.E., University of Roorkee, 1958; M.S., Purdue University, 1964; Ph.D., California Institute, 1967. Research Fellow, 1967-. (Thomas)

Wesley Gray Nigh, Ph.D., *Research Fellow in Chemistry*
B.S., University of California (Los Angeles), 1960; Ph.D., University of Washington, 1965. California Institute, 1967-68.

Hiromichi Noguchi,** Ph.D., *Research Fellow in Chemical Engineering*
B.S., Waseda University, 1958; M.S., Tokyo Institute of Technology, 1960; Ph.D., 1964. Resident Research Associate, Jet Propulsion Laboratory, 1967-. California Institute, 1967-68.

Roger Gordon Noll,*** Ph.D., *Assistant Professor of Economics*
B.S., California Institute, 1962; M.A., Harvard University, 1965; Ph.D., 1967. Instructor, California Institute, 1965-67; Assistant Professor, 1967-.

Ulf Norrsell, Ph.D., *Research Fellow in Biology*
B.M., University of Lund, Sweden, 1957; Ph.D., University of Goteborg, 1966. California Institute, 1968-. (Alles)

Wheeler James North, Ph.D., *Professor of Environmental Health Engineering*
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)

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)

Graeme Nyberg, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Western Australia, 1963; Ph.D., University of Cambridge, 1967. California Institute, 1968-69.

Patrick William Nye, Ph.D., *Research Fellow in Applied Science*
B.Sc., Reading University (England), 1958; Ph.D., 1962. Staff Physicist, California Institute, 1965-66; Research Fellow, 1966-. (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)

John Beverley Oke, Ph.D., *Professor of Astronomy; Staff Member, Mount Wilson and Palomar Observatories*
B.A., University of Toronto, 1949; M.A., 1950; Ph.D., Princeton University, 1953. Assistant Professor, California Institute, 1958-61; Associate Professor, 1961-64; Professor, 1964-. (Robinson)

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-. (Dabney)

Angelo Antonio Orio, Ph.D., *Research Fellow in Chemistry*
Ph.D., University of Padua, 1963. California Institute, 1967-68 .

Robert Allen Osteryoung, Ph.D., *Visiting Associate in Chemistry*
B.S., University of Ohio, 1949; M.S., University of Illinois, 1951; Ph.D., 1954. Group Leader, North American Aviation Science Center, 1962-. California Institute, 1963-. (Gates)

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)

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)

**Part-time

***Leave of absence, first term, 1968-69

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)

Richard Ghrist Parker, Ph.D., *Research Fellow in Chemistry*
B.S., Carnegie-Mellon University, 1963; Ph.D., University of Nebraska, 1967. California Institute, 1968-69.

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 University, 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-.

John Stuart Pearse, Ph.D., *Research Fellow in Biology*
B.Sc., University of Chicago, 1958; Ph.D., Stanford University, 1965. California Institute, 1967.

Charles William Peck, Ph.D., *Assistant 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-. (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.

Phillip James Edwin Peebles, Ph.D., *Visiting Associate in Physics*
B.S., University of Manitoba, 1958; M.A., Princeton University, 1959; Ph.D., 1962. Associate Professor of Physics, Princeton University, 1968-. California Institute, 1968-69.

Bertram Peretz, Ph.D., *Research Fellow in Biology*
B.S., University of Michigan, 1955; B.S.E., 1959; M.S., 1963; Ph.D., University of Iowa, 1968. California Institute, 1968-69.

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)

Deane Millar Peterson, Ph.D., *Research Fellow in Astronomy*
B.A., Northwestern University, 1963; M.S., 1964; Ph.D., Harvard University, 1968. California Institute, 1968-69. (Mt. Wilson Office)

Vahe Petrosian, Ph.D., *Research Fellow in Physics*
B.E.E., Cornell University, 1962; M.S., 1963; Ph.D., 1967. California Institute, 1967-. (Kellogg)

Margarete Petzuch, Ph.D., *Research Fellow in Biology*
Ph.D., University of Munich, 1967. California Institute, 1968-69.

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.)

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. Research Fellow, California Institute, 1959-65; Senior Research Fellow, 1965-. (Alles)

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-. (Sloan)

Cornelius John Pings, Ph.D., *Professor of Chemical Engineering*
B.S., California Institute, 1951; M.S., 1952; Ph.D., 1955. Associate Professor, 1959-64; Professor, 1964-. (Spalding)

**Part-time

Milton S. Plesset, Ph.D., *Professor of Engineering Science*
B.S., University of Pittsburgh, 1929; Ph.D., Yale University, 1932. Associate Professor, 1948-51; Professor, 1951-. (Thomas)

Chung-Kwong Poon, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Hong Kong, 1964; Ph.D., University College, London University, 1967. California Institute, 1968. (Noyes)

David Peter Pope, Ph.D., *Research Fellow in Materials Science*
B.S., University of Wisconsin, 1961; M.S., California Institute, 1962; Ph.D., 1967. Research Fellow, 1967-. (Keck)

Evert Jan Post, Ph.D., *Senior Research Fellow in Electrical Engineering*
B.S., M.S., Delft Institute of Technology, 1949; Ph.D., University of Amsterdam, 1964. Staff Member, Air Force Cambridge Research Laboratories, 1961-. California Institute, 1968.

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

Charles Young Prescott, Ph.D., *Research Fellow in Physics*
B.A., Rice University, 1961; Ph.D., California Institute, 1966. Research Fellow, 1966-. (Synchrotron)

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

Jens Pukies, Dr.rer.nat., *Research Fellow in Chemistry*
Dipl., Technical University of Brunswick, 1965; Dr.rer.nat., Technical University of Berlin, 1967. California Institute, 1968-69.

Rene Racine, Ph.D., *Research Fellow in Astronomy*
B.A., Laval University, 1958; B.Sc., 1963; M.A., University of Toronto, 1965; Ph.D., 1967. California Institute, 1967-. (Mount Wilson Office)

Roger James Radloff, Ph.D., *Research Fellow in Biology*
B.S., Iowa State University, 1962; Ph.D., California Institute, 1968. Research Fellow, 1967.

Michael Augustine Raftery, Ph.D., *Assistant 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-. (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)

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)

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)

Claudio Rebbi, Laurea, *Research Fellow in Theoretical Physics*
Laurea, University of Turin, 1965. California Institute, 1968-. (Sloan)

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

**Part-time

Martin John Rees, Ph.D., *Research Fellow in Astronomy*
B.A., University of Cambridge, 1963; M.A., Ph.D., 1967. California Institute, 1968.

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)

Manfred Wilhelm Renz, Dr.rer.nat., *Research Fellow in Chemistry*
B.Sc., The University of the Saar, 1961; M.Sc., Free University of Berlin, 1964; Dr.rer.nat., Technical University of Berlin, 1967. California Institute, 1967-68.

John Hall Richards, Ph.D., *Associate 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-. (Crellin)

Charles Francis Richter, Ph.D., *Professor of Seismology*
A.B., Stanford University, 1920; Ph.D., California Institute, 1928. Assistant Professor, 1937-47; Associate Professor, 1947-52; Professor, 1952-. (Seismo Lab.)

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-.

Eugene Roberts, Ph.D., *Visiting Professor of Biology*
B.S., Wayne University, 1940; M.S., University of Michigan, 1941; Ph.D., 1943. Director, Division of Neurosciences, City of Hope Medical Center, 1968-. California Institute, 1968.

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)

Julian Lee Roberts, Jr., Ph.D., *Visiting Associate in Chemistry*
B.A., University of Southern California, 1957; Ph.D., Northwestern University, 1962. Associate Professor, University of Redlands. California Institute, 1968-69.

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)

Leon S. Rochester, Ph.D., *Research Fellow in Physics*
A.B., University of Chicago, 1962; Ph.D., California Institute, 1968. Research Fellow, 1968-69. (Sloan)

Bruce Joseph Rogers, Ph.D., *Visiting Associate in Biology*
B.S.F., University of California, 1949; M.S.F., 1950; Ph.D., California Institute, 1955. Plant Physiologist, U. S. Department of Agriculture, 1967-. California Institute, 1967-68.

David Herbert Rogstad, Ph.D., *Research Fellow in Radio Astronomy*
B.S., California Institute, 1962; M.S., 1964; Ph.D., 1967. Research Fellow, 1966-. (Robinson)

Louis Deane Rollmann, Ph.D., *Research Fellow in Chemistry*
B.A., University of Kansas, 1960; Ph.D., 1967. California Institute, 1967-68.

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., *Assistant Professor of History*
B.A., University of California (Los Angeles), 1957; M.S., 1959; Ph.D., 1965. Visiting Assistant Professor, California Institute, 1966-68; Assistant Professor, 1968- .(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)

Robert F. Roy, Ph.D., *Senior Research Fellow in Geophysics*
B.A., Harvard College, 1952; M.A., Harvard University, 1960; Ph.D., 1963. California Institute, 1966-. (Seismo Lab.)

Bruce Herbert Rule, B.S., *Staff Member, Chief Engineer, Mount Wilson and Palomar 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)

*Leave of absence, 1968-69
**Part-time

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 Fluid Mechanics*
B.A., Trinity College, University of Cambridge, 1953; M.A., Ph.D., 1956. California Institute, 1964-. (Firestone)

Bruce Hornbrook Sage,* Ph.D., Eng.D., *Professor of 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, 1937-39; Associate Professor, 1939-44; Professor, 1944-. (Spalding)

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)

Lionel Salem, Ph.D., D.Sc., *Visiting Associate in Chemistry*
Lic., University of Paris (Sorbonne), 1957; Ph.D., University of Cambridge, 1960; D.Sc., University of Paris, 1962. California Institute, 1967.

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, Mount Wilson and Palomar Observatories*
A.B., University of Illinois, 1948; Ph.D., California Institute, 1953; Sc.D., Yale University, 1966; D.Sc., University of Chicago, 1967. Mt. Wilson Observatory, 1948-. (Mt. Wilson Office)

Emerson Cecil Sanford, Ph.D., *Research Fellow in Chemistry*
B.Sc., Mt. Allison University, New Brunswick, 1964; M.Sc., 1966; Ph.D., McMaster University, Ontario, 1968. California Institute, 1968-69.

Wallace Leslie William Sargent, Ph.D., *Associate Professor of Astronomy; Staff Member, Mount Wilson and Palomar 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)

Stuart H. Schaar, Ph.D., *Visiting Lecturer in International Affairs*
B.A., City College of New York, 1958; Ph.D., Princeton University, 1966. Member, American Universities Field Staff, Inc. California Institute, 1969.

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)

Charles Bruce Schewene, Ph.D., *Research Fellow in Chemistry*
A.B., Villa Madonna College, Kentucky, 1961; Ph.D., University of Wisconsin, 1967. California Institute, 1967-. (Crellin)

Klaus Schilling, Dr.rer.nat., *Research Fellow in Theoretical Physics*
Dipl., University of Bonn, 1963; Dr.rer.nat., University of Hamburg, 1966. Research Associate, 1966-. California Institute, 1968-69.

Maarten Schmidt, Ph.D., Sc.D., *Professor of Astronomy; Staff Member, Mount Wilson and Palomar Observatories*
Ph.D., University of Leiden, 1956; Sc.D., Yale University, 1966. Carnegie Fellow, Mount Wilson and Palomar Observatories, 1956-58; Associate Professor, California Institute, 1959-64; Professor, 1964-. (Robinson)

Christopher Henry Scholz, Ph.D., *Research Fellow in Geophysics*
B.S., University of Nevada, 1964; Ph.D., Massachusetts Institute of Technology, 1967. California Institute, 1967-68.

Michael Thomas Scholz, Dr.rer.nat., *Research Fellow in Astrophysics*
Dipl., University of Hamburg, 1964; Dr.rer.nat., 1966. California Institute, 1967-68.

*Leave of absence, 1968-69

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)

Harvey J. Schugar, Ph.D., *Research Fellow in Chemistry*
B.S., Carnegie-Mellon University, 1958; M.A., Columbia University, 1959; Ph.D., 1961. California Institute, 1967-68.

Martin Harvey Schultz, Ph.D., *Associate Professor of Mathematics*
B.S., California Institute, 1961; A.M., Harvard University, 1962; Ph.D., 1965. California Institute, 1968-. (Sloan)

Frank J. Sciulli, Ph.D., *Research Fellow in Physics*
A.B., University of Pennsylvania, 1960; M.S., 1961; Ph.D., 1965. California Institute, 1966-. (Synchrotron)

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

Leonard Searle, Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
Ph.D., Princeton University, 1956. Senior Research Fellow in Astronomy, California Institute, 1960-63; Staff Member, 1968-. (Mt. Wilson 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)

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., *Assistant Professor of Chemical Engineering*
B.S., University of Rochester, 1964; Ph.D., Princeton University, 1967. California Institute, 1967-. (Spalding)

Edwin Charles Seltzer, Ph.D., *Research Fellow in Physics*
B.S., California Institute, 1959; Ph.D., 1966. Research Fellow, 1965-. (W. Bridge)

Sedat Serdengecti, Ph.D., *Visiting Associate in Jet Propulsion*
B.S., Syracuse University, 1951; M.S., California Institute, 1952; Ph.D., 1955. Associate Professor of Engineering, Harvey Mudd College, 1965-. Research Fellow, California Institute, 1955-56; Visiting Associate, 1967-68.

Manoochehr Shahab, Ph.D., *Research Fellow in Chemistry*
B.A., University of Colorado, 1952; Ph.D., 1956. Staff Member, Development and Research, National Iranian Oil Company, 1962-. California Institute, 1967-68.

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

Jerome Lee Shapiro, Ph.D., *Associate Professor of Applied Science*
B.M.E., City College of New York, 1954; M.S., University of Michigan, 1955; Ph.D., 1961. Research Fellow in Engineering, California Institute, 1961-63; Assistant Professor of Applied Science, 1963-67; Associate Professor, 1967-. (Thomas)

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)

J. Arthur Shercliff, Ph.D., *Visiting Professor of Aeronautics*
M.A., Ph.D., University of Cambridge, 1954. Professor of Engineering Science, University of Warwick, 1965-. California Institute, 1968.

Bruce Arne Sherwood, Ph.D., *Assistant Professor of Physics*
B.S., Purdue University, 1960; M.S., University of Chicago, 1963; Ph.D., 1966. Research Fellow, California Institute, 1966; Assistant Professor, 1966-. (Bldg. T-4)

Richard Thorpe Shield, Ph.D., *Professor of Applied Mechanics*
B.Sc., Kings College, Durham University, 1949; Ph.D., 1952. California Institute, 1965-. (Thomas)

Akio Shiraishi, Ph.D., *Research Fellow in Applied Science*
B.S., Kyushu University, 1962; M.S., 1964; Ph.D., 1967. California Institute, 1968-. (Booth)

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)

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)

Martha Nichols Simon, Ph.D., *Research Fellow in Chemistry*
A.B., Radcliffe College, 1962; Ph.D., Cornell University, 1967. California Institute, 1967-. (Church)

Michal Simon, Ph.D., *Research Fellow in Astronomy*
B.A., Harvard College, 1962; Ph.D., Cornell University, 1967. California Institute, 1967-. (Robinson)

Josef Singer, Ph.D., *Visiting Professor of Aeronautics*
B.Sc., Imperial College, University of London, 1948; M.S., Polytechnic Institute of Brooklyn, 1953; Ph.D., 1957. Professor; Head, Department of Aeronautical Engineering, Israel Institute of Technology, 1965-. California Institute, 1968-69.

Ashok Kumar Sinha, Ph.D., *Research Fellow in Materials Science*
B.S., Indian Institute of Science, Bangalore, 1964; Ph.D., Oxford University, 1966. California Institute, 1968-69.

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)

Richard C. Slansky, Ph.D., *Research Fellow in Theoretical Physics*
B.A., Harvard College, 1962; Ph.D., University of California, 1967. California Institute, 1967-. (Sloan)

Brian Leslie Smith, Ph.D., *Research Fellow in Chemical Engineering*
B.Sc., Queen Mary College, University of London, 1957; Ph.D., 1960. Lecturer in Physics, University of Sussex, 1962-. California Institute, 1960-62; 1964; 1967.

David Rodman Smith, Ph.D., *Associate Professor of English*
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-. (Dabney)

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)

James Hart Smith, Ph.D., *Research Fellow in Chemistry*
B.S., Yale University, 1963; Ph.D., University of California, 1967. California Institute, 1967-. (Crellin)

John Michael Smith, Ph.D., *Assistant Professor of Chemistry*
B.S., University of Michigan, 1962; Ph.D., University of California (Los Angeles), 1966. California Institute, 1966-. (Gates)

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)

John Donald Speight, Ph.D., *Research Fellow in Materials Science*
B.Sc., University of Birmingham, 1963; Ph.D., 1967. California Institute, 1968. (Keck)

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)

Rangasami Sridhar, Ph.D., *Associate Professor of Electrical Engineering*
B.S., University of Mysore, 1955; M.S., Purdue University, 1957; Ph.D., 1960. California Institute, 1965-. (Steele)

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-.

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 Applied 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. California Institute, 1964-. (Thomas)

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)

William Sheldon Stewart, Ph.D., *Research Associate in Biology*
B.A., University of California (Los Angeles), 1936; M.A., 1937; Ph.D., California Institute, 1939. Director, Los Angeles State and County Arboretum, 1955-. California Institute, 1955-.

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)

Robert David Stolow, Ph.D., *Visiting Associate in Chemistry*
S.B., Massachusetts Institute of Technology, 1953; Ph.D., University of Illinois, 1956. Associate Professor of Organic Chemistry, Tufts University, 1964-. California Institute, 1967-68.

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-. (W. Bridge)

Thomas Foster Strong,* M.S., *Associate Professor of Physics*
B.S., University of Wisconsin, 1922; M.S., California Institute, 1937. Assistant Professor, 1944-65; Associate Professor, 1965-; Dean of Freshmen, 1946-68.

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, 1968-69.

Felix Strumwasser, Ph.D., *Associate Professor of Biology*
B.A., University of California (Los Angeles), 1953; Ph.D., 1957. California Institute, 1964-. (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)

Alfred Henry Sturtevant, Ph.D., Sc.D., *Thomas Hunt Morgan Professor of Biology, Emeritus*
A.B., Columbia University, 1912; Ph.D., 1914; Sc.D., Princeton University, 1947; Sc.D., University of Pennsylvania, 1949. Professor, California Institute, 1928-51; Thomas Hunt Morgan Professor of Genetics, 1951-62; Professor Emeritus, 1962-. (Kerckhoff)

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)

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Clare C. C. Yu Sun, Ph.D., *Research Fellow in Biology*
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Carl Magnus Svahn, Fil.lic., *Research Fellow in Biology*
Fil.lic., University of Stockholm, 1967. California Institute, 1968-69.

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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)

John Edward Swisher, Ph.D., *Research Fellow in Biology*
B.S., Stetson University, 1958; M.S., University of Florida, 1961; Ph.D., 1965. California Institute, 1965-. (Alles)

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Christian Ignatius Tanzer, Ph.D., *Research Fellow in Chemistry*
B.Sc., The University of Adelaide, 1963; Ph.D., 1968. California Institute, 1968-69. (Crellin)

Gary N. Taylor, Ph.D., *Research Fellow in Chemistry*
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Hugh Pettingill Taylor, Jr., Ph.D., *Associate 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-. (Mudd)

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B.S., National Taiwan University, 1959; M.A., Stanford University, 1960; Ph.D., 1963. California Institute, 1963-. (Alles)

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)

Paul Milton Thomas, Ph.D., *Research Fellow in Biology*
B.S., Allegheny College, 1958; M.A., University of Michigan, 1959; M.S., 1962; Ph.D., 1964. Associate Professor of Biology, Pasadena College, 1966-. California Institute, 1967-68.

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Donald Robert Thompson, Jr., Ph.D., *Research Fellow in Physics*
B.S., Case Western Reserve University, 1964; Ph.D., University of Minnesota, 1968. California Institute, 1968-69.

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)

Kip Stephen Thorne, Ph.D., *Associate 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-. (Kellogg)

Keh-Ping Ting, Ph.D., *Research Fellow in Biology*
B.Sc., Taiwan Provincial Chung Hsing University, 1957; Ph.D., University of Alberta, 1966. California Institute, 1968-69. (Kerckhoff)

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-. (Sloan)

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)

Upendra Trivedi, Ph.D., *Research Fellow in Theoretical Physics*
B.Sc., University of Delhi, 1960; M.Sc., 1962; Ph.D., University of Bombay, 1968. California Institute, 1968-69.

James Wellington Truran, Ph.D., *Research Fellow in Physics*
B.A., Cornell University, 1961; M.A., Yale University, 1963; Ph.D., 1965. Assistant Professor of Space Physics, Yeshiva University, 1967-. California Institute, 1968-69.

Fun Dow Tsay, Ph.D., *Arthur Amos Noyes Research Fellow in Chemistry*
B.S., National Taiwan University, 1961; M.A., Washington University, 1965; Ph.D., 1968. California Institute, 1968-69.

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., *Research Fellow in Materials Science*
B.S., National Taiwan University, 1960; M.S., California Institute, 1963; Ph.D., 1966. Research Fellow, 1966-. (Keck)

Takashi Tsuji, Ph.D., *Senior Research Fellow in Astrophysics*
B.S., University of Tokyo, 1960; M.A., 1962; Ph.D., 1965. Research Fellow, California Institute, 1966-67; Senior Research Fellow, 1967-. (Robinson)

Albert Tyler, Ph.D., *Professor of Biology*
A.B., Columbia University, 1927; M.A., 1928; Ph.D., California Institute, 1929. Instructor, 1929-38; Assistant Professor, 1938-46; Associate Professor, 1946-50; Professor, 1950-. (Alles)

Roger Keith Ulrich, Ph.D., *Research Fellow in Physics*
B.S., University of California, 1963; Ph.D., 1968. California Institute, 1968-69. (Kellogg)

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-.

Sidney van den Bergh, Dr.rer.nat., *Research Associate in Astronomy*
A.B., Princeton University, 1950; M.Sc., The Ohio State University, 1952; Dr.rer.nat., University of Göttingen, 1956. Professor of Astronomy, University of Toronto, 1966-. California Institute, 1968-69.

Johannes Cornelis Vanderleeden, Ph.D., *Research Fellow in Physics*
B.S., The Ohio State University, 1957; M.S., 1959; Ph.D., 1966; California Institute, 1966-. (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)

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)

Eric Varley, Ph.D., *Senior Research Fellow in Applied Mathematics*
B.Sc., University of Manchester, 1955; M.S., 1957; Ph.D., Brown University, 1961. Lecturer in Theoretical Mechanics, University of Nottingham, 1964-. California Institute, 1967.

Arthur Harris Vaughan, Jr., Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
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Sharon Tena Vaughan, Ph.D., *Research Fellow in Biology*
B.S., University of Oklahoma, 1963; M.S., University of Illinois, 1965; Ph.D., 1967. California Institute, 1967-. (Church)

Giulio Vitale Samuele Venezian, Ph.D., *Research Fellow in Engineering Science*
B.E., McGill University, 1960; Ph.D., California Institute, 1965. Research Fellow in Geophysics, 1965-66; Research Fellow in Engineering Science, 1966-. (Karman)

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)

Natarajan Visvanathan, Ph.D., *Research Fellow in Astronomy*
B.Sc., Madras University, 1952; Ph.D., Australian National University, 1966. California Institute, 1966-. (Mount Wilson Office)

Rochus E. Vogt, Ph.D., *Associate Professor of Physics*
S.M., University of Chicago, 1957; Ph.D., 1961. Assistant Professor, California Institute, 1962-65; Associate Professor, 1965-. (W. Bridge)

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)

Hugo Rudolf Fritz Wasgestian, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Frankfurt, 1958; M.A., 1962; Ph.D., 1966. California Institute, 1968-69. (Crellin)

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-. (Sloan)

Bi-Cheng Wang, Ph.D., *Research Fellow in Chemistry*
B.S., Cheng-Kung University, Taiwan, 1960. Ph.D., University of Arkansas, 1968. California Institute, 1968-69.

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; 1962; 1963; 1964; 1965; 1966; 1967; 1968. (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, California Institute, 1955-59; Associate Professor, 1959-62; Professor, 1962-. (Arms)

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, 1939-41; Associate Professor, 1949-57; Professor, 1957-. (Thomas)

Robert D. Wayne, M.A., *Assistant Professor of German*
Ph.B., Dickinson College, 1935; M.A., Columbia University, 1940. Instructor, California Institute, 1952-62; Assistant Professor, 1962-. (Dabney)

Spencer R. Weart, Ph.D., *Research Fellow in Astrophysics*
B.A., Cornell University, 1963; Ph.D., University of Colorado, 1968. California Institute, 1968-69.

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)

Jean J. Weigle, Ph.D., *Research Associate in Biology*
Ph.D., University of Geneva, 1923. California Institute, 1949-. (Church)

John R. Weir, Ph.D., *Associate Professor of Psychology*
B.A., University of California (Los Angeles), 1948; M.A., 1951; Ph.D., 1951. Associate, California Institute, 1951-53; Associate Professor, 1953-. (Throop)

David Calvin Weisser, Ph.D., *Research Fellow in Physics*
B.S., City College of New York, 1963; M.S., University of Minnesota, 1966; Ph.D., 1968. California Institute, 1968-69.

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)

Steven Charles Welch, Ph.D., *Research Fellow in Chemistry*
B.S., University of California (Los Angeles), 1964; Ph.D., University of Southern California, 1968. California Institute, 1968-69.

John Brewer Weldon, M.A., *Registrar*
A.B., Culver-Stockton College, 1924; M.A., University of Nebraska, 1934. California Institute, 1964-. (Throop)

James Adolph Westphal, B.S., *Senior Research Fellow in Planetary Science; Staff Associate, Mount Wilson and Palomar Observatories*
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Ward Whaling, Ph.D., *Professor of Physics*
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J. Millar Whalley, Ph.D., *Research Fellow in Biology*
B.Sc., University of Glasgow, 1963; Ph.D., 1967. California Institute, 1968-.

Lewis Turner Wheeler, Ph.D., *Research Fellow in Applied Mechanics*
B.S., University of Houston, 1963; M.S., 1964; Ph.D., California Institute, 1968. Research Fellow, 1968.

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)

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)

George Denis Wignall, Ph.D., *Research Fellow in Chemical Engineering*
B.Sc., University of Sheffield, 1962; Ph.D., 1965. California Institute, 1968. (Spalding)

Mark Edward Williamson, M.D., *Research Fellow in Applied Science*
B.A., Johns Hopkins University, 1960; M.D., 1964. California Institute, 1968.

Olin Chaddock Wilson, Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
A.B., University of California, 1929; Ph.D., California Institute, 1934. Mt. Wilson Observatory, 1931-. (Mt. Wilson Office)

Charles Harold Wilts, Ph.D., *Professor of Electrical Engineering*
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Daniel H. Winicur, Ph.D., *Research Fellow in Chemistry*
B.S., City College of New York, 1961; M.S., University of Connecticut, 1963; Ph.D., University of California (Los Angeles), 1968. California Institute, 1968-69.

Meldrum Barnett Winstead, Ph.D., *Visiting Associate in Chemistry*
B.S., Davidson College, 1946; M.A., University of North Carolina, 1949; Ph.D., 1952. Associate Professor of Chemistry, Bucknell University, 1956-. California Institute, 1967-68.

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Franklin Bruce Wolverton, Ph.D., *Research Fellow in Physics*
B.S., University of Michigan, 1961; Ph.D., California Institute, 1968. Research Fellow, 1968-69. (Bldg. T-4)

David Shotwell Wood, Ph.D., *Professor of Materials Science; Acting 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. (Keck, Throop)

William Barry Wood III, Ph.D., *Associate Professor of Biology*
A.B., Harvard College, 1959; Ph.D., Stanford University, 1963. Assistant Professor, California Institute, 1964-68; Associate Professor, 1968-. (Kerckhoff)

Robin Alan Wooding, Ph.D., *Senior Research Fellow in Hydraulics*
Ph.D., University of Cambridge, 1960. Principal Research Scientist, C.S.I.R.O., Canberra, 1966-. California Institute, 1968.

Captain Donald K. Woodman, B.S., *Assistant Professor of Aerospace Studies*
B.S., U.S. Military Academy, 1962. California Institute, 1967-. (Building T-1)

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-.

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)

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)

Karl Wulff, Dr.rer.nat., *Research Fellow in Chemistry*
Dr.rer.nat., University of Freiburg, 1968. California Institute, 1968-69.

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)

Tadashi S. Yamamoto, D.Sc., *Visiting Associate in Biology*
B.S., Hokkaido University, 1953; D.Sc., 1961. Assistant Professor of Embryology, 1965-. California Institute, 1968-69.

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, 1968-69.

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)

Chaim Yarnitzky, D.Sc., *Research Fellow in Chemistry*
B.Sc., Technion (Israel Institute of Technology), 1962; M.Sc., 1964; D.Sc., 1967. California Institute, 1968-69.

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)

Adriaan Cornelis Zaanen, Ph.D., *Visiting Professor of Mathematics*
Ph.D., State University of Leiden, 1938. Professor of Mathematics, 1956-. Visiting Associate, California Institute, 1964; Visiting Professor, 1960-61; 1968-69. (Sloan)

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-. (Sloan)

Marko Zalokar, D.Sc., *Gosney Research Fellow in Biology*
Dipl., University of Ljubljana, 1940; D.Sc., University of Geneva, 1944. Research Fellow, California Institute, 1947-49; Gosney Research Fellow, 1967-68.

Fernando Claudio Zawislak, Ph.D., *Research Fellow in Physics*
B.S., Federal University of Rio Grande do Sul, Brazil, 1957; Lic., 1959; Ph.D., 1967. California Institute, 1968. (W. Bridge)

Laszlo Zechmeister, Dr.Ing., *Professor of Organic Chemistry, Emeritus*
Diploma of Chemist, 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)

Herman Ernst Zieger, Ph.D., *Visiting Associate in Chemistry*
B.S., Muhlenberg College, 1956; Ph.D., The Pennsylvania State University, 1961. Assistant Professor, Brooklyn College, The City University of New York, 1965-. California Institute, 1967-68.

Gene Robert Ziegler, Ph.D., *Research Fellow in Chemistry*
B.S., Illinois Institute of Technology, 1963; Ph.D., University of California, 1966. California Institute, 1967-68. (Crellin)

Harold Zirin, Ph.D., *Professor of Astrophysics; Staff Member, Mount Wilson and Palomar Observatories*
A.B., Harvard College, 1950; A.M., Harvard University, 1951; Ph.D., 1953. Visiting Associate, California Institute, 1963; Professor, 1964-. (Robinson)

Iris Ives Zschokke-Granacher, Ph.D., *Research Fellow in Electrical Engineering*
Ph.D., University of Basel, 1960. Staff Member, Institute of Applied Physics, University of Basel. California Institute, 1968.

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-. (Sloan)

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, Mount Wilson and Palomar Observatories, 1948-68; Professor Emeritus, 1968-. (Robinson)

GRADUATE FELLOWS, SCHOLARS, AND ASSISTANTS, 1967-68

Roger Henry Abel, *Danforth Fellow, Graduate Teaching Assistant, Chemistry*
B.A., Hope College, 1965

Mashood Olayide Adegbola, *Graduate Research Assistant,* Electrical Engineering*
B.S.E.E., Purdue University, 1965; M.S., California Institute, 1966

Saul Joseph Adelman, *National Defense Education Act Fellow, Astronomy*
B.S., University of Maryland, 1966

Randolph Ademola Adu, *African American Institute, Bennett Scholar, Graduate Research Assistant, Civil Engineering*
A.B., Harvard University, 1966

Bernard Ikecukwu Afoeju, *Graduate Teaching Assistant,* Mechanical Engineering*
B.S., Yale University, 1967

Jerre Basch L. Agresti, *Special Fellowship, Oberholtz Scholar, Graduate Teaching Assistant, Biology*
B.A., University of Miami, 1962; M.S., 1965

Nawal Abd El-Hay Ahmed, *Oberholtz Scholar, Graduate Teaching Assistant, Biology*
B.Sc. (Hons) (Bi and Ed), Ain Shams University, 1959; B.Sc. (Hons) (Zoo and Chem), 1961

Jose Alberto Albano Do Amarante, *National Aeronautics and Space Administration International Fellow, Physics*
Eng., Instituto Tecnologico de Aeronautica, 1966

William Longstreet Ames, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*
S.B., Massachusetts Institute of Technology, 1964; M.S., California Institute, 1967

P. V. Anandamohan, *Clinedinst Scholar, Graduate Laboratory Assistant, Aeronautics*
B.E., Coimbatore Institute of Technology, 1967

Christopher Marlowe Anderson, *Van Maanen Fellow, Astronomy*
B.S., University of Arizona, 1963

Franci Louise Anderson, *Graduate Teaching Assistant,* Chemistry*
B.S., Coe College, 1963; M.A., Harvard University, 1966

Kurt Steven Anderson, *Clinedinst Scholar, Graduate Research Assistant, Astronomy*
B.S., California Institute, 1963.

Michael Paul Anthony, *National Aeronautics and Space Administration Trainee, Graduate Research Assistant, Electrical Engineering*
B.S., California Institute, 1966; M.S., 1967

Walter Joseph Arabasz, *Drake Scholar, Graduate Research Assistant, Geology*
B.S., Boston College, 1964; M.S., California Institute, 1966

Vijay Hanumappa Arakeri, *Graduate Teaching Assistant,* Mechanical Engineering*
B.S., Utah State University, 1967

Johann Arbocz, *GALCIT Wind Tunnel Fellow, Aeronautics*
B.S., Northrop Institute of Technology, 1963; M.S., California Institute, 1964

David Woods Arnett, *National Institutes of Health Trainee, Engineering Science*
B.S.E.E., Purdue University, 1964; M.S.E.E., University of Pennsylvania, 1966

Alain Adrien Artaud, *Graduate Student, Electrical Engineering*
Ing., Ecole Polytechnique (Paris), 1964; Ing., Ecole Nationale Superieure de l'Aeronautique (Paris), 1967

Jeanette Asay, *National Defense Education Act Fellow, Graduate Teaching Assistant, Chemistry*
B.A., University of Utah, 1965

Gerald Richard Ash, *National Aeronautics and Space Administration Trainee, Electrical Engineering*
B.S., Rutgers University, 1964; M.S., California Institute, 1965

*Assistantship so marked carries tuition award.

Barbara Joan Furman Attardi, *National Defense Education Act Fellow, Biology*
B.S., Cornell University, 1964

Jerome Martin Auerbach, *National Science Foundation Trainee, Graduate Teaching Assistant, Mechanical Engineering*
Sc.B., Brown University, 1967

Floyd Richard Ault, *National Science Foundation Trainee, Engineering Science*
B.S., University of California (Los Angeles), 1967

Richard Harold Ault, *Graduate Teaching Assistant,* Physics*
B.S., University of Miami, 1964; M.S., California Institute, 1966

Soe Aung, *Graduate Research Assistant,* Chemistry*
B.Sc. (Gen. Hons), University of Rangoon, 1963

Alejandro Avila-Bernal, *United Nations Educational Scientific Cultural Organization, Dobbins Scholar, Chemical Engineering*
B.S., Instituto Politecnico Nacional Certificado De Estudio Ciclo Profesional, 1956

Raymond Dean Ayers, *Murray Scholar, Materials Science*
B.S., California Institute, 1963; M.S., 1964

Christopher Henry Bajorek, *National Science Foundation Trainee, Electrical Engineering*
A.A., Pasadena City College, 1964; B.S., California Institute, 1967

Dennis Dillon Baker, *National Aeronautics and Space Administration Trainee, Astronomy*
B.A., University of California, 1964

Mary Baker, *United States Public Health Service Trainee, Applied Mechanics*
B.S.E.M., University of Wisconsin, 1966; M.S., California Institute, 1967

George Nick Balanis, *Graduate Research Assistant,* Electrical Engineering*
B.S., California Institute, 1967

Steven Worth Baldwin, *National Institutes of Health Trainee, Chemistry*
A.B., Dartmouth College, 1964

Benedict William Bangerter, *Graduate Research Assistant,* Chemistry*
B.A., Macalester College, 1963

James Henry Barbee, *National Defense Education Act Fellow, Chemical Engineering*
B.S., University of Washington, 1965; M.S., California Institute, 1967

Brian Thomas Barcelo, *National Aeronautics and Space Administration Trainee, Aeronautics*
B.S., Tulane University, 1965; M.S., California Institute, 1966

John Roger Barker, *Graduate Research Assistant,* Chemical Engineering*
B.Sc. (Hons), College of Science and Technology (England), 1961

Stephen Joseph Barker, *National Science Foundation Trainee, Engineering Science*
B.S., Harvey Mudd College, 1967

Alan Joseph Barnett, *National Defense Education Act Fellow, Chemistry*
B.S., City College of New York, 1967

Michael I. Baskes, *Hertz Foundation Fellow, Materials Science*
B.S., California Institute, 1965

Luc Olivier Bauer, *Graduate Research Assistant,* Engineering Science*
Dipl., Ecole Polytechnique Lausanne, 1962; M.S., California Institute, 1964

William Robert Bauer, *Graduate Research Assistant,* Chemistry*
B.S., California Institute, 1961; B.A., Oxford University, 1963

Carl Edward Baum, *Graduate Student, Electrical Engineering*
B.S., California Institute, 1962; M.S., 1963

George deSille Beardsley, *Graduate Student, Materials Science*
B.S., University of Vermont, 1967

*Assistantship so marked carries tuition award.

Steven Kent Beckendorf, *National Science Foundation Fellow, Biology*
A.B., University of California (Los Angeles), 1966

Eric Edward Becklin, *Dobbins Scholar, Graduate Research Assistant,* Physics*
B.S., University of Minnesota, 1963

John Winston Belcher, *Graduate Research Assistant,* Physics*
B.A., Rice University, 1965

Lon Edward Bell, *Graduate Student, Mechanical Engineering*
B.S., California Institute, 1962; M.S., 1963

Ricardo Pablo Belloni, *Hanson Fellow, Aeronautics*
B.S., Northrop Institute of Technology, 1967

Larry Ira Benowitz, *United States Public Health Service Trainee, Biology*
B.ChE., Cooper Union, 1966

Michael Frederick Bent, *Graduate Teaching Assistant, Graduate Research Assistant,* Physics*
B.Sc., Dalhousie University, 1965; M.Sc., 1966

William Beranek, Jr., *National Institutes of Health Trainee, Chemistry*
B.S., University of Wisconsin, 1967

Kostia Bergman, *National Defense Education Act Fellow, Resident Associate, Biology*
B.A., Johns Hopkins University, 1965

Edward Francis Bernard, *National Science Foundation Trainee, Graduate Teaching Assistant, Physics*
B.S., Oregon State University, 1966

Uri Bernstein, *Graduate Teaching Assistant,* Physics*
S.B., Massachusetts Institute of Technology, 1963

Michael Dean Bertolucci, *Graduate Teaching Assistant,* Chemistry*
A.A., Santa Rosa Junior College, 1961; B.S., San Jose State College, 1967

Timothy Charles Betts, *National Aeronautics and Space Administration Trainee, Chemistry*
A.B., Humboldt State College, 1966

Jacobo Bielak, *Graduate Research Assistant,* Civil Engineering*
Civil Engineer, National University of Mexico, 1963; M.S., Rice University, 1966

Richard Henry Bigelow, *National Science Foundation Fellow, Engineering Science*
B.S., California Institute, 1966; M.S., 1967

Henry Joel Bilow, *National Science Foundation Fellow, Electrical Engineering*
B.S.E.E., Illinois Institute of Technology, 1965; M.S.E.E., 1966

Roland Charles Binst, *Graduate Teaching Assistant,* Mechanical Engineering*
Ing. Civ., Ing. Mech., University of Louvain, 1965; Dipl. Nuclear Science, 1967

Steven Allen Bissell, *National Defense Education Act Fellow, Graduate Teaching Assistant, Biology*
B.S., Harvey Mudd College, 1965; M.S., California Institute, 1967

James Edwin Blakemore, *National Science Foundation Fellow, Chemical Engineering*
B.S., The University of Tennessee, 1966

Richard Joseph Blint, *Graduate Teaching Assistant,* Chemistry*
B.A., St. Mary's College, 1967

Philippe Jean Blondy, *Tektronix Fellow, Electrical Engineering*
Ing., Institut Polytechnique de Grenoble (Ensehrmaj), 1965; M.S., California Institute, 1967

Fred Andrew Blum, Jr., *Howard Hughes Fellow, Physics*
B.S., University of Texas, 1962; M.S., California Institute, 1964

Joseph William Blum, *Graduate Teaching Assistant, Murray Scholar, Applied Mathematics*
B.S., Purdue University, 1963; M.S., 1964

*Assistantship so marked carries tuition award.

George Wallace Bluman, *Graduate Teaching Assistant, Drake Scholar, Applied Mathematics*
B.Sc., University of British Columbia, 1964

Alan Brian Blumenthal, *Graduate Teaching Assistant, Special Fellowship, Spalding Scholar, Biology*
A.B., Lafayette College, 1964

Donald Lawrence Blumenthal, *Graduate Research Assistant,* Aeronautics*
B.S., California Institute, 1965

Steven Raymond Boettcher, *Graduate Teaching Assistant, Murray Scholar, Applied Mathematics*
B.S., University of Wisconsin, 1967

Kenneth Paul Bogart, *National Science Foundation Fellow, Graduate Teaching Assistant, Mathematics*
B.S., Marietta College, 1965

James Leon Bolen, Jr., *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
B.S., Clemson University, 1966

Charles LaMonte Borders, Jr., *United States Public Health Service Fellow, Graduate Teaching Assistant, Chemistry*
B.A., Bellarmine College, 1964

David Boss, *National Science Foundation Trainee, Mathematics*
B.S., Clarkson College of Technology, 1967

Robert William Bower, *Graduate Research Assistant,* Electrical Engineering*
B.A., University of California (Berkeley), 1962; M.S., California Institute, 1963

Ray Douglas Bowman, *National Institutes of Health Trainee, Chemistry*
A.B., Indiana University, 1964

Haines John Boyle, *Graduate Teaching Assistant,* Mathematics*
B.S., Worcester Polytechnic Institute, 1962; M.A., University of Massachusetts, 1965

Donald Campbell Brabston, Jr., *Woodrow Wilson Fellow, Applied Mathematics*
B.S., Georgia Institute of Technology, 1967

Jim Neal Brantner, *Graduate Student, Mechanical Engineering*
B.S., United States Military Academy, 1967

William Garfield Bridges, Jr., *Graduate Teaching Assistant,* Mathematics*
A.B., University of Connecticut, 1964; M.S., Syracuse University, 1966

Gary Duane Brinker, *Graduate Research Assistant, Drake Scholar, Engineering Science*
S.B., Massachusetts Institute of Technology, 1962

Robert Terry Brinkmann, *Drake Scholar, Geology*
B.S., Capital University, 1964; M.S., University of Florida, 1966

Leonard William Brownlow, *Graduate Research Assistant,* Electrical Engineering*
B.A., Pomona College, 1966; M.S., University of Arizona, 1967

Robert Jay Buck, *Graduate Teaching Assistant,* Mathematics*
B.A., University of Buffalo, 1963

Jeffrey Allen Burke, *Graduate Student, Electrical Engineering*
B.S.E.E., University of Michigan, 1967

Patricia Virginia Burke, *Graduate Teaching Assistant,* Biology*
B.A., Pomona College, 1964; M.S., California Institute, 1967

Thomas Edmund Burke, *Graduate Research Assistant,* Chemistry*
B.A., University of Minnesota, 1962

William Lionel Burke, *United States Steel Fellow, Bridge Scholar, Physics*
B.S., California Institute, 1963

Maxwell Donald Burland, *Graduate Teaching Assistant,* Chemistry*
A.B., Dartmouth College, 1965

*Assistantship so marked carries tuition award.

Tim Jay Burns, *Graduate Teaching Assistant, California State Scholar, Applied Mechanics*
B.S., University of Redlands, 1967

Jerry Butman, *Ford Foundation Fellow, Electrical Engineering*
B. Eng., McGill University, 1965; M.S., California Institute, 1966

Michael Akylas Caloyannides, *Graduate Research Assistant,* Electrical Engineering*
B.S., California Institute, 1967

Frank Udo Canis, *Ford Foundation Fellow, Mechanical Engineering*
B. Eng., McGill University, 1967

Robert David Carlitz, *National Defense Education Act Fellow, Physics*
B.S., Duke University, 1965

Douglas Arthur Carne, *National Science Foundation Trainee, Applied Mechanics*
A.B., Occidental College, 1965; B.S., California Institute, 1967

David Gerald Carta, *Drake Scholar, Engineering Science*
B.S., California Institute, 1962; M.S., 1963

Bruce Alan Carter, *Graduate Teaching Assistant,* Geology*
M.S., California Institute, 1965

Lucian Carlton Carter III, *Graduate Teaching Assistant,* Physics*
B.A., University of Texas, 1960; B.S. (Ch), 1960; B.S. (Ph), 1961

William Parker Carter, *Graduate Teaching Assistant,* Chemistry*
B.A., University of California (Riverside), 1967

David Chapman Cartwright, *Graduate Research Assistant,* Chemistry*
B.S., Hamline University, 1962; M.S., California Institute, 1963

Lee Wendel Casperson, *National Aeronautics and Space Administration Trainee, Electrical Engineering*
B.S., Massachusetts Institute of Technology, 1966; M.S., California Institute, 1967

Philip Earl Cassady, *National Science Foundation Fellow, Aeronautics*
S.B., Massachusetts Institute of Technology, 1963; S.M., 1963

Richard Guy Casten, *National Defense Education Act Fellow, Applied Mathematics*
A.B., Temple University, 1965

John Millard Caywood, *Graduate Research Assistant,* Electrical Engineering*
B.S., California Institute, 1963; M.S., 1964

James Philip Cerne, *Graduate Research Assistant,* Geology*
B.S., Case Institute of Technology, 1967

Clyde Chadwick, *National Aeronautics and Space Administration Trainee, Geology*
S.B., Massachusetts Institute of Technology, 1965

Milton M. T. Chang, *Graduate Research Assistant,* Electrical Engineering*
B.S., University of Illinois, 1964; M.S., California Institute, 1965

Chia-Chun Chao, *T. S. Brown Scholar, Aeronautics*
B.Sc., Taiwan Provincial Cheng Kung University, 1962; M.S., California Institute, 1964

Chih-Chieh Chao, *Graduate Research Assistant,* Electrical Engineering*
B.S., University of Illinois, 1965; M.S., California Institute, 1966

Richard Bruce Chapman, *Baker Foundation Fellow, Engineering Science*
B.S., Purdue University, 1965; M.S., California Institute, 1966

Wilfred Peter Charette, *Graduate Student, Electrical Engineering*
B.S., California Institute, 1962; M.S., 1964

Sung-jen Chen, *Graduate Student, Chemical Engineering*
B.S., National Taiwan University, 1962; M.S., Kansas State University, 1965

Yu-Ssu Chen, *Graduate Research Assistant,* Physics*
B.S., National Taiwan University, 1963; M.A., Rice University, 1966

*Assistantship so marked carries tuition award.

Shiu-lang Shirley Cheng, *Graduate Research Assistant,* Chemistry*
B.S., National Taiwan University, 1963

Shiu-uh Cheng, *Graduate Research Assistant, Dobbins Scholar, Physics*
B.S., National Taiwan University, 1963; M.S., Tufts University, 1966

Man-Cheong Cheung, *GALCIT Wind Tunnel Fellow, Aeronautics*
B.S., Taiwan Provincial Cheng Kung University, 1964; M.S., California Institute, 1965

Ko-Chuan Chi, *Graduate Teaching Assistant,* Electrical Engineering*
B.A., National Taiwan University, 1960; B.S., University of Wisconsin, 1965; M.S., California Institute, 1966

Wu-sun Chia, *Graduate Research Assistant,* Chemical Engineering*
B.S., National Taiwan University, 1962; M.S., University of Saskatchewan, 1965

Dennis Don Chilcote, *United States Public Health Service Trainee, Chemical Engineering*
B.S., University of Minnesota, 1965

Kwang-nan Chow, *Graduate Teaching Assistant,* Mathematics*
B.S., National Taiwan University, 1964

Louise Tsi Chow, *Graduate Research Assistant,* Chemistry*
B.S., National Taiwan University, 1965

Theresa Kee-Yu Chow, *Graduate Teaching Assistant,* Mathematics*
B.S., National Taiwan University, 1962; M.A., Oregon State University, 1965

Clark Gardner Christensen, *National Science Foundation Fellow, Astronomy*
B.S., Brigham Young University, 1966

Daphne Stewart Christensen, *E. N. Brown Scholar, Aeronautics*
B.S., University of Southern California, 1956; M.S., 1957

Billie Mae Chu, *U. S. Public Health Fellow, Aeronautics*
B.A., Agnes Scott College, 1948; M.A., Emory University, 1949

David Chu, *National Defense Education Act Fellow, Physics*
B.S., California Institute, 1966

Frank I-Chien Chu, *Graduate Teaching Assistant,* Chemical Engineering*
B.S., National Taiwan University, 1964

Kwong Wah Chu, *National Aeronautics and Space Administration Trainee, Astronomy*
S.B., Massachusetts Institute of Technology, 1967

Allen Tse-Yung Chwang, *Graduate Teaching Assistant,* Mechanical Engineering*
B.Sc., Shu Hai College, 1965; M.S., University of Saskatchewan, 1967

George Richmond Clark, *National Science Foundation Trainee, Graduate Teaching Assistant, Geology*
A.B., Cornell University, 1961; M.S., California Institute, 1966

John Pierce Classen, *National Aeronautics and Space Administration Trainee, Graduate Teaching Assistant, Aeronautics*
B.S.E., Princeton University, 1966

Dean Norman Clay, *Gradaute Teaching Assistant,* Geophysics*
B.Sc., McGill University, 1963; M.S., California Institute, 1966

David Alvin Clayton, *U. S. Public Health Service Fellow, Biology*
B.S., Northern Illinois University, 1965

Barry Michael Cohen, *Graduate Teaching Assistant,* Mechanical Engineering*
B.S., Northeastern University, 1967

Judith Gamora Cohen, *National Science Foundation Trainee, Astronomy*
B.A., Radcliffe College, 1967

Russel Elliot Cole, *National Science Foundation Fellow, Electrical Engineering*
B.S., University of California (Berkeley), 1967

*Assistantship so marked carries tuition award.

Elmer William Colglazier, Jr., *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*
B.S., California Institute, 1966

Donald James Collins, *Graduate Teaching Assistant,* Aeronautics*
B.S., University of Arizona, 1962; M.S., 1963

Steven Douglas Colson, *Graduate Research Assistant,* Chemistry*
B.S., Utah State University, 1963

Jack Clifton Comly, Jr., *National Science Foundation Fellow, Physics*
B.S., California Institute, 1966

Robert William Conn, *Atomic Energy Commission Fellow, Engineering Science*
B.Ch.E., Pratt Institute, 1964; M.S., California Institute, 1965

John Thomas Conoboy, Jr., *Special Fellowship, Drake Scholar, Geology*
A.B., Western Reserve University, 1967

Clay Michael Conway, *Graduate Teaching Assistant,* Geology*
B.A., Brigham Young University, 1966

Robert Sanderson Cooke, *U. S. Public Health Service Fellow, Chemistry*
A.B., Wesleyan University, 1966

Nolan Gerald Core, *National Institutes of Health Trainee, Engineering Science*
A.B., Harvard University, 1967

Thomas Dennis Coskren, *National Science Foundation Fellow, Geology*
S.B., Massachusetts Institute of Technology, 1963

Gerald Michael Cotreau, *Bell Labs Fellow, Electrical Engineering*
A.A., Pensacola Junior College, 1964; B.S., University of Florida, 1967

Sydney Pollock Craig, *Special Fellowship, Oberholtz Scholar, Biology*
B.S., Purdue University, 1966

Jane Mary Harris Cramer, *U. S. Public Health Service Fellow, Biology*
B.A., Carleton College, 1964

Jane Ellen Crawford, *Graduate Teaching Assistant,* Chemistry*
A.B., University of California (Santa Barbara), 1966

Stephen Paul Creekmore, *Rand Corporation Fellow, Graduate Teaching Assistant, Physics*
A.B., Williams College, 1963

Antonio Crespo-Martinez, *GALCIT Wind Tunnel Fellow, Aeronautics*
Ing., Escuela Tecnica Superior de Ingenieros Aeronauticos (Madrid), 1964; M.S., California Institute, 1965

Alan Coffman Cummings, *National Aeronautics and Space Administration Trainee, Physics*
B.A., Rice University, 1966

John Gillette Curro, *Graduate Research Assistant, Murray Scholar, Materials Science*
B.Ch.E., University of Detroit, 1965

James Alfred John Cutts, *Graduate Research Assistant,* Geophysics*
B.A. (Hons), St. John's College (Cambridge), 1965; M.S., California Institute, 1967

Jeffrey Nicholas Cuzzi, *National Aeronautics and Space Administration Trainee, Geology*
B.S., Cornell University, 1967

Luc Philippe Marie Cyrot, *Graduate Student, Electrical Engineering*
Ing., Ecole Nationale Superieure de l'Aeronautique, 1967

Frederick Willis Dahlquist, *National Institutes of Health Trainee, Chemistry*
B.A., Wabash College, 1964

Michael Edward Dahmus, *U. S. Public Health Service Fellow, Oberholtz Scholar, Biology*
B.S., Iowa State University, 1963

*Assistantship so marked carries tuition award.

Dikran Damlamayan, *Radio Corporation of America Fellow, Electrical Engineering*
B.S., California Institute, 1963; M.S., 1964

Michael Brian D'Amore, *National Defense Education Act Fellow, Chemistry*
B.S., Providence College, 1967

Robert Frederick Davey, *National Science Foundation Fellow, Aeronautics*
B.S., U.S. Air Force Academy, 1962; M.S., California Institute, 1964

Theodore Herbert Davey, *National Aeronautics and Space Administration Trainee, Electrical Engineering*
B.S., California Institute, 1962; M.S., 1963

Charles Newbold David, *Special Fellowship, Oberholtz Scholar, Biology*
A.B., Harvard University, 1962

John Bruce Davies, *International Business Machines Fellow, Geophysics*
B.S., University College of Swansea (Wales), 1963; M.S., California Institute, 1967

Allyn Merrill Davis, *National Science Foundation Trainee, Chemical Engineering*
B.S., Clarkson College of Technology, 1964; M.S., California Institute, 1965

Daniel Lee Davis, *National Defense Education Act Fellow, Mathematics*
B.S., Georgia Institute of Technology, 1965

Ronald Wayne Davis, *National Institutes of Health Trainee, Chemistry*
B.S., Eastern Illinois University, 1964

Daniel Joseph Dawson, *Graduate Teaching Assistant,* Chemistry*
B.S., University of North Carolina, 1967

Peter William Day, *National Science Foundation Fellow, Graduate Teaching Assistant, Mathematics*
B.S., Emory University, 1966

Phoebe Kin-Kin Wong Dea, *Graduate Teaching Assistant,* Chemistry*
B.S., University of California (Los Angeles), 1967

John Charles Dean, *Graduate Teaching Assistant,* Electrical Engineering*
B.S., University of California (Santa Barbara), 1967

Guy DeBalbine, *Drake Scholar, Engineering Science*
Dipl. Ing., Ecole Centrale des Arts et Manufactures (Paris), 1963; M.S., California Institute, 1964

Paul Maurice Debrule, *Graduate Teaching Assistant,* Engineering Science*
Ing., Physicien, Universite de Liege, 1967

Richard John Defouw, *National Science Foundation Trainee, Astronomy*
A.B., Harvard University, 1966

Michael Ernest Delaney, *Graduate Teaching Assistant, Murray Scholar, Applied Mathematics*
B.Sc., University of London, 1965; M.Phil., University of London, 1967

Raymond Kay DeLong, *Graduate Research Assistant, Dobbins Scholar, Mechanical Engineering*
B.S., Kansas State University, 1962; M.S., California Institute, 1965

Terry Joseph Delph, *Boeing Fellow, Aeronautics*
B.A.E., Georgia Institute of Technology, 1967

Andrea DeMari, *Graduate Research Assistant,* Electrical Engineering*
Ing., Politecnico di Torino, 1962; M.S., California Institute, 1964

Joseph Bernard Dence, *DuPont Teaching Assistant,* Chemistry*
B.A., Bowling Green State University, 1963

William Michael Denny, *Graduate Research Assistant,* Physics*
B.S., St. Louis University, 1964

Brogan Traolach De Paor, *Graduate Teaching Assistant, Murray Scholar, Applied Mathematics*
B.Sc., University College, Cork, 1966; M.Sc., 1967

*Assistantship so marked carries tuition award.

Leland Allen DePriest, *National Institutes of Health Trainee, Engineering Science*
B.S., California Institute, 1965

Satish Vithal Desai, *Graduate Teaching Assistant,* Chemical Engineering*
B.Tech., Indian Institute of Technology, 1964; M.S., California Institute, 1965

William Robert Devereaux, *National Science Foundation Fellow, Chemistry*
S.B., Massachusetts Institute of Technology, 1964

Samuel Digirolamo, *Graduate Laboratory Assistant, Rutherford Scholar, Aeronautics*
B.S., St. Louis University, 1967

John Cedric Dill, *National Institutes of Health Trainee, Engineering Science*
B.A.Sc., University of British Columbia, 1962; M.S., North Carolina State College of Agriculture and Engineering, 1964

Raymond Benedict Dirling, Jr., *Graduate Student, Aeronautics*
B.S., Virginia Polytechnic Institute, 1964; M.S., 1965

John David Ditmars, *United States Public Health Service Trainee, Civil Engineering*
B.S.E., Princeton University, 1965; M.S., California Institute, 1966

Charles Joseph Dixon, *National Aeronautics and Space Administration Trainee, Electrical Engineering*
B.S., University of Washington, 1967

Peter Gerard Dodds, *Graduate Teaching Assistant,* Mathematics*
B.Sc. (Hons), University of New England (Australia), 1964

Billy Ray Dodson, *National Institutes of Health Trainee, Engineering Science*
B.S., New Mexico State University, 1958; M.S., 1960

Robert Joseph D'Orazio, *Graduate Student, Electrical Engineering*
B.S., Drexel Institute of Technology, 1967

James Germain Downward, IV, *National Defense Education Act Fellow, Graduate Teaching Assistant, Physics*
S.B., Massachusetts Institute of Technology, 1965

William Jack Driskell, *National Defense Education Act Fellow, Biology*
B.S., University of Georgia, 1967

James Johnson Duderstadt, *Baker Fellow, Engineering Science*
B.E., Yale University, 1964; M.S., California Institute, 1965

William Kyle Dugan, *National Science Foundation Trainee, Graduate Teaching Assistant, Mathematics*
B.S., St. John's University, 1967

Robert George Dunlap, *Graduate Student, Aeronautics*
S.B., Massachusetts Institute of Technology, 1967

Thomas Harold Dunning, Jr., *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
B.S., University of Missouri, 1965

Joseph Daniel Dupcak, *Ford Foundation Fellow, Aeronautics*
B.S.E., Princeton University, 1967

Paul Marie Dupont, *Graduate Laboratory Assistant,* Aeronautics*
Eng., Universite de Louvain, 1967

Mirmira Ramarao Dwarakanath, *Graduate Research Assistant,* Physics*
B.Sc. (Hons), The Central College (Bangalore), 1958; M.Sc., 1961

Don Lindsay Dwiggins, *Graduate Research Assistant, Engineering Science*
B.A., University of California (Santa Barbara), 1962

John Joseph Dykla, *National Science Foundation Fellow, Physics*
B.S., Loyola University, 1966

Richard Timothy Eakin, *United States Public Health Service Fellow, Biology*
B.S., University of Texas, 1963

*Assistantship so marked carries tuition award.

Benjamin Nathaniel Early, *National Science Foundation Fellow, Electrical Engineering*
B.S., Howard University, 1966; M.S., California Institute, 1967

Moises Eisenberg-Grunberg, *Rockefeller Foundation Grant, Biology*
Faculty of Sciences of University of Chile, 1967

Sarah Roberts Elgin, *National Science Foundation Fellow, Biology*
B.A., Pomona College, 1967

Robert Lawrence Elgin, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*
B.A., Pomona College, 1966

James Bernard Ellern, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
B.S., University of Illinois, 1962

Stephen Dean Ellis, *National Science Foundation Fellow, Physics*
B.S.E., University of Michigan, 1965

James Auby Ellison, *National Defense Education Act Fellow, Applied Mathematics*
B.S., University of Wisconsin, 1964; M.S., 1965

Michael Sadek El Raheb, *Graduate Teaching Assistant,* Aeronautics*
B.Sc., Cairo University, 1964; M.S., California Institute, 1966

Christopher England, *National Science Foundation Trainee, Chemical Engineering*
B.S., University of Southern California, 1965; M.S., California Institute, 1967

Philip John Erdelsky, *National Science Foundation Fellow, Graduate Teaching Assistant, Mathematics*
B.S., Case Institute of Technology, 1966

David Albert Evans, *Coates Scholar, Chemistry*
A.B., Oberlin College, 1963

Edward Norton Evans, *Graduate Teaching Assistant,* Electrical Engineering*
B.S., University of California (Berkeley), 1967

Lawrence Curtis Evans, *National Science Foundation Fellow, Physics*
A.B., Pomona College, 1966

William Warren Everett, *National Defense Education Act Fellow, Applied Mathematics*
E.Math., Colorado School of Mines, 1965

Helio Vasconcelos Fagundes, *Brazil Ministry of Education Fellow, Physics*
B.A., Universidade de Sao Paulo, 1963

Steven Mark Farber, *National Aeronautics and Space Administration Trainee, Electrical Engineering*
B.S., California Institute, 1964; M.S., Stanford University, 1965

Fernando Lawrence Fernandez, *Aerospace Fellow, Aeronautics*
M.E., Stevens Institute of Technology, 1960; M.S., 1961

Rena Fersht, *Graduate Teaching Assistant,* Aeronautics*
B.Sc., Israel Institute of Technology (Haifa), 1962; M.Sc., 1964

Paul Lee Fehder, *Graduate Research Assistant,* Chemistry*
S.B., Massachusetts Institute of Technology, 1964

Donald George Fesko, *National Science Foundation Fellow, Chemical Engineering*
B.S.Ch.E., Clarkson College, 1966

John Lionel Firkins, *Graduate Teaching Assistant,* Chemistry*
B.Sc. (Hons), University of Victoria, 1965

Richard Alan Firtel, *National Science Foundation Fellow, Biology*
A.B., Dartmouth College, 1966

James Edward Fisher, *Graduate Teaching Assistant,* Geology*
B.S., Villanova University, 1966

*Assistantship so marked carries tuition award.

James Louis Fisher, *Graduate Research Assistant,* Mathematics*
B.Sc. (Hons), University of Alberta, 1965

Raymond Kurt Fisher, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*
S.B., Massachusetts Institute of Technology, 1965

Jeffrey Edward Flatgaard, *National Science Foundation Trainee, Biology*
A.B., Johns Hopkins University, 1962

Jacques Pierre Fleuret, *Graduate Student, Electrical Engineering*
Ing., Ecole Nationale Superieure des Telecommunications, 1967

Michael T. Flood, *Graduate Research Assistant,* Chemistry*
B.S., Holy Cross, 1964; M.A., Columbia University, 1965

Paul John Flory, Jr., *National Science Foundation Trainee, Biology*
A.B., Harvard University, 1967

Michael Glen Foley, *Hertz Foundation Fellow, Aeronautics*
B.S., California Institute, 1967

Blair Allen Folsom, *Graduate Teaching Assistant,* Mechanical Engineering*
B.S., California State College (Long Beach), 1967

Douglas Gun Fong, *Graduate Research Assistant, Dobbins Scholar, Physics*
A.B., Princeton University, 1961

Kirby William Fong, *National Science Foundation Fellow, Applied Mathematics*
B.S., University of California (Berkeley), 1967

Richard W. Forester, *Graduate Teaching Assistant,* Geology*
B.Sc. (Hons), McGill University, 1965; M.Sc., 1967

Harold Edwin Foster, *National Science Foundation Trainee, Electrical Engineering*
S.B., Massachusetts Institute of Technology, 1956; S.M., 1956

Kenneth William Foster, *Graduate Teaching Assistant, Oberholtz Scholar, Biology*
B.Sc. (Hons), University of Victoria, 1965

Michael Ralph Foster, *National Aeronautics and Space Administration Trainee, Aeronautics*
S.B., Massachusetts Institute of Technology, 1965; S.M., 1966

Jonathan Akin French, *Graduate Research Assistant,* Civil Engineering*
A.B., Harvard College, 1961; M.S., California Institute, 1964

Jay Albert Frogel, *National Defense Education Act Fellow, Astronomy*
A.B., Harvard University, 1966

Gary Stephen Fuis, *National Science Foundation Fellow, Geology*
B.A., Cornell University, 1966

Dennis Masato Furuike, *Hertz Foundation Fellow, Applied Mechanics*
B.A., Occidental College, 1965; B.S., California Institute, 1967

Edward Stowell Gaffney, *National Science Foundation Fellow, Geology*
B.S., Yale University, 1964; M.A., Dartmouth College, 1966

David Charles Gakenheimer, *National Aeronautics and Space Administration Trainee, Applied Mechanics*
B.E.S., Johns Hopkins University, 1965; M.S., California Institute, 1966

Vassilios Elias Galanoudes, *National Institutes of Health Trainee, Engineering Science*
B.S.E.E., California State College (Los Angeles), 1964; M.S., California Institute, 1967

John Daniel Gallivan, *Graduate Research Assistant,* Physics*
B.Sc., University College (Dublin), 1961; M.Sc., 1962

Detlef Hain Garbrecht, *German National Scholar, Civil Engineering*
Diplom-Ingenieur, Technische Hochschule Karlsruhe, 1967

Thomas Lee Garrard, *National Aeronautics and Space Administration Trainee, Physics*
B.A., Rice University, 1966

*Assistantship so marked carries tuition award.

Philip Wayne Garrison, *National Science Foundation Trainee, Aeronautics*
B.S.Ae.E., Auburn University, 1965

John Edward Geltosky, *National Defense Education Act Fellow, Biology*
B.S., Memphis State University, 1967

Michael James George, *Graduate Research Assistant,* Physics*
B.S., University of North Carolina, 1963

Robert Allen Gillham, Jr., *National Science Foundation Fellow, Chemistry*
B.S., San Jose State College, 1965

Robert Ridgeway Gilpin, *Graduate Research Assistant, Murray Scholar, Engineering Science*
B.Sc., University of Alberta, 1964; M.S., California Institute, 1965

Mark Goldstein, *Graduate Teaching Assistant,* Physics*
B.S., Harvey Mudd College, 1965

Stuart Frederick Goldstein, *U. S. Public Health Service Fellow, Oberholtz Scholar, Biology*
B.A., University of Minnesota, 1962

Richard Ira Gomberg, *National Science Foundation Trainee, Engineering Science*
B.S., University of Puerto Rico, 1967

Ernest William Goodell, *Graduate Teaching Assistant, Drake Scholar, Biology*
B.S., Colorado State University, 1964

Seymour Evan Goodman, *National Science Foundation Trainee, Applied Mathematics*
B.S., Columbia University, 1965; M.S., 1966

David Marshall Gordon, *Graduate Research Assistant,* Physics*
B.S., Ohio State University, 1963; M.S., 1965

Harold William Gordon, *U. S. Public Health Service Fellow, Oberholtz Scholar, Biology*
B.S., Case Institute of Technology, 1967

Jeffrey Archibald Gorman, *Atomic Energy Commission Fellow, Engineering Science*
B.C.E., Cornell University, 1958; M.S., California Institute, 1966

Shakkottai P. Govindaraju, *GALCIT Wind Tunnel Fellow, Aeronautics*
B.E., University College of Engineering, 1962; M.E., Indian Institute of Science, 1964

Robert Lee Gran, *National Science Foundation Trainee, Graduate Teaching Assistant, Mechanical Engineering*
B.S., University of Washington, 1965; M.S., California Institute, 1966

Paul Sheldon Grand, *United States Public Health Service Fellow, Graduate Teaching Assistant, Chemistry*
B.S., Queens College, 1963

Gary Lars Grasdalen, *National Aeronautics and Space Administration Trainee, Geology*
A.B., Harvard College, 1967

Richard Rutherford Green, *National Science Foundation Trainee, Electrical Engineering*
B.S., California Institute, 1964; M.S., 1965

Curtis Greene, *National Science Foundation Fellow, Graduate Teaching Assistant, Mathematics*
A.B., Harvard College, 1966

Norton Robert Greenfeld, *National Science Foundation Trainee, Engineering Science*
B.S., California Institute, 1967

Eric Winslow Greisen, *National Science Foundation Fellow, Astronomy*
B.A., Cornell University, 1966

David Henry Griffel, *Graduate Teaching Assistant, Dobbins Scholar, Physics*
B.Sc. (Honors), Birmingham University (England), 1961

*Assistantship so marked carries tuition award.

Jack Denney Griffith, *Graduate Teaching Assistant, Drake Scholar, Biology*
B.A., Occidental College, 1964

Richard William Griffith, *Graduate Teaching Assistant,* Physics*
B.S., California Institute, 1963

Edward Grinthal, *National Science Foundation Trainee, Electrical Engineering*
B.E.E., New York University, 1962; M.S.E., University of Pennsylvania, 1964

William Paul Gruber, *Graduate Teaching Assistant, Murray Scholar, Mechanical Engineering*
B.S., University of Washington, 1962; M.S., California Institute, 1963

Frank John Grunthaner, *National Defense Education Act Fellow, Chemistry*
B.S., King's College, 1966

Steven Lawrence Guberman, *Woodrow Wilson Foundation Fellow, Chemistry*
B.A., State University of New York, 1967

Vincent Peter Gutschick, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
B.S., University of Notre Dame, 1966

Diane F. Gutterman, *Graduate Research Assistant,* Chemistry*
B.A., Cornell University, 1963; M.A., Columbia University, 1964

Roger Allison Haas, *Ford Foundation Fellow, Guggenheim Foundation Fellow, Engineering Science*
B.E.S., University of Florida, 1964; M.S., California Institute, 1965

Thomas Arthur Halgren, *Blacker Scholar, Graduate Research Assistant, Chemistry*
A.B., Wabash College, 1963

David Barnett Hall, *National Science Foundation Trainee, Physics*
S.B., Massachusetts Institute of Technology, 1965

John Henry Hall, *National Science Foundation Trainee, Graduate Research Assistant,* Geochemistry*
B.A., Reed College, 1967

Joseph Hutchinson Ham IV, *National Science Foundation Fellow, Chemistry*
B.S., University of North Carolina, 1967

Edwin John Hamilton, *Graduate Research Assistant,* Chemistry*
B.A., New York University, 1963

Thomas Colgrove Hanks, *Graduate Research Assistant,* Geology*
B.S.E., Princeton University, 1966

David Marvin Hanson, *National Science Foundation Trainee, Chemistry*
B.A., Dartmouth College, 1964

Roy Woodrow Harding, Jr., *United States Public Health Service Fellow, Oberholtz Scholar, Biology*
B.S., George Washington University, 1962

Howard Elliot Harry, Jr., *Howard Hughes Foundation Fellow, Electrical Engineering*
B.S., California Institute, 1964; M.S., 1965

Ryusuke Hasegawa, *Graduate Research Assistant,* Materials Science*
B.E., Nagoya University (Japan), 1962; M.E., 1964

Loren Endicott Hatlen, *United States Public Health Service Fellow, Oberholtz Scholar, Biology*
B.A., University of California (Santa Barbara), 1962

Philip Jeffrey Hay, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
B.S., Franklin and Marshall College, 1967

Kenneth Leon Heitner, *National Science Foundation Fellow, Applied Mechanics*
B.S., Webb Institute of Naval Architecture, 1964

*Assistantship so marked carries tuition award.

Jimmy Lee Held, *Atomic Energy Commission Fellow, Applied Mechanics*
B.S., California Institute, 1967

Robert Jack Hemstead, *National Science Foundation Fellow, Mathematics*
B.S., Stanford University, 1964

John Robert Henderson, *Graduate Teaching Assistant,* Mathematics*
B.A., University of British Columbia, 1960; M.A., 1963

David Cecil Hensley, *Graduate Research Assistant,* Physics*
B.S., University of Arizona, 1960

Thomas Louis Henyey, *Graduate Teaching Assistant,* Geology*
A.B., University of California, 1962

Theodore William Hilgeman, *Graduate Research Assistant,* Physics*
S.B., Massachusetts Institute of Technology, 1964

David Paul Hill, *United States Geological Survey Employee Trainee, Geology*
B.S., San Jose State College, 1958; M.S., Colorado School of Mines, 1961

Roger Calvert Hill, *Graduate Teaching Assistant,* Physics*
B.S., California Institute, 1963

William Aro Hill, *National Defense Education Act Fellow, Graduate Teaching Assistant, Biology*
B.A., Cornell University, 1965

Robin David Alexander Hirshfeld, *North Atlantic Treaty Organization Scholar, Applied Mechanics*
B.Sc. (Hons), University of Newcastle-Upon-Tyne, 1967

John Anthony Hoef, Jr., *Graduate Teaching Assistant,* Aeronautics*
B.S., St. Louis University, 1967

John Brent Hoerner, *National Science Foundation Trainee, Civil Engineering*
B.S., California Institute, 1967

Donald Richard Hoffman, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
A.B., Harvard College, 1965

Hwei-Kwan Hong, *Graduate Research Assistant,* Chemistry*
B.S., National Taiwan University, 1963; M.S., National Tsing Hua University, 1965

Leroy Edward Hood, *Oberholtz Scholar, Biology*
B.S., California Institute, 1960; M.D., Johns Hopkins University, 1964

Bruce Lynn Hopper, *National Science Foundation Trainee, Mechanical Engineering*
B.S., Texas A & M University, 1967

Cornelius Oliver Horgan, *Graduate Teaching Assistant,* Applied Mechanics*
B.Sc., University College, 1964; M.Sc., 1965

Duane Thomas Hove, *Ford Foundation Fellow, Graduate Teaching Assistant, Aeronautics*
B.S., University of Minnesota, 1967

George Chi Hsu, *Graduate Research Assistant,* Chemical Engineering*
B.S., Tunghai University, 1964; M.S., Illinois Institute of Technology, 1967

Joel Anthony Huberman, *Roeser Scholar, Biology*
A.B., Harvard College, 1963

Bruce Samuel Hudson, *National Science Foundation Fellow, Chemistry*
B.S., California Institute, 1967

Mary Speck Hudson, *National Science Foundation Fellow, Chemistry*
B.S., Michigan State University, 1967

Evan Eugene Hughes, Jr., *Dobbins Scholar, Physics*
B.S., California Institute, 1962; M.S., 1963

*Assistantship so marked carries tuition award.

Linda Wray Hughes, *National Science Foundation Fellow, Biology*
B.A., Macalester College, 1967

Thomas Frederick Humphrey, *Graduate Research Assistant,* Physics*
B.S., University of Notre Dame, 1966

William James Hunt, *National Defense Education Act Fellow, Chemistry*
B.S., University of Mississippi, 1967

Clyde Allen Hutchison III, *United States Public Health Service Fellow, Oberholtz Scholar, Biology*
B.S., Yale University, 1960

Myung Kyu Hwang, *Graduate Teaching Assistant,* Chemical Engineering*
B.S., Seoul National University, 1965

Michael Stephen Hyland, *United States Public Health Service Trainee, Civil Engineering*
B.C.E., Manhattan College, 1967

Richard Walter Hyman, *National Institutes of Health Trainee, Chemistry*
B.S., University of California, 1962; M.S., Cornell University, 1964

Harry Lester Hyndman, *Graduate Research Assistant,* Chemistry*
B.S., University of Illinois, 1962

James Reid Ipser, *National Science Foundation Trainee, Physics*
B.S., Loyola University (New Orleans), 1964

Martin Henry Israel, *Graduate Research Assistant,* Physics*
S.B., University of Chicago, 1962

Kenneth Charles Jacobs, *National Defense Education Act Fellow, Graduate Teaching Assistant, Physics*
S.B., Massachusetts Institute of Technology, 1964

Richard Norman Jacobson, *Graduate Teaching Assistant,* Chemical Engineering*
B.S., Michigan State University, 1965

John Berkeley Jamieson, *McCallum Fellow, Oberholtz Scholar, Biology*
B.A., University of California (Berkeley), 1967

Kenneth Marc Jassby, *National Research Council of Canada Fellow, Drake Scholar, Materials Science*
B.Eng., McGill University, 1965; M.Eng., 1966

Robert Francis Jeffers, *Graduate Teaching Assistant,* Applied Mechanics*
B.Sc., National University of Ireland (Cork), 1964; M.Sc., 1965; M.S., California Institute, 1966

James Gregory Jerrell, *Bell Telephone Laboratory Fellow, Electrical Engineering*
S.B., Massachusetts Institute of Technology, 1967

Algirdas Joseph Jesaitis, *National Defense Education Act Fellow, Biology*
B.S., New York University, 1967

Raymond Leonard Joesten, *Graduate Teaching Assistant,* Geology*
B.S., San Jose State College, 1966

Gordon Oliver Johnson, *National Aeronautics and Space Administration Trainee, Electrical Engineering*
B.S., Walla Walla College, 1966; M.S., California Institute, 1967

Torrence Vaino Johnson, *National Aeronautics and Space Administration Trainee, Geology*
B.S., Washington University, 1966

Lorella Margaret Jones, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*
B.A., Radcliffe College,1964; M.S., California Institute, 1966

Richard Douglas Kerr Josslin, *U. S. Public Health Service Trainee, Graduate Teaching Assistant, Biology*
S.B., Massachusetts Institute of Technology, 1965

*Assistantship so marked carries tuition award.

Bruce Rene Julian, *National Science Foundation Fellow, Geophysics*
B.S., California Institute, 1964; M.S., 1966

Pierre Henri Jungles, *Graduate Research Assistant,* Geology*
Ing., Universite de Liege, 1967

Howard Arthur Kabakow, *Graduate Teaching Assistant,* Physics*
B.S., California Institute, 1962

Luis Ricardo Kahn, *Graduate Teaching Assistant,* Chemistry*
B.S., The City College of New York, 1966

Michael Irving Kane, *Atlantic-Richfield Fellow, Dobbins Scholar, Chemical Engineering*
B.S., University of California (Los Angeles), 1966

Joseph Francis Karnicky, *National Science Foundation Fellow, Chemistry*
B.S., Villanova University, 1965

Dennis Robert Kasper, *U. S. Public Health Service Environmental Health Trainee, Civil Engineering*
B.S., Loyola University (Los Angeles), 1966; M.S., California Institute, 1967

David Brandeis Katzin, *National Defense Education Act Fellow, Chemistry*
B.S., University of Chicago, 1967

Steven Kenneth Kauffmann, *National Defense Education Act Fellow, Physics*
B.S., California Institute, 1965

Elton Neil Kaufmann, *National Science Foundation Trainee, Physics*
B.S., Rensselaer Polytechnic Institute, 1964.

Robert Nicholas Kavanagh, *National Institutes of Health Trainee, Engineering Science*
B.S., University of Saskatchewan, 1964; M.Sc., 1966

Ender Mustafa Kaya, *Graduate Laboratory Assistant,* Civil Engineering*
B.S., C. W. Post College, 1967

Douglas Allan Keeley, *National Research Council of Canada Fellow, Dobbins Scholar, Astronomy*
B.Sc. (Hons), University of Manitoba, 1964

John Joseph Kenny, *Howard Hughes Foundation Fellow, Electrical Engineering*
B.S., University of Rhode Island, 1963; M.S., California Institute, 1964

Ronald Lee Kerber, *National Aeronautics and Space Administration Trainee, Graduate Teaching Assistant, Engineering Science*
B.S., Purdue University, 1965; M.S., California Institute, 1966

Hugh Hartman Kieffer, *Graduate Teaching Assistant,* Geology*
B.S., California Institute, 1961

Susan Werner Kieffer, *National Science Foundation Trainee, Geophysics*
B.S., Allegheny College, 1964; M.S., California Institute, 1967

John Andrew Kiger, Jr., *U. S. Public Health Service Fellow, Biology*
B.S., California Institute, 1963

Jong Hyun Kim, *Graduate Teaching Assistant,* Mechanical Engineering*
B.S., Seoul National University, 1966; M.S., University of Missouri, 1967

Ronald Brian Kirk, *Graduate Teaching Assistant,* Mathematics*
B.A., University of Colorado, 1963

Randall Keenan Kirschman, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*
B.S.E.Ph., University of California, 1965

Mark Brecher Kislinger, *National Aeronautics and Space Administration Trainee, Physics*
B.A., University of California, 1965

Robert Vernon Kline, *Graduate Research Assistant,* Physics*
S.B., Massachusetts Institute of Technology, 1967

*Assistantship so marked carries tuition award.

John Michael Klineberg, *Graduate Student, Aeronautics*
B.S.E., Princeton University, 1960; M.S., California Institute, 1962

Ronald Harrison Knapp, *Graduate Teaching Assistant,* Mechanical Engineering*
B.S., University of Hawaii, 1967

LeRoy Paul Knauth, *Graduate Research Assistant,* Geology*
B.A., University of Chicago, 1966

Gary Don Knott, *Graduate Student, Engineering Science*
B.A., American University-Washington, D.C., 1964

Denny Ru-Sue Ko, *GALCIT Wind Tunnel Fellow, Aeronautics*
B.S., National Taiwan University, 1960; M.S., University of California, 1964

John Kent Koester, *National Science Foundation Trainee, Applied Mechanics*
B.S., University of Notre Dame, 1964; M.S., California Institute, 1965

Toby Martin Kolstad, *Ford Foundation Fellow, Applied Mechanics*
B.S., Tulane University, 1967

James Anthony Komarek, *Graduate Teaching Assistant,* Electrical Engineering*
B.S., Iowa State University, 1967

Ronald Jerome Konopka, *National Science Foundation Fellow, Biology*
B.S., University of Dayton, 1967

Daniel Julius Krause, *Graduate Student, Materials Science*
B.Met.E., Ohio State University, 1958; M.S., California Institute, 1959

David Louis Kreinick, *Graduate Research Assistant,* Physics*
B.A., Brandeis University, 1963; M.S., California Institute, 1965

George Paul Kreishman, *Graduate Teaching Assistant,* Chemistry*
B.S., University of Wisconsin, 1967

Paula Kreisman, *Graduate Research Assistant,* Chemistry*
B.S., Barnard College, 1965; M.S., Columbia University, 1966

Mark Howard Kryder, *Tektronix Foundation Fellow, Graduate Teaching Assistant,* Electrical Engineering*
B.S., Stanford University, 1965; M.S., California Institute, 1966

Mitsuru Kurosaka, *Drake Scholar, Mechanical Engineering*
B.S., University of Tokyo, 1959; M.S., 1961

Stephen Lane Kurtin, *Howard Hughes Foundation Fellow, Electrical Engineering*
S.B., Massachusetts Institute of Technology, 1966; S.M., 1966

Harold Charles Kurtz, *Dobbins Scholar, Mathematics*
B.S., California Institute, 1962; M.S., 1965

Robert Charles Ladner, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
B.A., Rice University, 1966

Theodore Willis Laetsch, *National Defense Education Act Fellow, Applied Mathematics*
B.S., Washington University, 1961; S.M., Massachusetts Institute of Technology, 1962

Peter Leonard Lagus, *National Aeronautics and Space Administration Trainee, Geology*
B.S., Washington University, 1965

Bruce Meno Lake, *Graduate Research Assistant, Henry Laws Scholar, Aeronautics*
B.S.E., Princeton University, 1963; M.S., California Institute, 1964

Ernest Yee Yeung Lam, *Norman Bridge Scholar, Chemistry*
B.Sc., University of Hong Kong, 1959; B.Sc.Sp. (Hons), 1960

Arthur Lonne Lane, *Graduate Research Assistant,* Chemistry*
A.B., Harvard College, 1961; M.S., University of Illinois, 1963

Richard Neil Lane, *National Defense Education Act Fellow, Mathematics*
B.S., California Institute, 1965

*Assistantship so marked carries tuition award.

William Finlay Langford, *National Research Council of Canada Fellow, Murray Scholar, Applied Mathematics*
B.Sc., Queen's University, 1966

Alvin Henry Larsen, *Graduate Teaching Assistant,* Chemical Engineering*
B.S., (Chem. Eng.) (Hons), University of Utah, 1965; B.A., (Physics), 1965

Harold Theodore Larson, *Graduate Research Assistant,* Physics*
B.A., Los Angeles State College, 1963; M.S., California Institute, 1965

Richard Bondo Larson, *Graduate Research Assistant, Clinedinst Scholar, Astronomy*
B.Sc., University of Toronto, 1962; M.A., 1963

Raymond Walter Latham, *Blacker Scholar, Electrical Engineering*
B.Eng., McGill University, 1958; M.S., California Institute, 1959

Diane Lynne Mitchell Lau, *National Defense Education Act Fellow, Chemistry*
B.A., University of Chicago, 1957

Joseph Po-keung Lau, *Graduate Research Assistant,* Engineering Science*
B.Sc., Purdue University, 1962; M.S., California Institute, 1963

Jean-Pierre Laussade, *Graduate Research Assistant,* Electrical Engineering*
Ing., Ecole Superieure d'Electricite (Paris), 1964; M.S., California Institute, 1965

Stephen Stuart Lavenberg, *National Science Foundation Trainee, Electrical Engineering*
B.E.E., Rensselaer Polytechnic Institute, 1963; M.S., California Institute, 1964

James Robert Lawrence, *Graduate Teaching Assistant,* Geochemistry*
B.S., Union College, 1964; M.S., California Institute, 1966

Chong Sung Lee, *Graduate Research Assistant,* Chemistry*
B.S., Seoul National University, 1964

Don Howard Lee, *National Science Foundation Trainee, Electrical Engineering*
B.S., California Institute, 1963; M.S., 1964

Jiin Jen Lee, *Graduate Research Assistant,* Civil Engineering*
B.S., National Taiwan University, 1962; M.S., Utah State University, 1966

Jo Woong Lee, *Graduate Research Assistant,* Chemistry*
B.S., Seoul National University, 1964; M.S., 1965

Paul Lung Sang Lee, *Graduate Research Assistant,* Physics*
B.S., California Institute, 1967

Jack Edward Leonard, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
A.B., Harvard College, 1967; B.D., Southern Methodist University

Jacques Jean Lerau, *Graduate Student, Civil Engineering*
Dipl., Institut National Des Sciences Appliquees (Toulouse), 1967

Menachem Levanoni, *Graduate Research Assistant, Graduate Teaching Assistant, Dobbins Scholar, Physics*
B.Sc., Hebrew University (Jerusalem), 1964

Robert Allen Levenson, *Graduate Research Assistant,* Chemistry*
B.A., Clark University, 1964; M.A., Columbia University, 1966

Lucien Benjamin Levy, *Graduate Teaching Assistant,* Mathematics*
B.A., University of California (Los Angeles), 1966

Victor Kee-Chung Liang, *Graduate Teaching Assistant,* Physics*
B.Sc., Massachusetts Institute of Technology, 1964; A.M., Harvard University, 1965

Hong Sup Lim, *Graduate Teaching Assistant,* Chemistry*
B.S., Seoul National University, 1965; M.S., 1967

Leroy Chi-tsun Lin, *Graduate Research Assistant,* Chemistry*
B.S., Tunghai University (China), 1960; M.S., Texas Christian University, 1963

Stephen Chung-Hsiung Lin, *Graduate Research Assistant,* Materials Science*
B.S., National Taiwan University, 1963; M.S., California Institute, 1965

*Assistantship so marked carries tuition award.

Wen Kuan Lin, *Graduate Research Assistant,* Physics*
B.S., National Taiwan University, 1962

John Priidik Lindal, *Graduate Teaching Assistant,* Mathematics*
B.Sc., University of British Columbia, 1966

Robert Gary Lindgren, *Hertz Foundation Fellow, Chemical Engineering*
B.S., University of Minnesota, 1965

Michael Jay Lineberry, *Atomic Energy Commission Fellow, Graduate Teaching Assistant, Mechanical Engineering*
B.S., University of California (Los Angeles), 1967

Richard Gwin Lipes, *National Science Foundation Fellow, Physics*
S.B., Massachusetts Institute of Technology, 1964

Edward David Lipson, *National Science Foundation Fellow, Physics*
B.Sc., University of Manitoba, 1966

David Harris Live, *Graduate Teaching Assistant,* Chemistry*
B.A., University of Pennsylvania, 1967

James Barrie Logan, *United States Public Health Service Fellow, Biology*
B.S., University of Texas, 1962

Ruth B. Riley Logan, *National Defense Education Act Fellow, Biology*
B.S., Michigan State University, 1966

Stewart Christian Loken, *Graduate Research Assistant,* Physics*
B.Sc., McMaster University, 1966

Glen Warren Loughner, *National Science Foundation Fellow, Graduate Research Assistant, Chemistry*
B.S., Georgetown University, 1966

Richard Elmer Lowe, *Graduate Student, Civil Engineering*
B.E., University of Southern California, 1961

Cary Lu, *United States Public Health Service Fellow, Biology*
A.B.., University of California (Berkeley), 1966

Kau-un Lu, *Graduate Teaching Assistant,* Mathematics*
B.S., National Taiwan University, 1961

Tyzz-Dwo Lu, *Graduate Research Assistant,* Civil Engnieering*
B.S., National Taiwan University, 1964; M.S., Duke University, 1967

Kenneth Raymond Ludwig, *Graduate Teaching Assistant,* Geochemistry*
B.S., California Institute, 1965; M.S., 1967

Glenn Richard Luecke, *National Science Foundation Fellow, Graduate Teaching Assistant, Mathematics*
B.S., Michigan State University, 1966

John Edward Lupton, *National Defense Education Act Fellow, Physics*
A.B., Princeton University, 1966

Gary Luxton, *Schlumberger Foundation Fellow, Physics*
B.Sc., McGill University, 1964; M.S., California Institute, 1966

William Carl Lyford, *National Science Foundation Trainee, Mathematics*
B.S., Clarkson College, 1966

Lahmer Lynds, *Graduate Research Assistant,* Chemistry*
B.A., University of California (Berkeley), 1954

Alexander Newell Lyon, *United States Public Health Service Fellow, Oberholtz Scholar, Biology*
B.S., California Institute, 1962

Peter Bruce Lyons, *Graduate Research Assistant,* Physics*
B.S., University of Arizona, 1964

*Assistantship so marked carries tuition award.

Thomas William MacDowell, *Graduate Teaching Assistant, Murray Scholar, Applied Mathematics*
B.S., California Institute, 1964

Donald David Macmurchie, *Graduate Teaching Assistant,* Chemistry*
B.Sc., University of Victoria, 1967

Michael James Mahon, *National Science Foundation Trainee, Engineering Science*
B.S., Saint Louis University, 1963; M.S., California Institute, 1965

Philippe Louis Maitrepierre, *Graduate Research Assistant,* Materials Science*
Ing., Ecole Nationale Superieure des Mines (Paris), 1965; M.S., California Institute, 1966

Michael Majteles, *Graduate Teaching Assistant,* Engineering Science*
B.S., University of California (Berkeley), 1967

Saurindranath Majumdar, *Graduate Teaching Assistant, Henry Laws Scholar, Aeronautics*
B.E., University of Calcutta, 1963; M.Eng., McGill University, 1965

Hay Boon Mak, *General Atomic Fellow, Physics*
B.Sc., St. Joseph's College, 1966

Michael Leigh Mallary, *National Defense Education Act Fellow, Physics*
B.S., Massachusetts Institute of Technology, 1966

Melvin David Mandell, *National Defense Education Act Fellow, Chemistry*
S.B., University of Chicago, 1966

Jerry Mar, *National Research Council of Canada Fellow, Graduate Teaching Assistant, Dobbins Scholar, Physics*
B.Sc., University of British Columbia, 1964

Panagiotis Zissis Marmarelis, *Graduate Research Assistant,* Engineering Science*
B.S.E.E., Lehigh University, 1966; M.S., California Institute, 1967

Ernesto R. Martin, *Graduate Teaching Assistant,* Mechanical Engineering*
B.S., University of Florida, 1967

Wallace William Martin, *Graduate Teaching Assistant,* Mechanical Engineering*
B.A.Sc., University of Toronto, 1967

Mario Martinez-Garcia, *Graduate Research Assistant,* Physics*
Lic. Ciencias Fisicas, Instituto Tecnologico y de Estudios Superiores de Monterrey, 1965

Dennis Ludwig Matson, *National Aeronautics and Space Administration Trainee, Geophysics*
A.B., San Diego State College, 1964

Donald Eugene Maurer, *National Science Foundation Fellow, Mathematics*
B.A., University of Colorado, 1964

Joyce Lee Bennett Maxwell, *United States Public Health Service Fellow, Oberholtz Scholar, Biology*
A.B., University of California (Los Angeles), 1963

Daryl Norman May, *Henry Laws Scholar, Graduate Research Assistant, Aeronautics*
B.Sc., Southampton University, 1965; D.C.Ae., College of Aeronautics, Cranfield, Beds, England, 1967

Arthur Eugene Mays, *Graduate Teaching Assistant,* Chemistry*
B.S., Rensselaer Polytechnic Institute, 1967

Warren Louis McBride, *John Stauffer Fellow, Chemical Engineering*
B.S., Purdue University, 1967

William Keith McClary, *Cole Scholar, Graduate Teaching Assistant, Physics*
B.Sc., University of Alberta, 1966

David John McConnell, *McCallum Fellow, Oberholtz Scholar, Biology*
B.A. (Hons), Trinity College (Dublin), 1966

*Assistantship so marked carries tuition award.

Thomas Bard McCord, *Graduate Research Assistant,* Geophysics*
B.S., Pennsylvania State University, 1964; M.S., California Institute, 1966

Dennis Lloyd McCreary, *Graduate Teaching Assistant,* Chemistry*
B.S., California Institute, 1965; M.A., Columbia University, 1966

John Thomas McCrickerd, *National Science Foundation Trainee, Engineering Science*
S.B., Massachusetts Institute of Technology, 1964; M.S., California Institute, 1965

Arthur Bruce McDonald, *National Research Council of Canada Fellow, Dobbins Scholar, Graduate Teaching Assistant, Physics*
B.Sc., Dalhousie University, 1964; M.Sc., 1965

Kirk Thomas McDonald, *National Science Foundation Fellow, Physics*
B.S., University of Arizona, 1966

Robert Leonard McDonald, *Graduate Teaching Assistant,* Electrical Engineering*
B.S., Iowa State University, 1967

Robert Norman McDonnell, *Graduate Teaching Assistant,* Mathematics*
S.B., University of Chicago, 1962; S.M., 1963

James Thomas McFarland, *National Science Foundation Trainee, Chemistry*
B.A., College of Wooster, 1964

Harold Finley McFarlane, *Atomic Energy Commission Fellow, Engineering Science*
B.S., University of Texas, 1967

Thomas Richard McGetchin, *Graduate Student, Geology*
A.B., Occidental College, 1959; Sc.M., Brown University, 1961

Thomas Conley McGill, Jr., *Howard Hughes Foundation Fellow, Electrical Engineering*
B.S. (Math), Lamar State College of Technology, 1963; B.S. (Elec.Eng.), 1964; M.S., California Institute, 1965

John Robert McGinley, Jr., *Graduate Research Assistant,* Geology*
S.B., Massachusetts Institute of Technology, 1952; M.S., University of Tulsa, 1963

David Jackson McGinty, *Woodrow Wilson Foundation Fellow, Chemistry*
B.S., Duke University, 1967

Patrick Anthony McGovern, *Graduate Research Assistant,* Electrical Engineering*
B.E. (Hons), University of Queensland, 1961; B.Sc., 1962; M.S., California Institute, 1963

Michael Herbert McLaughlin, *National Aeronautics and Space Administration Trainee, Graduate Teaching Assistant, Mechanical Engineering*
B.M.E., Cornell University, 1965

William Atwood McNeely, Jr., *National Science Foundation Trainee, Physics*
A.B., San Diego State College, 1965

Alan Noel Meier, *National Science Foundation Trainee, Aeronautics*
B.S., Northrop Institute of Technology, 1966

Paul Stuart Meltzer, *National Science Foundation Fellow, Biology*
A.B., Dartmouth College, 1967

Robert Thomas Menzies, *National Science Foundation Fellow, Physics*
S.B., Massachusetts Institute of Technology, 1965; M.S., California Institute, 1967

William James Metcalf, *National Defense Education Act Fellow, Physics*
B.S., University of California (Los Angeles), 1967

James Wilfred Meyer, *Graduate Teaching Assistant,* Chemistry*
B.S., University of Wisconsin, 1966

Georges Joseph Michaud, *Graduate Student, Astronomy*
B.A., Universite Lavel (Quebec), 1961; B.Ph., 1961; B.Sc., 1965

Dale Loy Miller, *Graduate Teaching Assistant,* Engineering Science*
B.S., Arlington State College, 1965

John Wayne Miller, *National Defense Education Act Fellow, Chemical Engineering*
B.S., Worcester Polytechnic Institute, 1967

*Assistantship so marked carries tuition award.

Ralph Edward Miller, *Graduate Teaching Assistant,* Chemistry*
B.S., Washington State University, 1964

Robert Sanford Mitcham, *Atomic Energy Commission Fellow, Mechanical Engineering*
B.S., United States Air Force Academy, 1967

Tse-Chin Mo, *Graduate Research Assistant,* Electrical Engineering*
B.S., National Taiwan University, 1964; M.S., California Institute, 1966

Charles Porter Moeller, *National Defense Education Act Fellow, Physics*
B.S., The University of Wisconsin (Milwaukee), 1966

David Michael Mog, *United States Public Health Service Fellow, Chemistry*
B.S., Case Institute of Technology, 1964

Douglas Crane Mohr, *National Institutes of Health Trainee, Chemistry*
B.S., San Diego State College, 1965

Lawrence Henry Mohr, *Graduate Teaching Assistant,* Chemistry*
B.S., University of California (Berkeley), 1967

John Irving Molinder, *Ford Foundation Fellow, Electrical Engineering*
B.S., University of Nebraska, 1963; M.S., Air Force Institute of Technology, 1964

Robert Alan Moline, *National Science Foundation Fellow, Physics*
B.S., California Institute, 1964

Kjeld Rahbaek Moller, *National Aeronautics and Space Administration International Fellow, Physics*
M.S., University of Copenhagen, 1964

Charles Thomas Molloy, *National Defense Education Act Fellow, Applied Mathematics*
B.S., California Institute, 1967

Charles Lloyd Moore, *Graduate Student, Mechanical Engineering*
B.S., United States Military Academy, 1966

John Daryl Moore, *Graduate Teaching Assistant,* Mechanical Engineering*
B.S., University of California (Berkeley), 1967

Wayne Meredith Moore, *National Institutes of Health Trainee, Engineering Science*
B.S., University of California (Los Angeles), 1967

Ronald Carl Moran, *Henry Laws Scholar, Graduate Teaching Assistant, Aeronautics*
B.S., University of Notre Dame, 1967

Francois Marie Michel Morel, *Graduate Student, Engineering Science*
Dipl., Institut Polytechnique de Grenoble, 1967

Jean-Pierre Georges Morel, *Henry Laws Scholar, Graduate Teaching Assistant, Aeronautics*
Ing., Ecole Centrale des Arts et Manufactures, 1965; Dr. Ing., Universite de Paris, 1967

Malcolm Cameron Morrison, *National Science Foundation Trainee, Chemical Engineering*
B.S., California Institute, 1964

Paul Frederick Morrison, *Graduate Research Assistant,* Chemistry*
B.S., University of Michigan, 1965

Michael Philip Mortell, *Graduate Student, Applied Mathematics*
B.S., University College (Cork), 1961; M.S., 1963; M.S., California Institute, 1964

Calvin Elroy Moss, *Dobbins Scholar, Graduate Research Assistant, Physics*
B.S., University of Virginia, 1961; M.S., California Institute, 1963

Adolph Vincent Mrstik, Jr., *Ford Foundation Fellow, Electrical Engineering*
B.S., University of Illinois, 1964; M.S., 1965

David Charles Muchmore, *Graduate Teaching Assistant,* Chemistry*
A.B., Dartmouth College, 1966

*Assistantship so marked carries tuition award.

Hans-Karl Christian Alfred Mueller, *Rutherford Scholar, Graduate Research Assistant, Aeronautics*
Dipl., Technische Hochschule Aachen, 1963; M.S., California Institute, 1964

Stanley Tetsu Murayama, *National Science Foundation Trainee, Chemistry*
B.S., University of California (Los Angeles), 1963

William Ignatius Murphy, *National Science Foundation Fellow, Biology*
B.S., Fordham University, 1967

Jay Dennis Murray, *National Science Foundation Fellow, Geology*
B.A., Hamilton College, 1966

Stephen S. Murray, *National Defense Education Act Fellow, Physics*
B.S., Columbia University, 1965

Stephen Auguste Muscanto, *Howard Hughes Foundation Fellow, Engineering Science*
B.S., Yale University, 1965; M.S., California Institute, 1967

John Richard Myers, *National Defense Education Fellow, Applied Mathematics*
B.S., Michigan State University, 1967

Thomas Andrew Nagylaki, *National Research Council of Canada Fellow, Graduate Teaching Assistant, Dobbins Scholar, Physics*
B.Sc. (Hons), McGill University, 1964

Robert David Nebes, *National Aeronautics and Space Administration Trainee, Biology*
B.S., Tufts University, 1965

James Henry Nelson, *National Institutes of Health Fellow, Graduate Teaching Assistant, Chemistry*
B.S., Brigham Young University, 1964

Michael Harvey Nesson, *Graduate Teaching Assistant, Drake Scholar, Biology*
S.B., Massachusetts Institute of Technology, 1960

Patrick Henly Nettles, Jr., *National Defense Education Act Fellow, Graduate Teaching Assistant, Physics*
B.S., Georgia Institute of Technology, 1964

John Edward Newbold, *McCallum Fellow, Oberholtz Scholar, Biology*
B.Sc., Birmingham University (England), 1962

Lawrence Ronald Newkirk, *Graduate Research Assistant,* Materials Science*
B.S., California Institute, 1966; M.S., 1967

Wei-Tou Ni, *Graduate Teaching Assistant,* Physics*
B.S., National Taiwan University, 1966

Howard White Nicholson, Jr., *National Defense Education Fellow, Graduate Teaching Assistant, Physics*
B.A., Hamilton College, 1966; S.B., Massachusetts Institute of Technology, 1966

Richard Carl Nielsen, *Hertz Foundation Fellow, Mechanical Engineering*
B.S., California Institute, 1966; M.S., 1967

Eric Arden Noe, *Graduate Teaching Assistant,* Chemistry*
B.S., University of Cincinnati, 1965

John Dennis Norgard, *National Defense Education Act Fellow, Electrical Engineering*
B.E.E., Georgia Institute of Technology, 1966; M.S., California Institute, 1967

Thomas James Noyes, *National Science Foundation Trainee, Graduate Teaching Assistant, Mathematics*
B.A., Oakland University, 1967

Edward Francis O'Brien, *Graduate Teaching Assistant,* Chemistry*
B.Sc., St. Dunstan's University, 1967

Richard John O'Connell, *National Science Foundation Fellow, Geology*
B.S., California Institute, 1963; M.S., 1966

*Assistantship so marked carries tuition award.

Robert West O'Connell, *National Science Foundation Fellow, Astronomy*
A.B., University of California, 1964

Hiroshi Ohtakay, *Graduate Research Assistant,* Electrical Engineering*
B.S., Tokyo Institute of Technology, 1961

Valdar Oinas, *National Defense Education Act Fellow, Astronomy*
A.B , Indiana University, 1965

Martin Yasuyuki Oiye, *National Science Foundation Trainee, Astronomy*
B.S., California Institute, 1967

Patricia Marie O'Keefe, *National Defense Education Fellow, Chemistry*
B.S., University of Delaware, 1965

Josephat Kanayo Okoye, *Graduate Research Assistant,* Civil Engineering*
B.S., Purdue University, 1965; M.S., California Institute, 1966

John Edwin O'Pray, *National Science Foundation Trainee, Aeronautics*
B.S., California Institute, 1967

Michael Keith O'Rell, *Graduate Teaching Assistant,* Chemistry*
B.S., University of California, 1966

Charles Douglas Orth, *Graduate Research Assistant,* Physics*
B.S., University of Washington, 1964

Patrick Stewart Osmer, *Graduate Teaching Assistant,* Astronomy*
B.S., California Institute, 1965

Alan Harold Osterheim, *Graduate Teaching Assistant,* Mechanical Engineering*
B.S., University of Hawaii, 1967

Michael John O'Sullivan, *Graduate Student, Applied Mechanics*
B.E., University of Auckland, 1962; B.Sc., 1963

David Keith Ottesen, *Graduate Teaching Assistant,* Chemistry*
B.S., New Mexico State University, 1966

Adelbert Owyoung, *Ford Foundation Fellow, Electrical Engineering*
B.S., University of California (Berkeley), 1967

Martin Lawrence Pall, *Oberholtz Scholar, Biology*
B.A., Johns Hopkins University, 1962

Karuppagounder Panaliswamy, *Graduate Teaching Assistant, Rutherford Scholar, Aeronautics*
B.Sc., Nallamuthu Gounder Mahalingam College, 1962; M.S., California Institute, 1967

Dimitri Anastassios Papanastassiou, *Graduate Teaching Assistant, Graduate Research Assistant,* Physics*
B.S., California Institute, 1965

Jung Suh Park, *Graduate Research Assistant,* Chemistry*
B.S., Seoul National University, 1966

Gerhard Hans Parker, *Fairchild Fellow, Graduate Teaching Assistant,* Electrical Engineering*
B.S., California Institute, 1965; M.S.,1966

John Stansfield Parkinson, Jr., *National Defense Education Act Fellow, Biology*
B.A., Haverford College, 1965

Christopher Alan Parr, *Graduate Research Assistant,* Chemistry*
B.S., University of California (Berkeley), 1962

Stanley Monroe Parsons, *National Institutes of Health Trainee, Chemistry*
B.S., California Institute, 1965

S. P. Parthasarathy, *Graduate Research Assistant, Rutherford Scholar, Aeronautics*
B.Sc. (Hons), Central College (Bangalore), 1958; M.Sc. (Physics), 1959; M.Sc., Indian Institute of Science (Aeronautics), 1964

*Assistantship so marked carries tuition award.

Navin Bhailalbhai Patel, *Graduate Research Assistant,* Physics*
B.Sc., University of Bombay, 1963; M.Sc., 1965; M.S., California Institute, 1967

Edward John Patula, *National Defense Education Act Fellow, Applied Mechanics*
B.S., Carnegie Institute of Technology, 1966; M.S., California Institute, 1967

James Edward Pearson, *Hertz Foundation Fellow, National Collegiate Athletic Association Scholarship, Electrical Engineering*
B.S., California Institute, 1967

Thomas Lorne Penner, *National Research Council of Canada Fellow, Dobbins Scholar, Chemistry*
B.Sc., University of Manitoba, 1965; M.Sc., 1966

Edward Harris Perry, *Ford Foundation Fellow, Guggenheim Fellow, Mechanical Engineering*
B.S., California Institute, 1966; M.S., 1967

Philip Reid Perry, *National Defense Education Act Fellow, Geology*
B.S., Cornell University, 1967

Sven Eric Persson, *Graduate Research Assistant,* Astronomy*
B.Sc., McGill University, 1966

Rex Bredesen Peters, *Ford Foundation Fellow, Mechanical Engineering*
B.S., California Institute, 1956; M.S., 1963

Arsine Victoria Peterson, *Graduate Research Assistant,* Astronomy*
S.B., Massachusetts Institute of Technology, 1963; M.S., California Institute, 1966

Bruce Alrick Peterson, *Graduate Teaching Assistant,* Astronomy*
S.B., Massachusetts Institute of Technology, 1963; M.S., California Institute, 1966

George Arthur Petersson, *National Science Foundation Trainee, Chemistry*
B.S., The City College of New York, 1964

Wayne Wallace Pfeiffer, *National Science Foundation Fellow, Engineering Science*
B.S., Wichita State University, 1965

Jacques Andre Philippet, *National Aeronautics and Space Administration International Fellow, Engineering Science*
Cand., University of Liege, 1964; Ing., 1967

Samuel Thomas Picraux, *National Aeronautics and Space Administration Trainee, Engineering Science*
B.S., University of Missouri, 1965; M.S., California Institute, 1967

Jay Cee Pigg, Jr., *National Science Foundation Fellow, Astronomy*
B.S., Loyola University (New Orleans), 1966

Michael Aron Piliavin, *National Defense Education Act Fellow, Engineering Science*
B.S., University of California (Los Angeles), 1966

Hugo de Oliveira Piva, *Graduate Student, Aeronautics*
Ae.E., Instituto Technologico de Aeronautica (Brazil), 1958; M.S., California Institute, 1965

Jaime Podolsky, *Graduate Teaching Assistant,* Electrical Engineering*
B.S., National University of Mexico, 1966

Ronald James Pogorzelski, *National Science Foundation Trainee, Electrical Engineering*
B.S., Wayne State University, 1964; M.S., 1965

John Nicholas Power, *National Defense Education Act Fellow, Physics*
B.S., Loyola College, 1967

James R. Preer, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
B.A., Swarthmore College, 1965

Daniel Adam Prelewicz, *National Defense Education Act Fellow, Graduate Teaching Assistant, Applied Mechanics*
B.S., State University of New York (Buffalo), 1965; M.S., 1966

*Assistantship so marked carries tuition award.

James Harold Prestegard, *National Science Foundation Fellow, Chemistry*
B.Chem., University of Minnesota, 1966

Richard Henry Price, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*
B.E.Ph., Cornell University, 1965

Eldon Bruce Priestley, *Graduate Teaching Assistant,* Chemistry*
B.Sc. (Hons), University of Alberta, 1965

Edmund Andrew Prych, *United States Public Health Service Trainee, Civil Engineering*
B.S., University of Massachusetts, 1961; S.M., Massachusetts Institute of Technology, 1963

Thomas Antone Pucik, *Rutherford Scholar, Graduate Teaching Assistant, Aeronautics*
B.S., California Institute, 1965; M.S., 1966

Jason Niles Puckett, *Tektronix Fellow, Graduate Teaching Assistant,* Electrical Engineering*
B.S., California Institute, 1965; M.S., 1966

George Harber Purcell, *National Science Foundation Fellow, Astronomy*
S.B., Massachusetts Institute of Technology, 1966

Mathagondapally Aswathaienger Ramaswamy, *Roeser Scholar, Graduate Research Assistant, Aeronautics*
B.E., College of Engineering, 1956; M.E., Indian Institute of Science, 1958

David Lawrence Randall, *Ford Foundation Fellow, Graduate Teaching Assistant, Engineering*
B.S.E. (Elect. Eng.), University of Michigan, 1963; B.S.E. (Math), 1963;
M.S., California Institute, 1965

Philip Wayne Randles, *Graduate Teaching Assistant,* Applied Mechanics*
B.S., Oklahoma State University, 1962; M.S., 1963

Carl Frithjof Rasmussen, *Graduate Student, Electrical Engineering*
A.A., Los Angeles City College, 1941; B.S., California Institute, 1947

Michael Eric Rassbach, *National Science Foundation Fellow, Physics*
B.A., Rice University, 1965; M.A., 1966

Prabhat Kumar Rastogi, *Graduate Research Assistant,* Materials Science*
B.Tech., Indian Institute of Technology, 1965; M.S., State University of New York, 1967

Gary Herbert Ratekin, *National Science Foundation Trainee, Aeronautics*
A.A., Bakersfield College, 1965; University of California (Berkeley), 1967

Nancy Katherine Rathjen, *New York State Regent College Teaching Fellow, Graduate Teaching Assistant,* Chemistry*
B.S., Rochester Institute of Technology, 1966

Arakali Lakshminarayan Ravimohan, *Graduate Teaching Assistant,* Chemical Engineering*
B.Tech., Indian Institute of Technology (Bombay), 1967

Charles Forest Raymond, *National Science Foundation Fellow, Geology*
A.B., University of California (Berkeley), 1961

Donald Sherwood Remer, *Graduate Teaching Assistant,* Chemical Engineering*
B.S.E., University of Michigan, 1965; M.S., California Institute, 1966

James Thomas Renfrow, *National Science Foundation Trainee, Graduate Teaching Assistant, Mathematics*
B.S., University of Michigan, 1964

Frank Lawrence Reynard, *National Defense Education Act Fellow, Chemistry*
B.S., Wheeling, College, 1967

Carl James Rice, *National Science Foundation Fellow, Physics*
B.A., University of Utah, 1964

*Assistantship so marked carries tuition award

James Kinsey Rice, *Graduate Research Assistant,* Chemistry*
B.S., Indiana University, 1963

Paul Granston Richards, *Resident Associate, Graduate Research Assistant,* Geophysics*
B.A., Cambridge University, 1965; M.S., California Institute, 1966

Merle Eugene Riley, *Graduate Research Assistant,* Chemistry*
B.S., Marietta College, 1963

Edward Albert Rinderle, Jr., *Murray Scholar, Graduate Teaching Assistant, Applied Mathematics*
B.S., Louisiana State University, 1966

Earl James Ritchie, Jr., *National Science Foundation Trainee, Geology*
B.S., Louisiana State University, 1967

Edward Failing Ritz, Jr., *National Defense Education Act Fellow, Physics*
S.B., Massachusetts Institute of Technology, 1966

Donald Lewis Robberson, *United States Public Health Service Fellow, Oberholtz Scholar, Biology*
B.S., Oklahoma Baptist University, 1963

Phillip Howard Roberts, Jr., *Graduate Research Assistant,* Physics*
B.S., University of Kansas, 1963; M.S., California Institute, 1965

William McKinley Robinson, Jr., *National Aeronautics and Space Administration Trainee, Aeronautics*
B.S., University of Tennessee, 1963; M.S., Arizona State University, 1965

Leon S. Rochester, *Graduate Research Assistant,* Physics*
A.B., University of Chicago, 1962

Stephen Dell Rockwood, *National Science Foundation Trainee, Graduate Teaching Assistant, Physics*
B.A., Grinnell College, 1965

Walter Collins Rode, *National Science Foundation Fellow, Chemistry*
S.B., Massachusetts Institute of Technology, 1967

Valentin Rodriguez, *Fairchild Camera & Instrument Corp. Fellow, Electrical Engineering*
B.E.E., Catholic University of America, 1964; M.S., California Institute, 1965

Michael Rogalski, *T. S. Brown Scholar, Materials Science*
Met. E., Colorado School of Mines, 1966

Robert George Rohwer, *United States Public Health Service Fellow, Oberholtz Scholar, Biology*
B.S., University of Wisconsin, 1967

James Robert Rose, *Keith Spalding Scholar, Graduate Teaching Assistant, Aeronautics*
B.A.Sc., University of Toronto, 1964; M.S., California Institute, 1965

John Brandt Rose, *National Institutes of Health Trainee, Chemistry*
B.A., Western Reserve University, 1965

Richard Stephen Rose, *Graduate Teaching Assistant,* Mechanical Engineering*
B.M.E., Rensselaer Polytechnic Institute, 1967

Robert Charles Rosenberg, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
B.A., Columbia University, 1967

Leo Carl Rosenfeld, *National Science Foundation Trainee, Physics*
S.B., Massachusetts Institute of Technology, 1966

George Robert Rossman, *National Science Foundation Fellow, Chemistry*
B.S., Wisconsin State, University, 1966

John Paul Roundhill, *National Science Foundation Trainee, Mechanical Engineering*
B.S., University of Washington, 1967

*Assistantship so marked carries tuition award.

James Lester Ruhlen, *Woodrow Wilson Foundation Fellow, Chemistry*
B.A., Wesleyan University, 1967

James Edward Rumbaugh, *National Science Foundation Trainee, Astronomy*
S.B, Massachusetts Institute of Technology, 1967

Charles Carroll Runyan, *National Defense Education Act Fellow, Chemistry*
B.S., University of Colorado, 1967

Denis Robert Rydjeski, *National Defense Education Act Fellow, Biology*
B.S., Purdue University, 1966

Anil Sadgopal, *Lucy Clark Fellow, Henry Laws Scholar, Biology*
B.Sc. (Hons), University of Delhi, 1960; M.Sc., Indian Agricultural Research Institute, 1962

Yilmaz Esref Sahinkaya, *Ford Foundation Fellow, Electrical Engineering*
Dipl. (M.E.), Loughborough College of Technology (England), 1961;
M.S.E., University of Michigan, 1962

Stephen Walter Salant, *National Defense Education Act Fellow, Biology*
A.B., Columbia University, 1967

Paul Klenett Salzman, *Graduate Student, Chemical Engineering*
B.S., New York University, 1955; M.Ch.E., Rensselaer Polytechnic Institute, 1959

Charles George Sammis, *Graduate Research Assistant,* Geology*
Sc.B., Brown University, 1965

Thomas Peter Santoro, *National Science Foundation Trainee, Electrical Engineering*
B.S., University of Rhode Island, 1967

Jeffrey Lee Saperstein, *Graduate Research Assistant, Wm. E. Ross Scholar, Aeronautics*
B.S., Columbia University, 1967

Jeffrey Drexel Scargle, *Graduate Research Assistant, Clinedinst Scholar, Astronomy*
B.A., Pomona College, 1963

Brian Morris Schaefer, *Ford Foundation Fellow, Engineering Science*
B.A.Sc., University of Waterloo, 1967

Phillip Cuthbert Schaefer, *U. S. Public Health Service Fellow, Chemistry*
B.A., Dartmouth College, 1964

Charles Albert Schaeffner, *Howard Hughes Foundation Fellow, Electrical Engineering*
B.S., Drexel Institute of Technology, 1961; M.S., University of Southern California, 1963

Paul Erick Scheffler, *National Science Foundation Trainee, Physics*
S.B. (Ph & EE), Massachusetts Institute of Technology, 1967

Gary Carl Scheidt, *National Science Foundation Fellow, Biology*
B.S., Michigan State University, 1967

Roger Selig Schlueter, *Ford Foundation Fellow, Graduate Teaching Assistant, Engineering Science*
B.S.Engr.Sc., Purdue University, 1964; M.S., California Institute, 1965

Charles Frederick Schmidt, Jr., *Graduate Teaching Assistant,* Chemistry*
B.S., Rensselaer Polytechnic Institute, 1967

Robert Jay Schmulian, *Graduate Teaching Assistant,* Applied Mathematics*
B.S., California Institute, 1963

David Norman Schramm, *National Defense Education Act Fellow, Physics*
S.B., Massachusetts Institute of Technology, 1967

Bernard Frederick Schutz, Jr., *National Defense Education Act Fellow, Physics*
B.S., Clarkson College of Technology, 1967

Rena Rachel Schwartz, *National Research Council of Canada Fellow, Dobbins Scholar, Mathematics*
B.Sc., McGill University, 1965

*Assistantship so marked carries tuition award.

Melvin Herbert Scott, Jr., *National Aeronautics and Space Administration Trainee, Lambda Chi Alpha Frat. Scholar, Mechanical Engineering*
B.S., Purdue University, 1967

John William Sedat, *U. S. Public Health Service Fellow, Biology*
B.A., Pasadena College, 1963

Abraham Seiden, *National Science Foundation Fellow, Physics*
B.S., Columbia University, 1967

Robert Seliger, *Graduate Student, Applied Mathematics*
B.S., Polytechnic Institute of Brooklyn, 1963

Alexander Semeniuk, *Ford Foundation Fellow, Applied Mechanics*
B.Sc., University of Alberta, 1965; M.Sc., 1966

William Davidson Seybold, *McCallum Fellow, Biology*
B.Sc., McGill University, 1967

Allen Curtis Shallbetter, *National Defense Education Act Fellow, Electrical Engineering*
B.S., Washington State University, 1967

Pattamadai Narasimhan, *Graduate Research Assistant,* Engineering Science*
B.Sc., Imperial College of Science and Technology (London), 1964; M.S., California Institute, 1967

Thomas Edward Sharon, *National Aeronautics and Space Administration Trainee, Graduate Research Assistant, Engineering Science*
S.B., Massachusetts Institute of Technology, 1967

Louis James Sharp IV, *U. S. Public Health Service Fellow, Chemistry*
B.S., University of Notre Dame, 1966

Allen David Shearn, *United States Public Health Service Fellow, Biology*
B.A., University of Chicago, 1964

Cheng-chung Shen, *Graduate Research Assistant,* Engineering Science*
B.S., National Taiwan University, 1959; S.M., Massachusetts Institute of Technology, 1964

Richard David Sherman, *National Aeronautics and Space Administration Trainee, Physics*
S.B., Massachusetts Institute of Technology, 1965; M.S., California Institute, 1966

Shelby Allen Sherrod, *National Science Foundation Fellow, Chemistry*
B.S., University of Kentucky, 1967

Yuch-ning Shieh, *Graduate Research Assistant,* Geology*
B.Sc., National Taiwan University, 1962

Thomas Yu-tzong Shih, *Graduate Teaching Assistant, Laws Scholar, Biology*
M.B., National Taiwan University, 1965

Carl Alvin Shollenberger, *Ford Foundation Fellow, Graduate Teaching Assistant, Aeronautics*
B.S., Pennsylvania State University, 1967

Gerson Seth Shostak, *National Aeronautics and Space Administration Trainee, Astronomy*
B.A., Princeton University, 1965

Arnold Louis Shugarman, *National Defense Education Act Fellow, Chemistry*
B.Sc., Los Angeles State College, 1964

Robert Steven Siegel, *National Science Foundation Fellow, Biology*
S.B., University of Chicago, 1967

Asher Sigal, *GALCIT Wind Tunnel, Fellow, Aeronautics*
B.Sc., Israel Institute of Technology, 1960; M.Sc., Israel Institute of Technology, 1966

Richard Neil Silver, *National Science Foundation Fellow, Physics*
B.S., California Institute, 1966

*Assistantship so marked carries tuition award.

Nagendra Singh, *Graduate Teaching Assistant,* Electrical Engineering*
B.Tech., Indian Institute of Technology, 1966; M.S., California Institute, 1967

John Edward Smart, *National Science Foundation Fellow, Graduate Teaching Assistant, Biology*
B.S., Ohio State University, 1965

Stephen Chester Smelser, *Graduate Research Assistant,* Chemical Engineering*
B.S., University of Michigan, 1964; M.S., California Institute, 1965

Charles Allen Smith, *National Science Foundation Trainee, Graduate Teaching Assistant, Biology*
S.B., Massachusetts Institute of Technology, 1966

Douglas Smith, *Graduate Research Assistant,* Geology*
B.S., California Institute, 1962; A.M., Harvard University, 1963

James Dow Smith, *Ford Foundation Fellow, Graduate Teaching Assistant, Aeronautics*
B.A.E., University of Minnesota, 1967

Joseph Harold Smith, *John Stauffer Fellow, Chemical Engineering*
B.S., Michigan Technological University, 1959; M.S., University of Washington, 1961

Martin Leo Smith, *National Science Foundation Fellow, Geology*
B.S., California Institute, 1967

Peter Lloyd Smith, *Graduate Research Assistant,* Physics*
B.Sc., University of British Columbia, 1965

Richard Ross Smith, *National Science Foundation Trainee, Engineering Science*
S.B., Massachusetts Institute of Technology, 1967

Ronald Lee Smith, *Standard Oil of California Fellow, Chemical Engineering*
B.E., Vanderbilt University, 1958; M.S., Rice University, 1965

Robert Carroll Smithson, *National Aeronautics and Space Administration Trainee, Physics*
B.S., University of Washington, 1966

Hermanus Snel, *National Aeronautics and Space Administration International Fellow, Aeronautics*
Ing., Delft Technological University, 1967

Ira Robert Snyder, *McDonnell-Douglas Fellow, Aeronautics*
B.S., Cornell University, 1967

Laurence Albert Soderblom, *Graduate Research Assistant,* Geology*
B.S., New Mexico Institute of Mining and Technology, 1966

Youn Soo Sohn, *Graduate Teaching Assistant,* Chemistry*
B.S., Seoul National University (Korea), 1963; M.S., 1965

Rafael Sorkin, *National Science Foundation Fellow, Physics*
A.B., Harvard University, 1966

Hartmut A. W. Spetzler, *National Defense Education Act Fellow, Geophysics*
B.S., Trinity University, 1961; M.S., 1962; M.S., California Institute, 1966

Harold Matthew Spinka, Jr., *National Science Foundation Fellow, Physics*
B.A., Northwestern University, 1966

Richard Anthony Sramek, *National Science Foundation Trainee, Astronomy*
S.B., Massachusetts Institute of Technology, 1965

Ramachandra Srinivasan, *Graduate Teaching Assistant,* Electrical Engineering*
B.E., Madras University, 1960; M.E., Indian Institute of Science (Bangalore), 1962; M.S.E.E., Purdue University, 1965

Karl John Stahl, *Graduate Teaching Assistant, Murray Scholar, Applied Mathematics*
B.S., University of Colorado, 1966; M.S., University of California (Berkeley), 1967

Ralph Horton Staley, *National Institutes of Health Trainee, Chemistry*
A.B., Dartmouth College, 1967

*Assistantship so marked carries tuition award.

James Herbert Starnes, Jr., *Lockheed Leadership Fund Fellow, Aeronautics*
B.S., Georgia Institute of Technology, 1961; M.S., 1963

Gaetan Joseph St-Cyr, *National Institutes of Health Trainee, Electrical Engineering*
B.S., California Institute, 1962; M.S., 1963

William C. Stavro, *Blacker Scholar, Aeronautics*
B.S., University of California (Los Angeles), 1962; M.S., 1964

John Paul Steele, *Graduate Research Assistant,* Geology*
B.Sc., University of Toronto, 1967

Eric Anthony Steinhilper, *National Aeronautics and Space Administration Trainee, Aeronautics*
Sc.B., Brown University, 1965; Sc.M., 1966

Rainer Ludwig Stenzel, *Graduate Research Assistant,* Electrical Engineering*
Dipl., Technische Hochschule (Braunschweig), 1965; M.S., California Institute, 1966

Michael Anthony Stephens, *Graduate Teaching Assistant, Geology*
B.S., University of Cincinnati, 1963; M.S., 1966

Donald James Sterba, *Graduate Teaching Assistant,* Physics*
B.S., University of Wisconsin, 1966

Robert George Stevenson, *Graduate Student, Aeronautics*
B.S., U. S. Naval Academy, 1960

William Arthur Stinger, *National Science Foundation Trainee, Aeronautics*
B.S.E., Princeton University, 1967

Donald Patrick Stockard, *National Science Foundation Trainee, Geology*
B.S., Carnegie Institute of Technology, 1965; Dartmouth College, 1967

Erik Storm, *Graduate Teaching Assistant, William E. Ross Scholar, Aeronautics*
B.S., California Institute, 1967

Donald Lionel Strange, *NATO Fellow, Dobbins Scholar, Physics*
B.Sc., Carleton University, 1966

Keith Duncan Stroyan, *National Science Foundation Trainee, Mathematics*
B.S., Drexel Institute of Technology, 1967

Arthur Dewey Struble III, *Murray Scholar, Aeronautics*
B.S., United States Naval Academy, 1967

Hal Jeffry Strumpf, *National Science Foundation Trainee, Chemical Engineering*
B.S., University of Rochester, 1966

Frank Thomas Surber, *Graduate Teaching Assistant, William E. Ross Scholar, Aeronautics*
B.S., University of Nebraska, 1967

Takao Suzuki, *General Telephone & Electronics Labs Fellow, Electrical Engineering*
B.S., Waseda University (Tokyo), 1962; M.S., 1964

Brian Hyman Tabak, *Graduate Teaching Assistant,* Electrical Engineering*
B.Eng. (Hons), McGill University, 1967

Robert Wofford Tate, *Howard Hughes Foundation Fellow, Electrical Engineering*
B.E., Yale University, 1963; M.Eng., 1963

Brent Dalton Taylor, *National Science Foundation Trainee, Graduate Teaching Assistant, Civil Engineering*
B.S., University of Utah, 1966; M.S., Northwestern University, 1967

Richard Forsythe Taylor, *Graduate Research Assistant, T. S. Brown Scholar, Mathematics*
A.B., University of Kansas, 1964

Joseph Dean Taynai, *Fairchild Camera & Instrument Fellow, Graduate Teaching Assistant,* Electrical Engineering*
B.S., California Institute, 1964; M.S., 1966

*Assistantship so marked carries tuition award.

Nathan Raymond Thach, Jr., *Graduate Student, Aeronautics*
B.S., University of Tennessee, 1964; M.S., 1965

Wayne Raymond Thatcher, *Seeley W. Mudd Fellow, Drake Scholar, Geophysics*
B.Sc., McGill University, 1964; M.S., Calfornia Institute, 1967

Jack Claude Thibeault, *National Defense Education Act Fellow, Chemistry*
B.S., Lowell Technological Institute, 1967

William Alvis Thomasson, *United States Public Health Service Fellow, Drake Scholar, Biology*
B.A., University of Chicago, 1955; M.S., California State College (Long Beach), 1955

Ansel Frederick Thompson, Jr., *United States Public Health Service Trainee, Civil Engineering*
B.S., Pennsylvania State University, 1963; M.S., California Institute, 1965

Bernard Tiegerman, *National Aeronautics and Space Administration Trainee, Aeronautics*
B.S., Polytechnic Institute of Brooklyn, 1968

Dino Sabatino Tinti, *Blacker Scholar, Chemistry*
B.A., University of California (Riverside), 1962

Ralph Christopher Tisdale, *Graduate Teaching Assistant,* Electrical Engineering*
B.S., Stanford University, 1967

Donald Dean Titus, *National Science Foundation Fellow, Graduate Teaching Assistant,* Chemistry*
B.S., University of Wyoming, 1966

James Waldo Toevs, *National Defense Education Act Fellow, Graduate Teaching Assistant, Physics*
B.Sc., University of Colorado, 1964

Lois Anne Toevs, *Graduate Teaching Assistant, Laws Scholar, Biology*
B.A., University of Colorado, 1964

Zoltan Andras Tokes, *Graduate Teaching Assistant, Laws Scholar, Biology*
B.S., University of Southern California, 1964

Ivar Harald Tombach, *Graduate Teaching Assistant, Blacker Scholar, Aeronautics*
B.S., California Institute, 1963; M.A.E., Cornell University, 1964

Clark John Tomita, *Graduate Teaching Assistant,* Electrical Engineering*
B.S., Illinois Institute of Technology, 1967

Richard Martin Traci, *National Science Foundation Fellow, Graduate Teaching Assistant, Aeronautics*
B.S., Carnegie Institute of Technology, 1967

Irving Marvin Treitel, *Graduate Research Assistant,* Chemistry*
B.A., Yeshiva University, 1964; M.S., Yale University, 1966

John Burgess Trenholme, *Graduate Student, Materials Science*
B.S., California Institute, 1961; M.S., 1962

Mihailo Dimitrije Trifunac, *Graduate Research Assistant,* Civil Engineering*
Dipl., University of Belgrade, 1965; M.S., Princeton University, 1966

Natalia Vojislav Pisker Trifunac, *Graduate Research Assistant,* Chemistry*
Dipl., University of Belgrade, 1965

John Charles Trijonis, Jr., *Hertz Foundation Fellow, Aeronautics*
B.S., California Institute, 1966; M.S., 1967

Virginia Louise Trimble, *National Science Foundation Fellow, Astronomy*
B.A , University of California (Los Angeles), 1964; M.S., California Institute, 1965

Donald Gene Truhlar, *National Defense Education Act Fellow, Chemistry*
B.A., Saint Mary's College, 1965

Nien-chien Tsai, *Graduate Research Assistant,* Civil Engineering*
B.S., National Taiwan University, 1961; M.S., California Institute, 1965

*Assistantship so marked carries tuition award.

Arthur P. Leigh Turner, *Hertz Foundation Fellow, Materials Science*
B.S., California Institute, 1964

Matias Jose Turteltaub, *Drake Scholar, Materials Science*
Ing., University of Chile, 1961; M.S., California Institute, 1965

William Boyce Upholt, *United States Public Health Service Fellow, Chemistry*
B.A., Pomona College, 1965

David William Vahey, *National Defense Education Act Fellow, Electrical Engineering*
S.B., Massachusetts Institute of Technology, 1966; M.S., California Institute, 1967

Shui Pong Van, *Graduate Research Assistant,* Chemistry*
B.Sc., Chung Chi College (Hong Kong), 1965

David Edwin Van Dillen, *Boeing Fellow, Aeronautics*
B.S., Rutgers University, 1967

Larry Shelton Varnell, *Graduate Research Assistant,* Physics*
B.S., University of the South, 1961

Athanassios Demetrius Varvatsis, *Xerox-Electro-Optical Systems Fellow, Electrical Engineering*
Dipl., National Technical University (Greece), 1960; M.S., California Institute, 1965

Keith Jordis Victoria, *Rand Corp. Fellow, Graduate Teaching Assistant, Aeronautics*
B.S.E., University of Michigan, 1962; M.S., California Institute, 1964

A. Vijayaraghavan, *Francis J. Cole Fellow, Mechanical Engineering*
B.E., Madras University, 1959; M.S., Syracuse University, 1966

Quat Thuong Vu, *Agency for International Development Fellow, Electrical Engineering*
B.S., University of Kentucky, 1965; M.S., California Institute, 1967

Albert Fordyce Wagner, *National Defense Education Act Fellow, Chemistry*
B.S., Boston College, 1966

Robert Gene Wagner, *Graduate Teaching Assistant,* Applied Mechanics*
B.A., Lehigh University, 1960; M.S., 1961

Stephen Perry Walch, *National Defense Education Act Fellow, Chemistry*
B.S., University of Maine, 1967

Patrick Lorne Walden, *National Defense Education Act Fellow, Physics*
B.Sc., University of British Columbia, 1966

John Longstreet Wallace, *National Aeronautics and Space Administration Trainee, Graduate Teaching Assistant, Physics*
A.B., Temple University, 1964; M.S., California Institute, 1966

Carl Christian Wamser, *National Science Foundation Fellow, Chemistry*
Sc.B., Brown University, 1966

Samuel Ward, *National Defense Education Act Fellow, Graduate Teaching Assistant, Biology*
A.B., Princeton University, 1965

John Webb, *Dobbins Scholar, CSIRO Postgraduate Studentship from Australian Government, Chemistry*
B.Sc., University of Sydney, 1967

John Clinton Webber, *Graduate Teaching Assistant,* Astronomy*
B.S., California Institute, 1964

Pax Samuel Pin Wei, *Graduate Research Assistant, Bennett Scholar, Chemistry*
B.S., National Taiwan University, 1960; M.S., University of Illinois, 1963

Patrick Dan Weidman, *E. N. Brown Scholar, Aeronautics*
B.S., California State Polytechnic College, 1963; M.S., California Institute, 1964

Frank Julian Weigert, *National Science Foundation Fellow, Chemistry*
S.B., Massachusetts Institute of Technology, 1965

*Assistantship so marked carries tuition award.

Kurt Walter Weiler, *Graduate Research Assistant,* Physics*
B.S., University of Arizona, 1964

Martin Eric Weiner, *National Science Foundation Trainee, Graduate Research Assistant, Materials Science*
B.S., California Institute, 1964; M.S., 1965

Jon Edward Weinzierl, *National Institutes of Health Trainee, Chemistry*
B.S., University of Illinois, 1963

Donna Etta Weistrop, *National Aeronautics and Space Administration Trainee, Astronomy*
B.A., Wellesley College, 1965

John Campbell Wells, *National Defense Education Act Fellow, Graduate Teaching Assistant, Mathematics*
S.B., Massachusetts Institute of Technology, 1963; S.M., 1963

David Bruce Wenner, *Graduate Teaching Assistant,* Geochemistry*
B.S., University of Cincinnati, 1963; M.S., California Institute, 1966

Gene Ward Wester, *National Science Foundation Fellow, Electrical Engineering*
B.S., University of Kansas, 1967

James Edward Westmoreland III, *National Aeronautics and Space Administration Trainee, Physics*
B.S., Georgia Institute of Technology, 1966

Lewis Turner Wheeler, *National Science Foundation Trainee, Graduate Research Assistant, Applied Mechanics*
B.S., University of Houston, 1963; M.S., 1964

James Hall Whitcomb, *Graduate Research Assistant,* Geology*
M.S., Oregon State University, 1964; Gp.Eng., Colorado School of Mines, 1962

David Halbert White, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*
B.S., Michigan State University, 1967

Quinn Ernest Whiting, *Graduate Teaching Assistant,* Mathematics*
B.A., University of Utah, 1963

Arthur Karl Whitney, *National Science Foundation Fellow, Graduate Teaching Assistant, Engineering Science*
B.Sc., Washington University, 1964

David Clinton Wilcox, *Ford Foundation Fellow, Graduate Teaching Assistant, Aeronautics*
S.B., Massachusetts Institute of Technology, 1966

Allan Edward Williams, *United States Public Health Service Fellow, Chemistry*
B.S., University of Redlands, 1965

Richard Jay Williams, *National Science Foundation Fellow, Electrical Engineering*
B.S., California Institute, 1967

Charles Arthur Willus, *National Aeronautics and Space Administration Trainee, Mechanical Engineering*
B.M.E., Cornell University, 1965

Charles Woodrow Wilson, Jr., *National Science Foundation Trainee, Chemistry*
B.A., Temple University, 1966

John Howard Wilson, *National Science Foundation Trainee, Biology*
A.B., Wabash College, 1966

Michael Barron Wilson, *National Science Foundation Trainee, Applied Mechanics*
B.S.E., University of Michigan, 1963; M.S., 1964

Sandra Winicur, *United States Public Health Service Fellow, Laws Scholar, Biology*
B.A., Hunter College, 1960; M.S., University of Connecticut, 1963

*Assistantship so marked carries tuition award.

Melvin Winokur, *Graduate Teaching Assistant,* Chemistry*
B.S., The City College of New York, 1964

Bruce Darrell Winstein, *National Defense Education Act Fellow, Physics*
B.S., University of California (Los Angeles), 1965

Nicholas Wilhelm Winter, *National Science Foundation Trainee, Chemistry*
B.S., Northern Illinois University, 1965

Warren Jackman Wiscombe, *National Science Foundation Trainee, Applied Mathematics*
B.S., Massachusetts Institute of Technology, 1964; M.S., California Institute, 1966

Robert Gordon Wolcott, *National Institutes of Health Trainee, Chemistry*
A.B., University of California (Riverside), 1966

Stephen Howard Wolfe, *Graduate Research Assistant,* Geophysics*
B.A., Cornell University, 1964

Franklin Bruce Wolverton, *Graduate Teaching Assistant,* Physics*
B.S., University of Michigan, 1961

Felix Shek Ho Wong, *Graduate Teaching Assistant,* Engineering Science*
B.S., Purdue University, 1964; M.S., California Institute, 1965

William Edwin Wright, *National Science Foundation Fellow, Physics*
B.S., Michigan State University, 1967

Jiunn-jeng Wu, *Dobbins Scholar, Aeronautics*
B.S., National Taiwan University, 1964; M.S., California Institute, 1966

Shyue Yuan Wu, *Graduate Research Assistant,* Chemical Engineering*
B.S., National Taiwan University, 1960

Max Wyss, *Graduate Research Assistant,* Geophysics*
Dipl., Eidgenossische Technische Hochschule (Zurich), 1964; M.S., California Institute, 1967

Keikichi Yagii, *Graduate Research Assistant,* Materials Science*
B.S., Osaka University (Japan), 1964

Amos Yahil, *Graduate Teaching Assistant,* Physics*
B.Sc., Hebrew University, 1966

I-min Yang, *Graduate Research Assistant,* Applied Mechanics*
B.S., National Taiwan University, 1958; M.S., 1964; M.S., California Institute, 1965

Steven Joseph Yellin, *National Science Foundation Trainee, Physics*
B.S., California Institute, 1963

Ka Bing Winson Yip, *Graduate Research Assistant,* Astronomy*
S.B., Massachusetts Institute of Technology, 1965

James Yoh, *Ford Foundation Fellow, Electrical Engineering*
B.S., California Institute, 1962; M.S., 1963

John Yoh, *Graduate Research Assistant,* Physics*
B.A., Cornell University, 1964; M.S., California Institute, 1966

Thomas King Lin Yu, *National Science Foundation Trainee, Electrical Engineering*
B.S., University of California (Los Angeles), 1966; M.S., California Institute, 1967

Eran Zaidel, *General Electric Fellow, Engineering Science*
A.B., Columbia University, 1966

John Andrew Zoutendyk, *Graduate Research Assistant, Murray Scholar, Engineering Science*
B.S., University of Washington, 1959; M.S., University of California (Los Angeles), 1961

Kenneth Allan Zuckerman, *National Science Foundation Trainee, Civil Engineering*
B.S.E., Princeton University, 1967

Craig Zumbrunnen, *National Defense Education Act Fellow, Geology*
B.A., University of Minnesota, 1966

*Assistantship so marked carries tuition award.

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Kai Jorgensen
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John B. Keating
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Willard W. Keith
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Donald V. Miller
M. Kinzie Miller
Bruce H. Mills
Mrs. Robert L. Minckler
George A. Mitchell
Louis T. Monson
Wellslake D. Morse
Lindley C. Morton
Francis L. Moseley
Samuel B. Mosher
Victor Moss
R. H. Moulton
Robert W. Moulton
Mrs. Seeley G. Mudd
Seeley W. Mudd II
William C. Mullendore
Mrs. William B. Munro
John S. Murray
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Thomas G. Myers
William F. Nash, Jr.
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Harlan J. Nissen
Louis E. Nohl
K. T. Norris
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Mrs. Thomas I. O'Connor
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Stuart O'Melveny
Mrs. Benjamin E. Page
John B. Parkin
Charles H. Percy
C. D. Perrine, Jr.
Ralph E. Phillips
Mrs. June Braun Pike
Hugh D. Powers
Arthur N. Prater
Mrs. Charles H. Prisk
Allen E. Puckett
William F. H. Purcell
Louis T. Rader
Simon Ramo
Richard S. Rheem
Will Richeson, Jr.
Bernard J. Ridder
Mrs. Alden G. Roach
Harold Roach
Mrs. Harry W. Robinson
John H. Rubel
Albert B. Ruddock
Mrs. Albert B. Ruddock
Billings K. Ruddock
Merritt K. Ruddock
Charles E. Rutherford
Paul C. Schaffner
Mrs. Howard J. Schoder
Jonathan Scott
Mrs. Jonathan Scott
Homer T. Seale
Mrs. Frank R. Seaver
Peter V. H. Serrell

Mark Serrurier
William T. Sesnon, Jr.
Mrs. Evelyn Sharp
Leroy B. Sherry
Herman V. Shirley
Henry E. Singleton
Dana C. Smith
Ralph L. Smith
Howard G. Smits
Mrs. Charles A. Smolt
Mrs. Keith Spalding
Mrs. Silsby M. Spalding
Herbert Speth
Lowell Stanley
Mrs. Harry G. Steele
Richard S. Steele
Mrs. Richard S. Steele
David H. Steinmetz
Ron Stever
Mrs. Charles H. Strub
Elbridge H. Stuart
D. Dwight Taylor
Mrs. Reese H. Taylor
Charles F. Thomas
Charles B. Thornton
George J. Tooby
Wayne L. Travis
Walter L. Treadway
Mrs. Walter L. Treadway
Mrs. John Treanor
Ray A. Tritten
Paul W. Trousdale
Edward E. Tuttle
Edward R. Valentine
Mrs. J. Benton Van Nuys
Howard G. Vesper
Harry J. Volk
Victor von Borosini
Richard R. Von Hagen
DeWitt Wallace
Vard B. Wallace
Thomas J. Watson, Jr.
Mrs. Gurdon W. Wattles
Richard F. Webb
George W. Weedon
Robert Welles
Roy E. Wendahl
John Robert White
Wm. R. Whittaker
Donald W. Whittier
Leland K. Whittier
N. Paul Whittier
James W. Wilkie
Leighton A. Wilkie
Robert J. Wilkie
Lawrence A. Williams
P. G. Winnett
Adrian G. Wood
Mrs. Adrian G. Wood
Mrs. Helen W. Woodward
Dean E. Wooldridge
H. Dudley Wright
William V. Wright
Mrs. Archibald B. Young
Mrs. Gertrude Kerckhoff Young
A. M. Zarem
William E. Zisch

INDUSTRIAL ASSOCIATES

The Office for Industrial Associates was established in 1949 to provide a practical channel for communications and intellectual interchange between the scientists and engineers of industry and the faculty of the Institute. Companies with a strong research interest have been attracted by this program. Features of the program are special conferences, early distribution of research reports, special library privileges, and exchanges of visits by faculty and company scientists, both on campus and at the research laboratories of the member companies. The membership fees (minimum $15,000 annually) make up a significant part of the unrestricted income available to the Institute to help maintain a competitive faculty salary scale and a strong program of basic engineering and scientific research.

The membership as of July 1, 1968, was as follows:

Aerojet-General Corporation
Aerospace Corporation
Atlantic Richfield Company
Avco Corporation
Beckman Instruments, Inc.
Bell & Howell Research Center
Bell Telephone Laboratories, Inc.
The Boeing Company
Campbell Soup Company
Carnation Company
Chrysler Corporation
Continental Oil Company
Crown Zellerbach Corporation
Deere & Company
Eastman Kodak Company
E. I. du Pont de Nemours and Company, Inc.
FMC Corporation
Ford Motor Company
General Dynamics Corporation
The Goodyear Tire & Rubber Company
Gulf Research & Development Company
Hercules Incorporated
Hughes Aircraft Company
Hycon Manufacturing Company
International Business Machines Corporation
International Minerals & Chemical Corporation
Litton Industries, Inc.
Lockheed Aircraft Corporation
Marathon Oil Company
Martin Marietta Corporation
McDonnell Douglas Corporation
Mobil Oil Corporation
North American Rockwell Corporation
Northrop Corporation
Occidental Pretroleum Corporation
The Procter & Gamble Company
Shell Oil Company
Southern California Edison Company
Standard Oil Company of California
  Chevron Research Company
The Superior Oil Company
Teledyne, Inc.
Texaco Inc.
TRW Inc.
Union Oil Company of California
United States Steel Corporation
The Upjohn Company
Xerox Corporation
  Electro-Optical Systems, Inc.

EARTHQUAKE RESEARCH AFFILIATES

The Earthquake Research Affiliates program has developed from an informal program designed for a group of companies that have sponsored research at the Institute's Seismological Laboratory for several years. Membership fees (minimum $2,500 annually) are now utilized by both the Seismological Laboratory and the Earthquake Engineering Research Laboratory. Member organizations are kept informed of current research in seismology and earthquake engineering by distribution of publications, conferences, field trips, and informal exchanges with the Institute faculty.

The membership as of July 1, 1968, was as follows:

FOUNDERS

Pacific Telephone and Telegraph Company
American Telephone and Telegraph Company
Associated Factory Mutual Fire Insurance Companies
The Atchison, Topeka and Santa Fe Railway
Bank of America
Southern California Gas Company
Southern Pacific Company
Union Pacific Railroad Company

MEMBERS

American Insurance Association
American Iron and Steel Institute
Bechtel Corporation
Dames & Moore
Department of Water and Power, City of Los Angeles
Esso Research and Engineering Company
Kaiser Steel Corporation
Mandrel Industries, Inc.
The Ampex Corporation
San Diego Gas and Electric Company
Southern California Edison Company

All Industrial Associate member companies are automatically members of the Earthquake Research Affiliates program.

CALTECH INDUSTRIAL RELATIONS SPONSORS

The Industrial Relations Center was established in 1939 to provide (1) instruction in supervision and management to regular students in four courses within the Division of Humanities and Social Sciences and (2) appropriate services to industrial, governmental, and other organizations through its management development, research and library facilities. The activities of the Center are described in more detail beginning on page 136. Additional information may be obtained from the Director.

The Center is financially supported through income from its services and from continuing annual fees or gifts, with a minimum of $500 and a maximum of $3,500 per year, based on the number of management personnel employed in the Los Angeles area by the Sponsor. The Sponsors of the Center as of July 1, 1968, were as follows:

American Cement Corporation
American Oil Company
American Potash & Chemical Corporation
Anonymous
Arrowhead Puritas Waters
Atlantic Richfield Company
Automobile Club of Southern California
Avery Products Corporation
Avon Products, Inc.
Bank of America NT & SA
Barco of California
Beckman Instruments, Inc.
Bekins Van & Storage Company
Bell & Howell/Consolidated Electrodynamics Corporation
Blue Cross of Southern California
Bullock's
Burroughs Corporation, Business Machines Group, Pasadena Plant
Byron Jackson Pumps, Inc.
California Federal Savings and Loan Association
California-Western States Life Insurance Company
Carnation Company
Cary Instruments
Conrac Corporation
Crown Zellerbach Foundation
Dana Laboratories Incorporated
Daniel, Mann, Johnson, & Mendenhall
The Digitran Company
Disney Foundation
Earth Sciences, A Teledyne Company
Electro-Optical Systems, Inc., A Subsidiary of Xerox Corporation
Electronic Specialty Company
Endevco Corporation
General Precision Systems Inc., Librascope Group
General Telephone Company of California

Glassco Instrument Company
Houston Fearless Corporation
The Irvine Company
ITT Cannon Electric
Lear Siegler, Inc., Astronics Division
Lockheed-California Company and Lockheed Aircraft Corporation
and its other Divisions and Subsidiaries
Mobil Oil Corporation, West Coast Marketing Division
Naval Electronics Laboratory Center
Norris Industries
North American Rockwell Corporation
Ocean Technology, Inc.
Pacific Lighting Service and Supply Company
Pacific Mutual Life Insurance Company
The Pacific Telephone and Telegraph Company,
Chief Engineer's Dept., L. A. North Area; and
Plant Department, Southern Counties Area
Philco-Ford Corporation, Aeronutronic Division
Pike Corporation of America
Products Research & Chemical Corp.
Purex Corporation, Ltd.
Rexall Drug and Chemical Company
San Diego Gas & Electric Company
Signal Oil and Gas Company
Southern California Edison Company
Southern California Gas Company
Southern Counties Gas Company of California
Southern Pacific Foundation
Southwestern Portland Cement Company
Sparkletts Drinking Water Corporation
Standard Oil Company of California
Sully-Miller Contracting Company
Texaco Inc.
The Times Mirror Company
Title Insurance and Trust Company Foundation
Union Bank
Union Oil Company of California
United California Bank
U.S. Electrical Motors, Division of Emerson Electric Co.
Vons Grocery Company
Jervis B. Webb Company of California
Western Gear Corporation

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.

The Institute 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, the Institute 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 the Institute 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 the Institute 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 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.

The Institute 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 the Institute 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 the Institute. Graduate students constitute a comparatively large portion (over 50 percent) of the total student body. Engaged themselves on 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 Institute 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 180 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 Institute 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.

Pasadena is at the foot of the San Gabriel Mountains, twenty-five miles from the Pacific Ocean. Caltech's campus is shown above.

HISTORICAL SKETCH

The California Institute of Technology, as it has been called since 1920, developed from a local school of arts and crafts, founded in Pasadena in 1891 by the Honorable Amos G. Throop and named, 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."

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


HALE


NOYES


MILLIKAN

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 from 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 700 undergraduates, 750 graduate students, and a faculty (including postdoctoral fellows) of about 600.

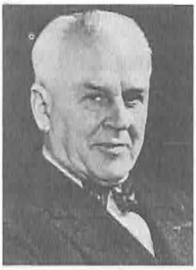
The Institute also attracted financial support from individuals, corporations, and foundations. In January 1920 the endowment had reached half a million dollars. In February of that year it was announced that $200,000 had been secured for research in chemistry and a like amount for research in physics. 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 field; 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 C.I.T. Trustees, the General Education Board, the Carnegie Institution 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 the Executive Council of the Institute. 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 the Institute 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



Robert A. Millikan, physics, 1923, measuring the charge of the electron and work on the photo-electric effect.

Thomas Hunt Morgan, medicine, 1933, the relation of chromosomes to heredity.

Carl D. Anderson, physics, 1936, for his discovery of the positron.

Edwin D. McMillan, physics, 1951, for his discovery of transuranic elements.

Linus Pauling, chemistry, 1954, for research into the nature of the chemical bond; 1962, Peace Prize

CALTECH'S NOBEL LAUREATES

William Shockley, physics, 1956, work on semiconductors and the transistor effect.

George W. Beadle, medicine, 1958, for his analysis of the chemical activity of genes.

Donald A. Glaser, physics, 1960, for his invention of the bubble chamber.

Rudolf Mössbauer, physics, 1961, discovery of recoil-free emission of gamma rays.

Charles H. Townes, physics, 1964, for development of the maser-laser principle.

Richard Feynman, physics, 1965, for fundamental work in quantum electrodynamics.

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 C.I.T.) 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, and the Institute 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 through an agreement between the Institute and the Carnegie Institution of Washington. Teaching and research in astronomy and astrophysics thus became a part of the Institute 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 the Institute 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 350, are the successors of those early dedicated pioneers who saw in Throop College the potentiality of becoming a great and famous institution. The Institute Associates, by their continued support, have played a vital part in the Institute's progress. In 1949 the Industrial Associates Program was organized as a mechanism for providing corporations with the opportunity of supporting fundamental research at the Institute and of keeping in touch with new developments in science and engineering.

For the five years beginning with the summer of 1940, the Institute devoted an increasingly large part of its personnel and facilities to the furthering of national defense and the war effort. The Institute'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 Institute-supervised courses: advanced meteorology for Army Air Force cadets; advanced work in aeronautics and ordnance for Army and Navy officer personnel; and the provision of instruction (as well as housing and subsistence) for a unit of the Navy V-12 Engineering Specialists. 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, a large-scale program of research. It was operated under contract with the Department of the Army until 1958 when it was transferred to the newly established National Aeronautics and Space Administration. JPL is now devoted wholly to the science and technology of space exploration. The laboratory launched the first U. S. satellite, Explorer I, in 1958; the Ranger VII, VIII, and IX moon probes in 1964 and 1965; the Mariner II and IV probes to Venus and Mars; and then in 1966 the highly successful Surveyor I probe to the moon.

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 the California Institute on September 1, 1946.

Today the Institute 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 the Institute 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 $73,000,000 and those invested in endowment about $93,000,000. 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 completed; 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 secure $16,100,000 to finance 18 needed buildings and an enlarged faculty salary fund. The goal was later raised, and by April 1962 the pledges to this campaign totaled over $19,350,000. 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—gift of an anonymous donor and the National Science Foundation (1968).

A new building to house high-energy physics and other activities in physics is under construction to be completed in 1969. This building was made possible by an arrangement with the Atomic Energy Commission and a grant from the National Science Foundation, with the addition of funds made available in the estate of an alumnus, George W. Downs. Also nearing completion, in the Tournament Park area on South Wilson Avenue, is a new central heating and refrigerating plant to serve the entire campus.

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. Twenty-five million dollars in gifts and pledges had been secured by March 1, 1968. 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 expanded facilities for behavioral biology, the humanities and social sciences, the computing center, geophysics and planetary science, engineering and applied science, astronomy and astrophysics, applied mathematics, business services (building already under construction), 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.

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, the Institute 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.

THE WILLIS H. BOOTH COMPUTING CENTER

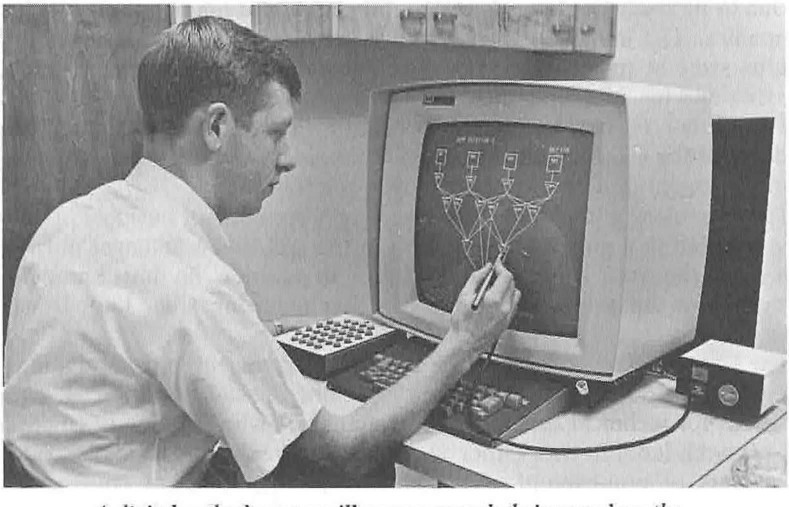
The Computing Center offers a comprehensive integrated set of facilities for the research and educational use of all divisions of the Institute.

One of these is a batch processing system which has used a shared file system based upon an IBM 7094 and an IBM 7040 compiler. In December of 1968 this will be replaced by an IBM 360/75 computer.

Another important system, particularly for student educational uses, is an IBM 360/50 interactive system serviced by 25 remote typewriter consoles and cathode ray display consoles. There are also a variety of other remote input/output devices and peripheral computers. This system is designed to multiplex a large number of simultaneous users in several basic modes of operation, all of which also can occur simultaneously.

One of these basic modes is designed for formal course work and other educational uses. This function is centered within the IBM 360/50 computer, a large portion of its bulk disc and drum memory and the remote typewriter consoles. The educational system employs an algebraic language that can be learned quickly and easily and provides good two-way communication between the creative thought processes of a human and interpretation by the computer of the human's wishes. This language, CITRAN, is a modification of JOSS, developed by the Rand Corporation.

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 experimental data language communications to further enhance the use of computers as adjuncts to human thought processes in the examination and conceptual analysis of data.



A digital cathode ray oscilloscope console being used on the IBM 360 system for the assimilation of neural models for a living nervous system

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.

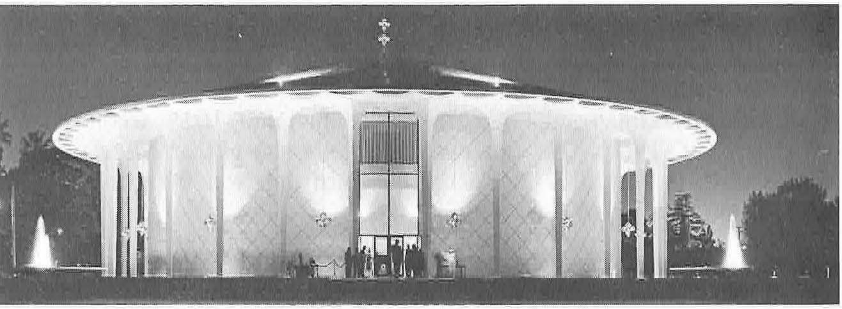
The Center participates in the education of undergraduate and graduate students of the California Institute of Technology, stressing the fundamentals of management and employer-employee relations.

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 management 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 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.

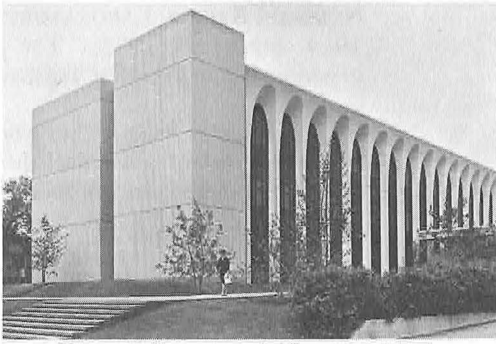
Throop Hall

W. M. Keck Engineering Laboratory



Beckman Auditorium

Winnett Student Center



Noyes Laboratory of Chemical Physics

Athenaeum

Firestone Flight Sciences Laboratory

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.

BUILDINGS AND FACILITIES

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 Mount Wilson and Palomar 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.

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 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 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 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 from 1931 to 1962 and chairman from 1943 to 1954.

Ruddock House. Named in honor of Mr. Albert B. Ruddock of Santa Barbara, a member of the Board of Trustees since 1938 and chairman from 1954 to 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.

MILLIKAN 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 from 1921 to 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 from 1917 to 1936.

CENTRAL PLANT, 1967.

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. In addition, there are library collections elsewhere on the campus in aeronautics, astrophysics, chemical engineering, electrical engineering, geology, and industrial relations. The libraries collectively subscribe to about 3,800 journals and contain about 175,000 volumes.

OFF-CAMPUS FACILITIES

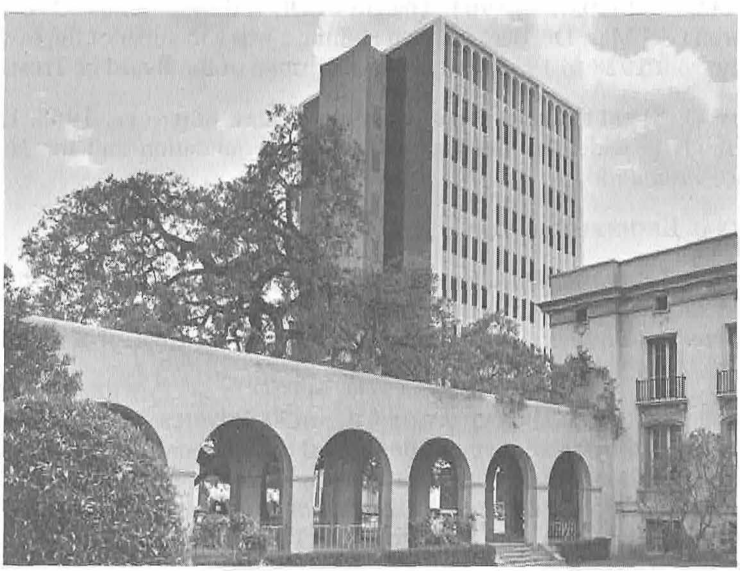
KRESGE SEISMOLOGICAL LABORATORY, 1928 (of the Division of the Geological Sciences), 220 North San Rafael Avenue, Pasadena. Named in recognition of a gift from The Kresge Foundation of Detroit, Michigan.

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.



The Institute's new Robert Andrews Millikan Memorial Library

The Sciences

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 (see page 300); 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.

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.

Entering graduate students are admitted for the Ph.D. program. Details of the scholastic requirements for the Ph.D. degree in Applied Mathematics are given under Section IV (page 255). The master's degree may be awarded in exceptional cases. The general Institute regulations (see Section IV) require the candidate for the master's degree to take at least 135 units of graduate work as a graduate student at the Institute, including 81 units of advanced graduate work in applied mathematics and 54 units of free electives.

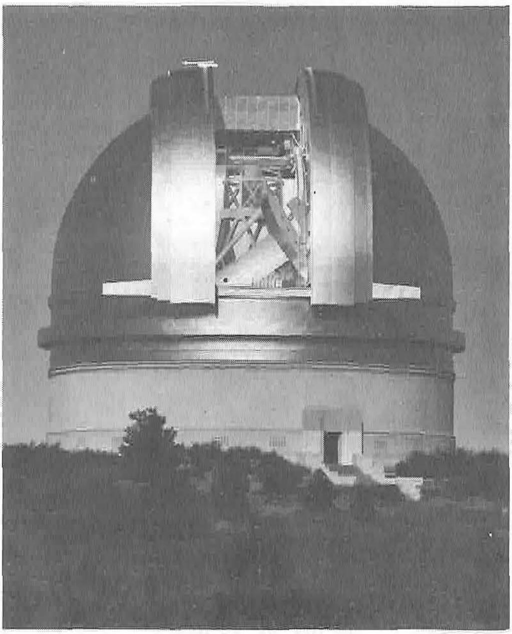
ASTRONOMY

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 contents 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 is under construction and will be installed at a new observing station in the Southern California mountains. 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 constructed 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.

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 Mount Wilson and Palomar 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 Mount Wilson and Palomar Observatories, and the Radio Observatory.

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



The 200-inch telescope at the Palomar Observatory

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.

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 co-operation 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, planetary physics, radio astronomy, astrophysics, and observations with large telescopes.

Neurobiologist records information storage and retrieval in a single nerve cell

Biology

UNDERGRADUATE AND GRADUATE WORK

Biology is today one of the most rapidly expanding and exciting of the sciences. Advances of a spectacular kind are being made in our understanding of living things. This is in large part so because it has been found possible to apply the methods, concepts, and approaches of mathematics, physics, and chemistry to the investigation of such biological problems as the manner in which molecules, genes, and viruses multiply themselves; the nature of enzyme reaction and of enzymatic pathways; the mechanisms of growth and development; and the nature of nerve activity, brain function, and behavior. There is great and increasing demand for experimental biologists, and qualified individuals will find opportunities for challenging work in basic research and in the applied fields of medicine, agriculture, and chemical industry.

Because of the preeminent position of the California Institute of Technology in both the physical and biological sciences, students at the Institute have an unusual opportunity to be introduced to modern biology. The undergraduate option is designed to give the student an understanding of the basic facts, techniques, and logic of biology as well as a solid foundation in physical science. Emphasis is placed on the general and fundamental properties of living creatures, thus unifying the traditionally separate fields of the life sciences. The undergraduate option serves as a basis for graduate study in any field of biology or for admission to the study of medicine.

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 advisor about this.

Graduate work leading to the Ph.D. degree is chiefly in the following fields: biochemistry, biophysics, cell biology, developmental biology, genetics, neurophysiology, plant physiology, and psychobiology. These represent the fields in which active research is now going on in the Division. Most of these fields are approached at the molecular as well as higher levels of organization; thus, no separate discipline of "molecular biology" is recognized in the Division. The disciplines of biochemistry and biophysics, of course, encompass most directly the area of molecular biology. Neurobiology and behavior are receiving increasing emphasis within the Division of Biology. Related developments in the Divisions of Chemistry, Engineering, and the Humanities and Social Sciences serve to fortify doctoral programs concerned with the study of brain and behavior. The emphasis in graduate work is placed on research. This is supplemented by courses and seminars in advanced subjects aimed at develop ing the student's insight and critical ability as an investigator.

PHYSICAL FACILITIES

The campus biological laboratories are housed in three buildings, the William G. Kerckhoff Laboratories of the Biological Sciences, the Gordon A. Alles Laboratory for Molecular Biology, and the Norman W. Church Laboratory for Chemical Biology. The Alles Laboratory links the Kerckhoff and Church laboratories at all floor levels. The three laboratories contain classrooms and undergraduate laboratories, an annex housing experimental animals, and numerous laboratories equipped for biological, biochemical, biophysical, and physiological 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, the Earhart Plant Research Laboratory, and the Dolk and Clark Greenhouses. In the Earhart Laboratory all the elements of climate, such as light, temperature, humidity, wind, rain, and gas content of air can be controlled simultaneously. These laboratories offer the opportunity to study plants under different synthetic climatic conditions, yet with reproducibility of experimental results.

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.

Reference should also be made to the Biological Systems Laboratory, which houses the joint research programs of the Biology and Engineering Divisions dealing with data processing systems and systems theory as they relate to the nervous system and sensory perception (see page 174).

Undergraduate research student operating a digital frequency sweep nuclear magnetic resonance spectrometer

Chemistry and Chemical Engineering

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, which was completed in 1937, 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, completed in 1955, is shared equally with the Division of Biology. The new Arthur Amos Noyes Laboratory of Chemical Physics was dedicated in 1968. It 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 Arthur Amos 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 workers.

The chemical engineering facilities are located in the Eudora Hull Spalding Laboratory of Engineering and in the adjoining Chemical Engineering Laboratory. These laboratories are well equipped for instruction in chemical engineering and for research programs involving studies of the phase relations and thermodynamic properties of fluids at moderately high pressures and temperatures, reaction kinetics, the transfers of material and energy in fluid systems, the structure of liquids, the physics and chemistry of plasmas, the mechanics of dispersions, suspensions, and structure-property relations of polymeric materials.

UNDERGRADUATE WORK

There are two undergraduate options in the Division, one in chemistry and the other in chemical engineering, and the required courses are the same for the first two years. Study in these options 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 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.

In the second year, for both chemistry and chemical engineering, there is 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 chemistry and chemical engineering options require a basic course in physical chemistry and a course in advanced analytical chemistry with an associated laboratory. For chemistry majors the chemistry option requires a course in physical chemistry laboratory, which is elective in the fourth year, whereas the chemical engineering option requires professional courses which include chemical engineering thermodynamics and engineering mathematics. Both options provide time for some of the elective courses described on page 272 (chemistry) or page 270 (chemical engineering).

In the fourth year, the chemistry option has no required professional courses (if physical chemistry laboratory has been completed), but permits specialization by electives of an advanced nature. The chemical engineering curriculum contains courses in transport phenomena, optimal design of chemical systems, physical chemistry laboratory and chemical engineering laboratory, as well as electives in engineering and science.

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.

GRADUATE WORK 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 effective stimulus to awaken, develop, and give direction to the creative force.

Soon after the graduate student arrives in the laboratories, he attends a series of orienting seminars that introduce him to the active research interests of the staff. He is then expected to talk in detail with each of several staff members whose fields attract him, eventually to settle upon the outlines of a problem that interests him, and to begin research upon it early in his first year. He 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 advisor is common, and interdisciplinary programs with biology, physics, and geology are open and recommended.

For an advanced degree, no graduate courses in chemistry are specifically required, but the student may plan a program of advanced courses (see pp. 316-322) in consultation, at first with a representative of the Divisional Committee on Graduate Study and later with his research advisor.

An extensive program of seminars enables the student to hear of and discuss notable work in his own and other areas. In the weekly Divisional Research Conference, 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.

Before the end of the winter term of his second year, the student should be ready to seek formal admission to candidacy for the Ph.D. degree. He then presents a research report that describes and justifies what he has done and what he hopes to do and propositions, or brief scientific theses, that he has originated and can defend. The independence, creativity, and intellectual maturity that he demonstrates in his presentation provide the basis for the decision as to his admission to candidacy.

The division has both M.S. and Ph.D. programs, but most students work directly toward the Ph.D. degree. Requirements for the master's degree in chemistry are given on page 286; those for the doctor's degree on page 241.

AREAS OF RESEARCH

A detailed listing of individual research interests is to be found on pages 321 and 322, in the description of course Ch 280. These can be grouped into the following general areas of interest:

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*, including studies of oxidation and proteolytic enzymes, the determination of amino acid sequences of proteins, the systematic modification of proteins, the physical chemistry of solutions of macromolecules, immunochemistry, and the fundamental processes of photosynthesis.

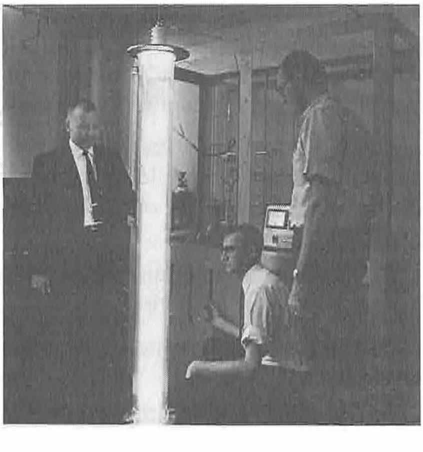
5. *Synthetic chemistry*, with recently increased emphasis on the synthesis of natural products and also including synthesis of theoretically interesting small molecules. In addition, research on the synthesis of new transition metal and rare earth complexes are under way.

GRADUATE WORK IN CHEMICAL ENGINEERING

Instruction and research in chemical engineering is offered leading to the degrees of Master of Science and Doctor of Philosophy.

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.



Chemical engineers study gas separation by preferential ionization in a glow discharge

Degrees. 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. The requirements include ChE 126 abc, Chemical Engineering Laboratory, which involves about one and a half terms of research under the supervision of a chemical engineering staff member. In addition there are electives, which may include humanities as well as graduate courses from other branches of science and engineering. A research report is required for the master's degree. The master's degree is not a prerequisite for Ph.D. work; however, at the cost of about one term of added residence it can be earned by those intending ultimately to obtain the Ph.D. degree.

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. In addition to acquiring proficiency at a high level in several areas vital to chemical engineering and satisfying division requirements in foreign languages and a minor program, the Ph.D. candidate must complete a significant program of scientific investigation and prepare a thesis describing this research. 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.

Ph.D. requirements are shown in more detail on page 242.

Instruction and Research. The major areas in which graduate research is currently concentrated are:

1. Reaction kinetics and combustion including both homogeneous and catalytic oxidation reactions; plasma chemistry; the decomposition of inorganic sulfur compounds; and both experimental and theoretical studies of oscillatory combustion.

2. Transport phenomena including turbulent heat and mass transfer in gases and liquids; measurements of diffusion coefficients, viscosities, and thermal conductivities over a wide range of pressures; and the development of mathematical methods for solution of complex transfer problems.

3. 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.

4. Thermodynamics and phase behavior including the volumetric and phase behavior of hydrocarbons; heats of vaporization of hydrocarbons.

5. Mechanics of suspensions and dispersions; chemistry and physics of aerosols.

6. Dynamics and optimal control of chemical reactors and systems.

7. Plasma chemistry and engineering, including diffusion and homogeneous and heterogeneous reactions.

8. Mechanical and ultimate properties of filled elastomers. Mechano-optical properties of rubbers. Mechanical properties of block co-polymers.

Graduate courses in chemical engineering are described starting on page 304. The 100-series courses are open to first-year graduate students while those in the 200-series are ordinarily taken only by more advanced students.

Facilities and Equipment. Chemical engineering is housed in the Eudora Hull Spalding Laboratory of Engineering and in the Chemical Engineering Laboratory which is contiguous to Spalding. The laboratories are well equipped both for instruction and for research and include the following major subdivisions:

The Transfer Laboratory, which is equipped for measurements of turbulent transfer of momentum, energy, and material. Combustion studies are also carried out in this laboratory.

The High Pressure Laboratory, which is equipped for precision measurements at pressures up to 15,000 psi and, in one case, to a temperature of 1500° F. Measurements include diffusion coefficients in liquids and gases, viscosity, thermal conductivity, heats of vaporization, Joule-Thomson coefficients, and volumetric and phase behavior of fluids.

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, and magnetic experiments over a range of temperature and pressure.

The Plasma Chemistry Laboratory, which includes equipment for generation of and measurements in plasma jets, electron beams, and glow discharges.

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. Molding and casting equipment for specimen preparation is also available.

The instructional laboratories are equipped for making precise measurements of transport and other phenomena.

Specialized Institute facilities are also available to students and staff. The Computing Center, which has exceptional capabilities, is described on page 135.

Caltech research teams work each summer on Blue Glacier in Washington

Geology

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 staff as listed on an earlier page of this catalog represents a variety of allied and integrated interests and is active in both teaching and research.

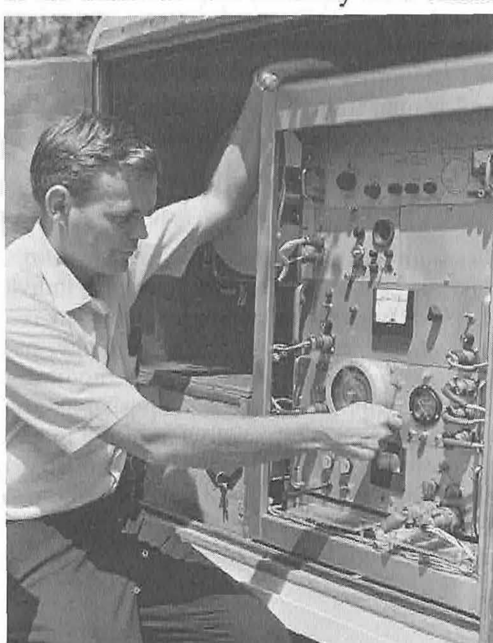
Physical facilities, both natural and man-made, are excellent. All the classroom instruction and most of the laboratory research in geology and geochemistry, as well as part of that in geophysics, are carried on in the Arms and Mudd laboratories. These are modern, five-story buildings which were specifically 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; organic-constituents laboratory; spectrographic, X-ray diffraction and X-ray fluorescent equipment; wet chemical laboratories; an electron microprobe facility; and facilities for rock and mineral analyses, sedimentation studies, thin- and polished-section work, and other requirements for comprehensive studies in the earth sciences. A new suite of laboratories for mineral separation and analyses is available for student use.

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, an induction furnace, 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 available. 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 a computer 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 seventeen 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. 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 Mount Wilson and Palomar Observatories with moderate-size reflecting telescopes especially designed and built to meet the needs of Division personnel.

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



A geophysicist uses trailer-mounted equipment to record micro-earthquakes along the San Andreas fault in California permits field studies throughout the entire year; consequently, year-round field training is an important part of the divisional program.

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.

UNDERGRADUATE WORK

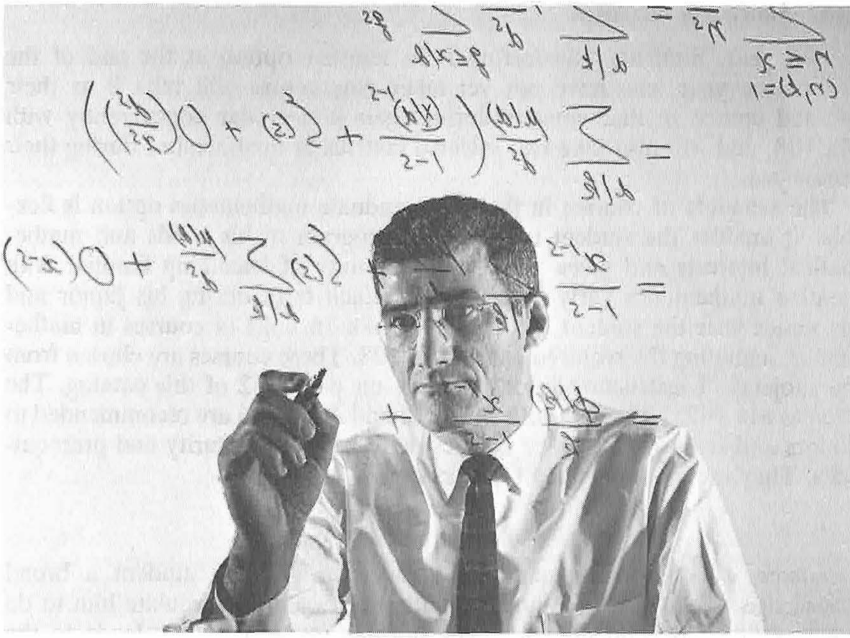
The aim of the undergraduate program in the geological sciences is to provide thorough training in basic geological disciplines and, wherever possible, to integrate the geological studies with and build upon the courses in mathematics, physics, chemistry, and biology taken during the earlier years at 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 or 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 and imaginative 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 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.

GRADUATE WORK

The number of courses required within the Division for an advanced degree is held to a minimum to permit individuality and flexibility in the various programs. Facilities are available for research and study in such subjects as geochemistry, geophysics, seismology, paleoecology, paleontology, petrology, geomorphology, glaciology, structural geology, stratigraphy, sedimentation, tectonophysics, mineral deposits, and planetary science.

The Division is especially interested in graduate students who have a sound and thorough training in physics, chemistry, biology, and mathematics as well as geology. Applicants with majors in these subjects and with a strong interest in the earth sciences will be given equal consideration for admission and appointment with geology majors.



Mathematics

UNDERGRADUATE WORK

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 intending 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 the 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.

GRADUATE WORK

Graduate work in mathematics is planned to give the student a broad knowledge of classical and modern mathematics and to stimulate him to do creative and independent work. The normal course of study leads to the Ph.D. degree and requires three or four years. Exceptional ability and graduate work done elsewhere may shorten this time.

The general Institute requirements for the Ph.D. degree are listed in Section IV under A and D. Additional requirements for mathematics are found on pages 253-254; they give information on placement examinations, language requirements, admission to candidacy, and final examinations.

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 general Institute requirements (see parts A and B of Section IV) specify that the candidate for the master's degree must take 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. The remaining 54 graduate units are electives from any field.

The candidate for the 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. This general knowledge will be tested through an oral examination. This examination can be waived at the discretion of the department.

Courses. The graduate courses which are offered are listed in Section VI. 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 299. They are taken normally by second-year and more advanced graduate students. They are usually given in alternate years. The 300 series includes the more 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. The student is reminded of the language requirements and of the requirements for a subject minor or a distributed minor. It is advisable for a student to satisfy these requirements as early as possible. In particular, the student should fill out the form listing his intended courses outside of mathematics and secure approval for this part of his plan of study.

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.

Research. Although supervision and guidance will be provided by members of the staff of the Institute, the thesis research, including the choice of a topic, is the responsibility of the student. Proper guidance can be given in almost any field in pure or applied mathematics and is not restricted to the immediate interests of the staff in mathematics. At present these interests include: group theory; algebraic and analytic theory of numbers; algebraic geometry; lattice theory; matrix theory; combinatorial analysis; ordinary and partial differential equations; measure and integration theory; Fourier and harmonic analysis; functional analysis; numerical analysis; differential geometry; topology; probability; some areas of applied mathematics.

A program of applied mathematics has been organized as a joint program of the Division of Physics, Mathematics and Astronomy, and the Division of Engineering and Applied Science. The course of study will lead 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. For details, see the separate section on applied mathematics.

Financial Aid. Besides the help provided by the nationwide fellowship programs, financial assistance may be provided by tuition scholarships and research or teaching assistantships. A scholarship and an assistantship may be held concurrently. The duties required of an assistant are light enough to allow the student to carry a full program of study.

PHYSICS

UNDERGRADUATE WORK

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 a more than usually 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.

GRADUATE WORK

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 (see page 251). 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. After the first year of graduate work, students with special technical training will find it comparatively easy to obtain part-time work during the summer on one or another of the research projects in physics. Students so employed are also expected to register for 15 or more units of research.

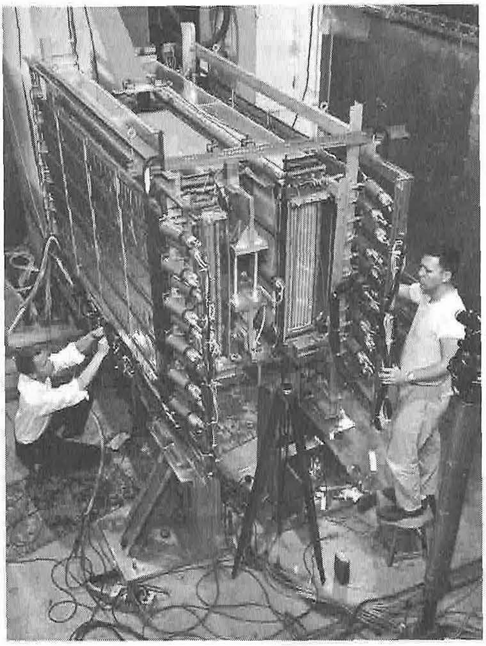
The Norman Bridge Laboratory of Physics is equipped to carry on research in most of the principal fields of physics. Facilities are provided for studies of cosmic rays, nuclear spectroscopy, Mössbauer Effect, space physics, solar physics, infrared astronomy and optical spectroscopy. In addition special facilities for research in nuclear physics are also provided in the W. K. Kellogg Radiation Laboratory, which is equipped with three electrostatic generators and a variety of auxiliary equipment. A 12-mev tandem electrostatic accelerator is installed in the Alfred P. Sloan Laboratory of Mathematics and Physics, which also contains laboratories for the investigation of the properties of matter at temperatures down to the milli-degree range. The Synchrotron Laboratory houses an electron accelerator which is now operating at energies up to 1.5 billion electron volts. The major portion of a new physics laboratory to be completed this year will be devoted to research in high-energy physics. The additional space provided in this building will permit an expanded "user's program" in which experiments are carried out at various national laboratories such as the Stanford Linear Accelerator Center and the Brookhaven National Laboratory, thus making possible studies of particles at the highest energies available. Work in high-energy physics bridges the gap between the nuclear physics research in the Kellogg and Sloan laboratories and the cosmic ray and elementary particle investigations that have been carried on for many years in the Norman Bridge Laboratory. Opportunities for study in theoretical physics in any one of a number of fields are particularly good for a limited number of students whose ability and background qualify them for theoretical work.

The student may either select his own problem in consultation with the department or work into one of the research projects already under way.

There is a general seminar or research conference each week which is regularly attended by all research workers and graduate students. In addition, a weekly theoretical seminar is conducted for the benefit of those interested primarily in mathematical physics, and there are several seminars on special fields of work such as nuclear physics, X-rays, and high-energy physics.

For graduates in physics the main outlets are positions in colleges and universities, in the research laboratories of the government, and in the increasing number of industrial research laboratories of the country.

In order to make it possible for students to carry on their researches even after they have satisfied the requirements for the Ph.D. degree, a number of postdoctoral research fellowships are available.



Spark chamber and scintillation counter assembly, designed and built by the Caltech high-energy physics group to study anti-proton and proton collisions at the Brookhaven 30 GeV proton accelerator

Engineering and Applied Science

UNDERGRADUATE WORK

"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."

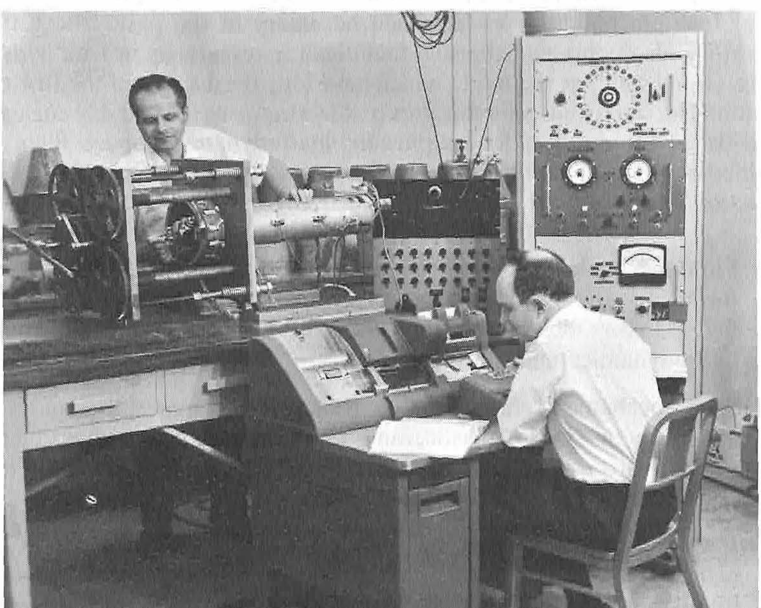
The course is designed to give the greatest possible flexibility as preparation for graduate study and for professional practice. The course involves four years of study leading to the degree of Bachelor of Science. The first year is essentially common for all students at the Institute. At the end of this year a student who elects engineering is assigned an advisor 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 advisor 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 men 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.

GRADUATE WORK

Graduate study and research opportunities exist in aeronautics, applied mechanics, chemical, civil, electrical, and mechanical engineering, engineering science, and materials science. An interdivisional program in applied mathematics is offered as explained on page 153. The courses leading to the degree of Master of Science normally require one year of work following the bachelor's degree and are designed to prepare the engineer for professional work of a more specialized and advanced nature. A second year of graduate work leads to the degree of Aeronautical Engineer, Civil Engineer, Electrical Engineer, or Mechanical Engineer. In addition, advanced work is offered in aeronautics, applied mathematics, applied mechanics, chemical engineering, civil engineering, electrical engineering, mechanical engineering, materials science, and engineering science leading to the degree of Doctor of Philosophy. In all phases of the graduate program students are encouraged to include in their courses of study a considerable amount of work outside of their specialized fields, particularly in mathematics and physics.

The Division of Engineering and Applied Science includes those curricula and facilities which are a part of the options of civil, electrical, or mechanical engineering, aeronautics, applied mathematics, applied mechanics, materials science, and engineering science in which degrees designated with these options are given. In addition, the Division includes subjects and research facilities in which no specific degree is offered, but which form a part of a student's course of study or are available to him as optional work. These subjects are hydraulics and hydrodynamics, jet propulsion, nuclear energy, physical metallurgy, biological engineering sciences, environmental health engineering, and information science. Some of the specialized laboratory facilities available for instruction and research are the various wind tunnels; the Computer Center; the Dynamics Laboratory; Nuclear Measurements Laboratory; and the several facilities for work in hydraulic structures, hydrodynamics, physical metallurgy and properties of materials, hydrology, water supply, environmental health, biological systems, and engineering seismology.



Research in aeronautics—studying the stability of thin conical and cylindrical shells

AERONAUTICS

The Graduate School of Aeronautics and the Guggenheim Aeronautical Laboratory, widely known as the GALCIT, were established in 1928 at the California Institute with the aid of the Daniel Guggenheim Fund for the Promotion of Aeronautics. In 1948 a Jet Propulsion Center, to provide facilities for study in that field, was established by the Daniel and Florence Guggenheim Foundation (see page 175). At about the same time an addition to the original Guggenheim Laboratory was constructed in an attempt to cope with the demands which twenty years of growth had imposed. The subsequent attainment of supersonic flight, and the more recent opening of what has been called the "Space Age," by the first Russian and United States orbiting satellites, tremendously increased both the scope and the research facility requirements of the field involving both science and engineering which is here called aeronautics. Generous donors have recently made it possible for the California Institute to more nearly satisfy the needs thus created. Both the Karman Laboratory of Fluid Mechanics and Jet Propulsion (a gift of the Aerojet-General Corporation) and the Firestone Flight Sciences Laboratory (donated by the Firestone Tire and Rubber Company) were completed and occupied during the academic year 1961-62. Together with the original Guggenheim Laboratory, to which they are contiguous, they constitute an integrated group of Graduate Aeronautical Laboratories (also known as GALCIT) in which the enlarged activities resulting from the extension of the aeronautical environment into space can adequately be accommodated. In particular, the Jet Propulsion Center is now able to concentrate its major activities in the Karman Laboratory rather than having its work scattered in several Institute buildings as has been necessary in the past. The Karman Laboratory also contains extensive facilities for researches in true hydrodynamics (using water as the fluid) which have long been a part of the Institute's program. The staffs housed in this group of laboratories are actively engaged in the fields of aeronautics, jet propulsion, hydrodynamics, space flight, and the allied sciences. The following are the major areas in which postgraduate instruction and advanced research are currently concentrated:

1. Fluid mechanics including classical hydrodynamics and aerodynamics; turbulence; stochastic and molecular approaches; hypersonic and rarefied gas flows including the effects of very high temperatures; magnetohydrodynamics and plasma physics.

2. Solid mechanics relating to the properties of materials; statics and dynamics of elastic, plastic, and viscoelastic bodies; fracture; finite strains; elastic waves; thermal stress; shell theory and photoelasticity.

3. Performance, structural mechanics, and flight dynamics of aircraft and spacecraft, including air and space vehicle performance, stability and control with the associated aerodynamic, propulsive, and environmental inputs; multistage rocket performance; aeroelasticity; orbital mechanics, trajectories, reentry mechanics and thermodynamics.

4. Jet and rocket propulsion of aircraft and spacecraft (see page 175).

In all four of the above areas primary emphasis is placed on the underlying mathematics, physics, and chemistry and on their application to the solution of the scientific and engineering problems involved.

The group of Graduate Aeronautical Laboratories contains very complete and diversified facilities in support of the above program. The 200-m.p.h., 10-foot-diameter wind tunnel which has been in continuous service for nearly 35 years continues to be a valuable tool for low-speed research and model testing. The fluid mechanics laboratory contains several smaller wind tunnels and a considerable amount of special apparatus and equipment suitable for the study of basic problems connected with turbulent flows. The problems of transonic, supersonic, and hypersonic flows may be investigated in other wind tunnels specifically designed for such purposes. In these tunnels velocities up to 10 times the speed of sound can be attained. Shock tubes, plasmajets, inverse pinch facilities, mercury tunnels, and other special items of laboratory apparatus are available for studies of extreme temperature, rarefied gas, and magnetohydrodynamic effects. The solid mechanics laboratories contain standard and special testing machines for research in aircraft and spacecraft structures and materials. Fatigue machines are also available as is photoelastic equipment for the study of stress distribution by optical methods. Special apparatus, including very high speed cameras, is used in studies of elastic waves, stress propagation, panel flutter, and the mechanics of static and dynamic fracture. The laboratory facilities for jet propulsion and hydrodynamics are described in the sections on the Jet Propulsion Center and on Hydrodynamics, starting on page 172. The laboratories also include excellent shop and library facilities, conference and study rooms, in addition to the usual lecture halls and offices.

Another activity which had its origin at the GALCIT and with which the aeronautics and jet propulsion groups continue to maintain close contact is the Jet Propulsion Laboratory. The Laboratory is owned and supported by NASA and is administered by the Institute. Its primary responsibility is the "development of spacecraft and the carrying out of unmanned lunar and interplanetary exploration." This includes an extensive supporting research and advanced technical development program on the fundamental problems of propulsion; fuels and combustion; high-temperature materials; rocket-motor design, guidance, and control; and electronic instrumentation for tracking and telemetering. Among the experimental facilities are a space environmental simulator; over a dozen rocket and thermal jet test cells; large laboratories devoted to space sciences, refractory materials, hydraulics, instrumentation, chemistry, combustion, heat transfer; and high-speed digital and analog computers. The Laboratory extends the use of these facilities to properly accredited Institute students who are doing thesis work.

As in the fields of physics, chemistry, and mathematics, emphasis is placed primarily upon the development of graduate study and research; but provision also has been made in the four-year undergraduate program for work leading to such graduate study and research. This affords a broad and thorough preparation in the basic science and engineering upon which aeronautics rests.

The graduate courses may be taken either by students who have completed a four-year course at the Institute, or by students from other colleges who have had substantially the same preparation. 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. The second-year work, however, may be taken only by students who have completed the first-year course at the Institute or who have had substantially the same preparation elsewhere.

Still more advanced study and research are offered for the degree of Doctor of Philosophy. This degree is given under the same general conditions as those that obtain in the other courses offered at the Institute.

Applied Mathematics

(See pages 143 and 159)

Applied Mechanics

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, random 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, and rheology of blood in small tubes.

The work for the degree of Master of Science in Applied Mechanics ordinarily consists of three terms of formal instruction in basic courses in applied science. Students are given considerable latitude in selecting these courses, in consultation with the staff, and are encouraged to elect basic courses in mathematics and physics as well as courses in other options of the Division of Engineering and Applied Science. Students who have completed four-year B.S. programs in undergraduate options such as applied mechanics, engineering science, physics, mathematics, or engineering options having a strong background in applied mathematics, will in general be eligible to apply for admission to M.S. candidacy status.

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.

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. Several analog computers are also available. Other specialized laboratories include the Heat Transfer Laboratory, which contains a forced convection heat transfer loop, and the Laboratory of Microhydrodynamics and Rheology, with equipment for precision viscosimetry and studies in streaming birefringence.

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. 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.

Students interested in any of these fields may work for advanced degrees in engineering science or any of the other branches of engineering at Caltech, including chemical engineering. Details of the program are worked out by the student and his advisor depending on individual interest.

Biological Systems Laboratory. (See page 174)

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.

Research is currently in progress in the W. M. Keck Laboratory of Environmental Health Engineering on several phases of waste water reclamation, including the adsorption and desorption of viruses, the coagulation of particles in turbulent shear fields, and the filtration of very small particles from fluids. An extensive research program in marine ecology, particularly on the effects of man on the marine environment, includes studies of the dispersion of biological particles in the offshore waters.

Work in aerosol physics with application to air pollution problems is also in progress. Included are theoretical studies of the size spectra of dispersed phases and of aerosol filtration by fibrous filters and experimental research on high speed beams of small particles.

Facilities available in the Keck Laboratories include a Zeiss electron microscope and assorted optical microscopes, Coulter particle size analyzer, ultracentrifuge, and a well-equipped chemical instrumentation laboratory.

Biomedical Transport Processes. Research in this field in chemical engineering and environmental health engineering 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 Mechanics. 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 Cardiovascular Research Laboratory of the University of Southern California. Studies are currently being made of the rheology of complex suspensions, and blood in Couette flow and in flow through tubes of diameters in the size range of interest in microcirculatory studies (5 to 500 micra). Also in progress are living microcirculatory tests of small animals. This research is being correlated with work on larger animals by active participation in work at the Cardiovascular Research Laboratory, located at the Los Angeles County Hospital, about nine miles from the California Institute of Technology.

Facilities are available in the Thomas Engineering Laboratory for measurement of viscosity, tube flow, and still and cine photomicrography, as well as for the necessary chemical and physiological preparations. Equipment has also been developed for measurement of the rheological properties of vessel walls as well as pressure-flow relations in living microcirculatory vessels.

Chemical Engineering

(See pages 148-153)

Civil Engineering

In civil engineering, instruction is offered leading to the degrees of Master of Science, Civil Engineer, and Doctor of Philosophy.

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 dynamic 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 mathematics and basic scientific principles to the solution of civil engineering problems. The general areas in which advanced work is offered are: (1) structural engineering and applied mechanics, (2) soil mechanics and foundation engineering, (3) hydraulics: hydrodynamics, hydraulic engineering, hydrology, and coastal engineering, and (4) environmental health engineering.

The emphasis in the undergraduate school of the Institute is on basic subjects in science and engineering. In particular, strong emphasis is placed on physics, mathematics, and solid and fluid mechanics. The first year of graduate study involves more specialized engineering subjects, but the student working for the Master of Science degree is encouraged not to overspecialize in one particular field of civil engineering.

Greater specialization is provided by work for the engineer's and for the doctor's degree. The candidate for these degrees 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.

Students who have not specialized in civil engineering as undergraduates 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 over-all field of civil engineering, as well as courses in his specialty. Most graduate students are also required to take further work in applied mathematics. In connection with research and course work students have ample opportunity to use the Institute high speed digital computing facilities.

Excellent research facilities are available to qualified graduate students in all of the general areas of civil engineering which have been mentioned. Facilities for structural engineering, soil mechanics, and earthquake engineering are located in the Thomas Laboratory of Engineering. Hydraulic research is carried on in the Laboratory of Hydraulics and Water Resources, which is located in the W. M. Keck Engineering Laboratories, and is described in detail under the section on Hydrodynamics (page 172). The Laboratory for Environmental Health Engineering is also located in the W. M. Keck Engineering Laboratories. Work in this field is closely integrated with research in hydraulics and water resources, as well as with biology and chemistry. It is also included among the Biological Engineering Sciences as described on page 167.

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. A detailed annual report of research is available from the Chairman of the Division of Engineering and Applied Science.

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, and the concepts and approaches of physics and mathematics 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, control systems, communication theory, and machine learning. The broad spectrum of problems falling within this branch of engineering provides exceptional and challenging opportunities for both theoretical and experimental work.

Quantum electronics experiment in the Steele Laboratory

The distinctive feature of undergraduate courses in electrical engineering is the strong emphasis on the underlying fundamental principles as opposed to techniques and applications. This, coupled with the abundance of mathematics and physics courses in the curriculum, the variety of elective choice, and the creative atmosphere in which the student finds himself, provides an excellent background for either advanced graduate work or industrial employment.

For many students the four-year program leading to 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.

Laboratory facilities are available for a wide variety of research activities. At present electrical engineering activities are housed mainly in a new building, the Harry G. Steele Laboratory of Electrical Sciences. This is a modern, 55,000-square-foot laboratory building located immediately north of the Booth Computing Center and designed specifically for the research needs of the electrical engineering faculty and students.

The *Communication and Control Systems Laboratory* is a center of research in the fields of statistical communication theory and modern control theory. Students and faculty of the laboratory are actively engaged in research on many important problems of communication and control theory, such as machine learning and pattern recognition, signal selection and coding, detection of signals in noise, spectral estimation, optimal control and stochastic optimal control, modeling of homeostatic systems, nonlinear estimation and system identification.

The *Plasma Dynamics 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 nonlinear beam-plasma interaction.

The Antenna Laboratory is a center for the mathematical study of problems in electromagnetic theory. Its activity includes 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 light and in the study of related physical phenomena. Research projects now in progress include: interaction of coherent light with atomic systems, non-linear effects in laser media, non-linear optics, light-hypersound interactions and electromagnetics of optical resonators. The facilities include a laser fabrication setup and equipment for spectroscopic studies in the ultraviolet, visible, near and medium infrared region.

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 and injection mechanisms in semiconductors, and generalized theory of field-effect and diffusion transistors. Facilities are available for vacuum evaporation and deposition, and for a variety of measurements on materials and devices.

The *Electronic Circuits Laboratory* deals with modern problems in analysis, design, and synthesis of electric and 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. 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 of charged particles in solids. In the past these subjects lay exclusively in the domain of university departments of physics and mathematics.

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.

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. Students tend to choose physics and applied mathematics as their minor subjects and to choose a thesis advisor 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 in Two Phase Flow," "Theory of Pulsed Neutron Experiments," and "Structure and Properties of Palladium-Silicon Alloys."

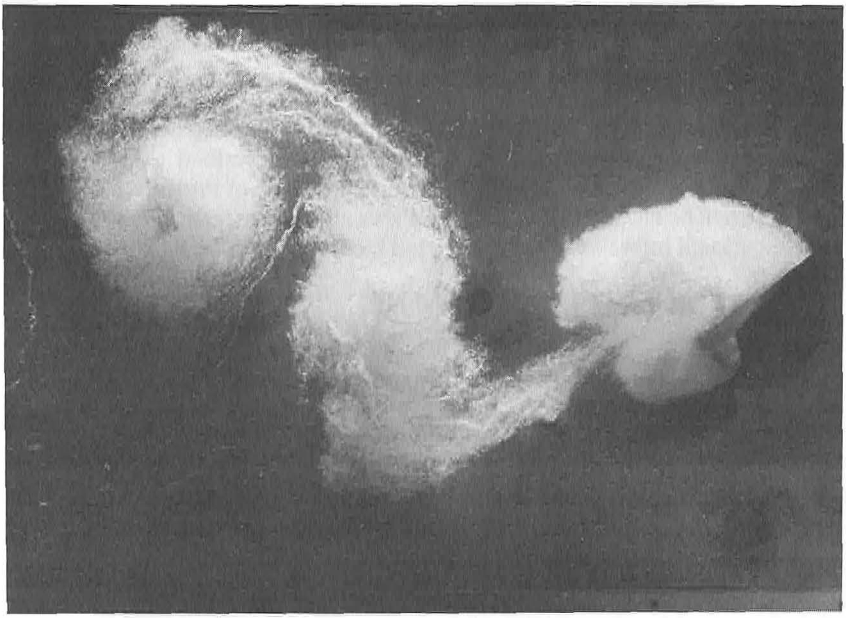
The program for the Master of Science degree is described on page 289.

Note: 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.

Hydrodynamics

Instruction and research in hydrodynamics and hydraulic engineering are concerned with various subjects which complement other Institute work in fluid mechanics. Current interests in this field include, for example, water waves, hydrodynamics of submerged or planing bodies, physics of cavitation, jets and cavity flows, flows of stratified fluids, turbulence and diffusion, open channel flow, sediment transportation, flow through porous media and hydraulic machinery. No specific degree in Hydrodynamics is given; however, advanced students working in this field may select enrollment and obtain degrees in Applied Mechanics, Civil Engineering, Mechanical Engineering, Engineering Science, and Aeronautics, depending upon their field of interest. The laboratories described below provide excellent facilities for graduate student research.

Hydrodynamics Laboratory. This laboratory is located in the Karman Laboratory of Fluid Mechanics and Jet Propulsion. It contains three major experimental facilities—the high-speed water tunnel, the free-surface water tunnel and the controlled-atmosphere launching tank. The high-speed water tunnel has a closed working section 14 inches in diameter and an alternate two-dimensional working section 6 by 30 inches, in which a maximum flow velocity of 85 feet per second can be obtained. The free-surface water tunnel can provide a maximum velocity of 27 feet per second in a working section 20 by 20 inches and 8 feet in length.



Flapped hydrofoil with cavitating wake

Hydraulics and Water Resources Laboratory. The W. M. Keck Engineering Laboratories provide space for an expanded basic research program in various phases of fluid mechanics and hydraulic engineering related to development and control of water resources. The facilities include: four recirculating tilting flumes for research in open channel flow, density currents and sediment transport (one is 130 feet long with cross section 43 inches wide by 24 inches deep, and others are respectively 60 feet, 40 feet, and 18 feet long); two fixed flumes for studies of boundary layer growth at low velocity, density currents, and flow in hydraulic structures; a low-turbulence water tunnel; a wave basin (32 feet long by 16 feet wide); a wave tank 100 feet long, 15 inches wide, and 24 inches deep; special tanks and circulation systems needed in research; miscellaneous equipment for a variety of student laboratory experiments; and extensive electronic instrumentation systems. A laboratory in nearby Azusa houses a large wave tank and wave basin and other facilities suitable for wave studies. Research projects are an integral part of the academic program and are carried out by the faculty, and by graduate students as thesis projects.

INFORMATION SCIENCE

Students who wish to follow a program in Information Science may do so in Engineering Science. 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

Candidates for advanced degrees in Engineering Science pursuing a program in Information Science may choose from a coordinated group of courses in Information Science and related disciplines and choose a research program in the subject area. The program for the Master of Science degree in Engineering Science is described on page 289.

Research laboratories important to this field are the Willis H. Booth Computing Center (see page 135) and the Biological Systems Laboratory.

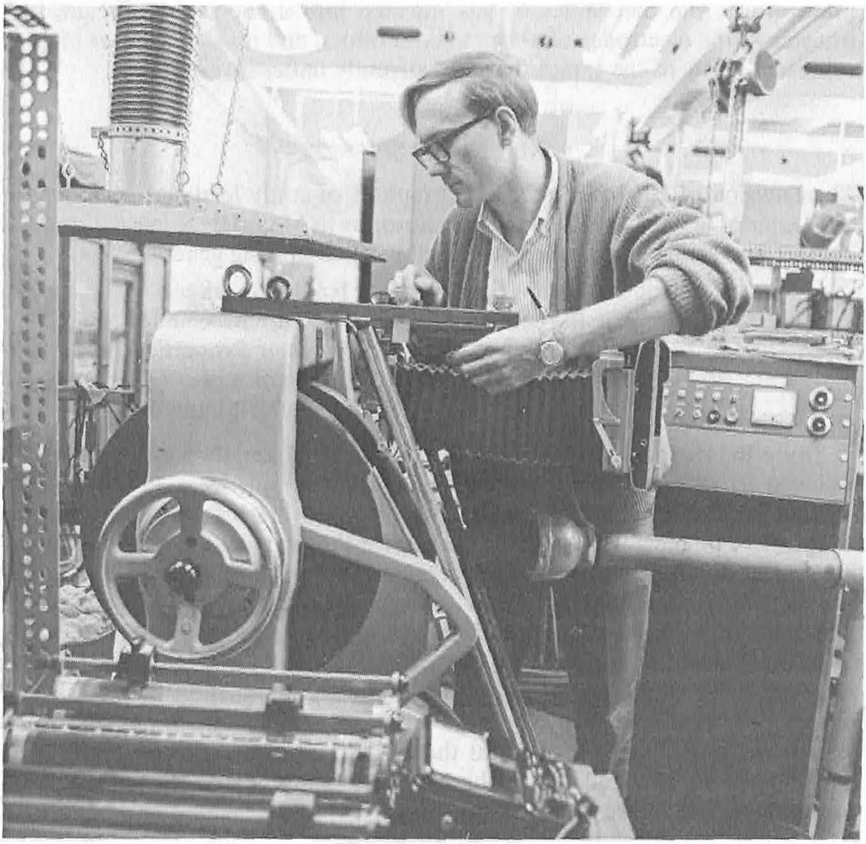
Biological Systems Laboratory. This laboratory contains facilities for research on living nervous systems. It is close to and integrated with the Willis H. Booth computer facilities and includes newly developed experiment control and data analysis systems. In addition, special facilities have been developed for advanced research on stimulus and response instrumentation. Present experimental research is concentrating on nervous and motor systems of insects and the visual systems of vertebrates, including humans.

*A closely related area of interest is that of communication theory and control theory. Courses in this area are offered under Electrical Engineering.

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 of the California Institute of Technology. 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



An engineer, studying ionized gases for use in power generation, photographs an electrical gas discharge mechanical engineering or aeronautics, but the courses are also available to students whose preparation has been in applied mechanics, engineering science, or physics. The complete program of instruction in jet propulsion for first-year graduate students is available to those candidates for the degree of Master of Science in Mechanical Engineering electing the jet propulsion option. Candidates for the degree of Master of Science in Aeronautics may take some of the courses in jet propulsion as electives. Candidates for the degree of Aeronautical Engineer or Mechanical Engineer may elect an option in jet propulsion for more advanced courses and research in this field.

Students admitted to work for the degree of Doctor of Philosophy in Aeronautics, Applied Mechanics, Engineering Science, or Mechanical Engineering may take part of their courses of instruction in jet propulsion and choose a research problem in jet propulsion as a thesis topic. The degree of Doctor of Philosophy does not carry a designation specifying the field of jet propulsion.

The Jet Propulsion Center is located in the new 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.

MATERIALS SCIENCE

The Division of Engineering offers programs of study leading to the degrees of Master of Science and Doctor of Philosophy in Materials Science. Graduate courses and research on solids is offered in the following general fields:

1. Electrical Properties
2. Magnetic Properties
3. Mechanical Properties
4. Dynamical Properties
5. Alloy Systems
6. Radiation Effects
7. Fracture Mechanics
8. Polymer Properties
9. Mechanics of Granular Media

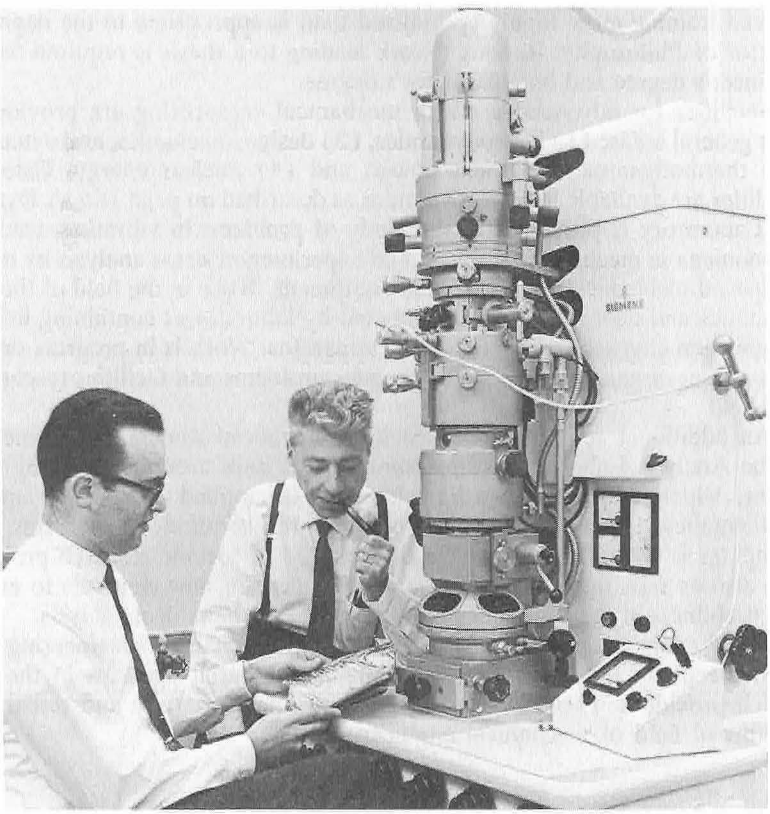
Study for the degree of Master of Science in Materials Science ordinarily will consist of three terms of course work totaling at least 135 units. The student is allowed considerable freedom in choosing his courses. However, he must obtain the approval of his advisor for the program and any subsequent changes. Formal thesis work is not required, although laboratory courses are provided as elective courses so that the student can utilize the basic equipment and techniques employed in a variety of research fields.

Work toward the degree of Doctor of Philosophy in Materials Science usually requires a minimum of two years following completion of the master's degree program. Ordinarily, at least one year of this time is devoted to research work leading to a doctoral thesis. The course work and thesis work are planned by the student and his advisory committee so as to fit best the background and interests of the student.

Instruction and research in materials science is available. Current research activities include: properties of thin metallic and insulating films, anisotropy with respect to magnetic and electrical properties, electron transport processes, relationship between mechanical properties and structure, fracture and fatigue damage in metals, behavior of metals under dynamic loading conditions, structure of alloys, kinetics of phase transformation, crystal structure and properties of metastable phases, theoretical and experimental studies of deformation processes, diffusion in solids, radiation effects on physical and mechanical properties of materials, and studies in the mechanics of granular materials.

Work in metallic materials is carried on in the Laboratory of Engineering Materials occupying two floors of the W. M. Keck Engineering Laboratories. These facilities include a 2-mev electron accelerator and a helium cryostat. Special laboratories are provided for studies on the mechanics of materials and for the dynamic application of stress.

The work on the magnetic and electrical properties of materials is carried on in the Steele Laboratory of Electrical Sciences. The work in the field of polymers and fracture mechanics is done with extensive facilities in the Spalding Laboratory of Engineering and Firestone Flight Sciences Laboratory. Facilities are available for work with granular materials in the Thomas Laboratory of Engineering.



An electron microscope used in studying the effects of very rapid cooling of alloys

Mechanical Engineering

Instruction in mechanical engineering is offered leading to the degrees of Master of Science, Mechanical Engineer, and Doctor of Philosophy.

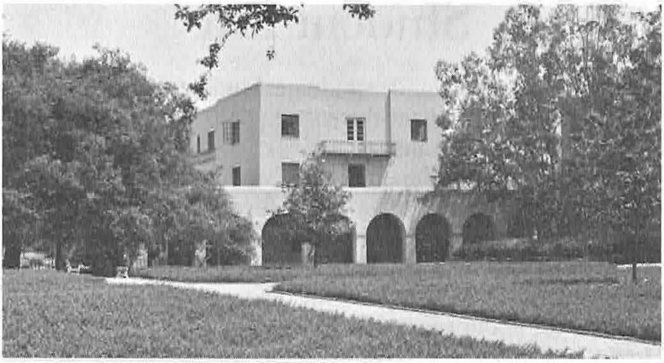
The undergraduate program of instruction in mechanical engineering is organized within the engineering option for the Bachelor of Science degree. The first-year graduate program is open to qualified students who have completed the four-year engineering course for the Bachelor of Science degree from the Institute, or have had substantially the same preparation in other colleges. The first four years at the Institute are concerned with basic subjects in science and engineering and in the humanities. The first graduate year, therefore, is somewhat more specialized, with options in general mechanical engineering, jet propulsion, or nuclear engineering. A schedule of subjects is specified for each of these first-year graduate options which may be modified with the approval of the student's adviser and the faculty in mechanical engineering to satisfy the special interest of the student.

Greater specialization is provided by the work for the engineer's or doctor's degree. The student is allowed considerable latitude in selecting his course of subjects, and is encouraged to elect related course work of advanced character in the basic sciences. The engineer's degree of Mechanical Engineer is considered as a terminal degree for the student who wishes to obtain advanced training more highly specialized than is appropriate to the degree of Doctor of Philosophy. Research work leading to a thesis is required for the engineer's degree and for the doctor's degree.

Facilities for advanced work in mechanical engineering are provided in four general areas: (1) hydrodynamics, (2) design, mechanics, and dynamics, (3) thermodynamics and heat power, and (4) nuclear energy. Extensive facilities are available in hydrodynamics as described on page 166. A Dynamics Laboratory is provided for the study of problems in vibration, transient phenomena in mechanical systems, and experimental stress analysis by means of special mechanical and electronic equipment. Work in the field of thermodynamics and heat power is implemented by laboratories containing internal combustion engines and heat-transfer apparatus. Work is in progress on certain phases of gas turbines which provides problems and facilities research in this field.

An additional activity of interest to all advanced students in engineering is the Analysis Laboratory. This laboratory is built around an analog computer, which merges the various interests in applied mechanics, applied mathematics, and electrical engineering in the solution of problems. The computer is valuable not only for the solution of specific research problems but also as research in itself in the development of new elements to extend the usefulness of the computer to more general mathematical analysis.

Close connections are maintained by the mechanical engineering staff with the many industries and governmental research agencies in the area which provide new, basic problems and facilities for study and research in the broad field of mechanical engineering.



Dabney Hall of the Humanities

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 California 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 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 unmarried faculty member. All Houses are under the general supervision and control of a member of the faculty known as the Master of Student Houses.

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 expected to live in the Houses. Those who have reason to believe they should live elsewhere should discuss the matter with the Associate Dean of Students. (See page 212)

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 touch football, softball, cross-country, swimming, basketball, tennis, track, and volleyball.

Ruddock

Lloyd

Page

Blacker

Dabney

Fleming

Ricketts

UNDERGRADUATE HOUSES

The Student Houses are pleasantly located in the east campus

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 designated as a memorial to the late Colonel E. C. 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 periodic joint meetings of the Faculty Committee on Student Relations and certain student body officers and elected representatives. These conferences serve as a clearing house for suggestions originating with either students or faculty.

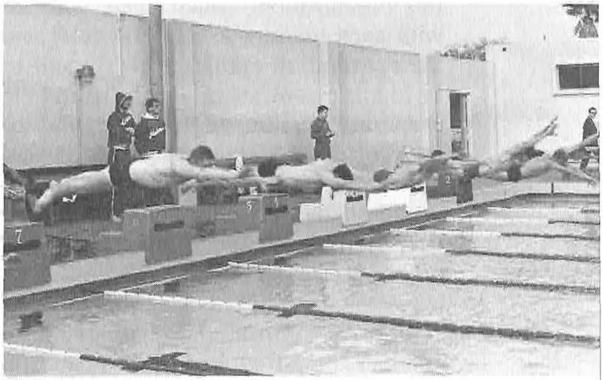
Option Advisers. Each member of the three undergraduate upper classes is assigned to an Option Adviser, a faculty member in the option in which the student is enrolled. The adviser interests himself in the student's selection of optional courses, progress toward his degree, and, eventually, in assisting 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-owned 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 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 any of the 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 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.

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 the Chemistry, Mathematics, and Physics Clubs, the Radio, Sailing, Flying, and Ski Clubs. The Christian Fellowship Group, Christian Science Group, Episcopal 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 Delta 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 students 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.

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.

DEPARTMENT OF AIR FORCE AEROSPACE STUDIES

THE United States Air Force offers Caltech students a unique opportunity to harmonize their military service obligation with their academic field of study and professional interests. This is accomplished through participation in the on-campus Air Force Reserve Officers' Training Corps "2-year Program," which is administered by the Department of Air Force Aerospace Studies. The California Institute of Technology unit of the AFROTC was established on campus at the beginning of the academic year 1951-52; it is a 7-unit course. Under its present "2-year" program, students are free to concentrate on general Institute requirements during the freshman and sophomore years.

As one of the world's leading technological organizations, in the forefront of aerospace age exploration, the USAF is interested in intelligent, energetic, and dedicated men who feel their responsibility to their country and their own professional career. Upon enrollment in the AFROTC program, students receive $500 per academic year, 1d draft classification, and all books and uniforms; upon completion, students have a broad range of opportunities to pursue graduate education prior to or after entry on active duty. In turn, the student agrees to faithfully pursue the Institute's established courses of study leading to a degree, to accept an Air Force commission as a 2nd Lieutenant upon completion of the AFROTC and degree programs, and to serve an active duty tour of four years in a technical area or five years after pilot/navigator training.

AFROTC graduates from Caltech are generally assigned to scientific engineering positions within the Air Force research and development activities. Those electing pilot or navigator duty can look toward assignments leading to experimental research as well as operational flying duties. As a major portion of its primary mission, the USAF manages and operates a series of the world's most advanced research, development, and test complexes. Here, Air Force scientists and engineers work in a professional, intellectual atmosphere in broad areas of basic and applied research to advance the state of aerospace technology. Extensive physical laboratory facilities as well as the favorable research environment and its support are considered excellent in every respect, providing a wealth of opportunity for creative accomplishment. For fiscal year 1969, in excess of $3 billion are budgeted for Air Force research, development, test, and evaluation.

Applications from undergraduate students are normally accepted early during the sophomore year in order to provide time for aptitude testing, medical examination, competitive selection, and participation in a summer training program of six weeks duration, conducted at an active Air Force installation. Applicants who have successfully competed and are qualified may then enroll in AFROTC at the beginning of their junior year. Some applications are also accepted from graduate students and junior and senior undergraduates providing that openings are available and the student will have at least two full years of study remaining at the Institute. These applications may be accepted throughout the year; applicants with more than two years remaining may be allowed to delay their entry on active duty for the time required to complete advanced degree requirements.

The AFROTC curriculum stresses student responsibility and involvement and is geared to an approach to learning that encourages inquiry, analysis, critical thinking, imagination, and discerning judgment. During the six-week field training session prior to actual enrollment, students become acquainted with the various activities that make up the Air Force and participate actively in leadership training experiences. In the first year, the curriculum covers the technological aspects and growth of aerospace power to include evolution of the national space effort and the contemplated roles of man in space. During the second year, the studies concentrate on the concept and variables affecting leadership, the need and nature of both self-discipline and military discipline, and the principles, practices, and techniques of management as applied to the complexities of the aerospace activities of industry and the goverment. Included in the program are visits to aerospace scientific and engineering complexes as well as visits by young Air Force officer engineer/scientists assigned to such technical activities. For cadets who are qualified and interested in pilot training the on-campus program offers the equivalent of about $600 worth of flight instruction during the second year, comprising 30 hours of ground school and 35 hours of actual flight training, the latter leading in most cases to a civilian pilot's license.

Persons desiring more specific information about the program, application procedures, and educational opportunities open to AFROTC graduates should contact Lt. Col. Charles J. Larkin, Professor of 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 is not coeducational and applications are accepted from men students only. 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 are not seeking a degree cannot be accepted.

Admission to the Freshman Class

The freshman class of approximately 180 men 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 Entrance 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 15, 1969. (Application to take entrance examinations must be made directly to the College Board at an earlier date, for which see page 190.)

Applicants living outside of the United States must submit their credentials by November 1, 1968.

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, 1969. 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 space provided on the application blank all the 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, 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, and English—of which two must be taken. No substitution of other tests can be permitted.

*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.

For admission in September 1969, the Scholastic Aptitude Test and achievement tests must be taken no later than the January 11 College Board test date. *It is important to note that no applicant can be considered in 1969 who has not taken the required tests by January 11, 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 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 65 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 examination applications should reach the appropriate office of the Board not later than the dates specified below.

	For examination centers located	
To take tests on	In the United States, Canada, the Canal Zone, Mexico, or the West Indies, applications must be received by	In Europe, Asia, Africa, Central and South America, and Australia, applications must be received by
December 7, 1968	November 9	October 12
January 11, 1969	December 7	November 16

Candidates are urged to send in their examination applications to the Board as early as possible, preferably at least several weeks before the closing date, 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 at least one week prior to the date of the 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 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. The registration card should be presented at Dabney Hall Lounge on the date of registration.

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 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 notice of 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 thermodynamics 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 who 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 third 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 into 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 receive credit for Math 1 a and will enroll in the course Math 1 b. They will begin their work in mathematics with a study of differential equations. Others will take the normal course Math 1 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 208).

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 215-216. No one can be considered for a scholarship grant who has not sent in a scholarship form according to the instructions on page 215. In computing need the California Institute uses the figure $3828 as covering 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 of $2878 is used for the expenses of those who live at home or with relatives or friends to whom they pay nothing for board and lodging. This figure includes the items listed above with the exception of board and lodging and with the addition of allowances for commuting expense and lunches. For further information on tuition and other costs, and on loans and the deferred payment plan see pages 211-214.

NEW STUDENT CAMP

All freshmen are required to attend the New Student Camp as a part of the regular registration procedure. Upperclass transfer students are not required to attend camp but are welcome to do so if they wish.

The camp takes place during three days immediately following freshman registration for the fall term. It is usually held at Camp Radford, a well-equipped camp owned by the city of Los Angeles and located in the San Bernardino Mountains east of the city of Redlands.

A large number of faculty members and upperclass student leaders attend the camp to assist the new student in his introduction into the Caltech community. Because of the comparatively small student body and the pressure of work once academic activity starts, it is important both to the student and to the Institute that new students become, at the very beginning, part of a homogeneous group sharing a common understanding of purpose and a common agreement on intellectual and moral standards. The three days at the camp afford the best possible opportunity for achieving this necessary unity.

STUDENTS' DAY

The California Institute holds an annual invitational Students' Day on the first Saturday in December. 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.

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 Professor of Air Force Aerospace Studies.

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 expect 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 188-191 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 188-191. 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 subjects *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 190) to send the scores to the Institute. If the SAT has not been taken previously, it must be taken by the March 1 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. Students must offer courses, both professional and general, substantially the same as those required in the various years at the Institute (see pages 265-282) or make up their deficiencies as soon as possible after admission.

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 this page and on page 197.

The Institute has recently made a radical revision of its basic two-year course in physics which is required of all students. The new course 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 revised first-year course covers kinematics, the Lorentz transformation, nonrelativistic and relativistic particle mechanics, electric and magnetic forces, Rutherford scattering, planetary motion, harmonic motion, geometrical optics, 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 for 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 quantitative analysis in the laboratory work. A transfer student who has had a one-year college course in inorganic chemistry and qualitative analysis will be considered to have met the first-year chemistry requirements, provided, of course, that 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 have not had the equivalent laboratory work elsewhere.

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

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.

The schedule for the examinations for admission to upper classes, September 29, 1969, is as follows:

Chemistry	(3 hours)	1:00 P.M.	May 9, 1969
Physics	(3 hours)	9:00 A.M.	May 10, 1969
Mathematics	(2 hours)	1:30 P.M.	May 10, 1969

No other examinations for admission to upper classes will be given in 1969.

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 193). 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 the parent or guardian responsible for the applicant's support. This form must reach the Admissions Office no later than April 15, and no applicant will be considered for a scholarship grant who does not have such a form on file here by that date.

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

REGISTRATION REGULATIONS

	Registration Dates	Fees Payable	Instruction Begins
Freshmen Students	Sept. 26, 1968	Sept. 26, 1968	Oct. 1, 1968
Upperclassmen and Graduate Students	Sept. 30, 1968	Sept. 30, 1968	Oct. 1, 1968

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 advisor 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 one of the Deans. 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 or ROTC. To carry excess units he must obtain the recommendation of his Departmental Advisor and the approval of the Undergraduate Academic Standards and Honors Committee (see page 206). 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 advisor. 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 undergraduate 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 19*. 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.

Student Trainees

Non-registered students engaged in recognized and approved training programs at the Institute are required to pay the applicable health fee to be eligible for benefits as provided from the Emergency Health Fund. Such benefits are described under "Student Health Services" on page 208.

1. A $15 fee will be assessed each participant in such a program conducted during the academic year.
2. A health fee of $9.00 will be assessed each participant in such a program conducted during the summer period.

In addition, a charge of two dollars, plus cost of medicine and laboratory services, will be charged for each visit to the Health Center during the academic year and summer period.

SCHOLASTIC GRADING AND REQUIREMENTS

SCHOLASTIC GRADING

Permanent grades in all freshman courses 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 in freshman courses in accordance with the normal usage for upperclassmen described below; it may also be used in continuing freshman courses in accordance with the following rules: (a) The performance of the freshman concerned was not significantly below the current passing level; (b) in the opinon of the instructor the freshman concerned was maintaining a steady and substantial rate of improvement; (c) no freshman shall be allowed two "E's" in the same course at the same time. Such an "E" would be changed to a "P" if the freshman earned a "P" for the following term; otherwise the "E" would be changed to "F."

For all undergraduate courses beyond the freshman year, the following system of grades is used to indicate the character of the student's work in his various subjects of study: "A" excellent, "B" good, "C" satisfactory,* "D" poor, "E" conditioned, "F" failed, "Inc" incomplete.

In addition, Grades of A+ and A—, B+ and B—, C+ and C—, and D+ may, where appropriate, be used for undergraduates only.

In certain designated courses (see page 203), the grade of "P" indicating Pass may be given, but it is not counted in computing the grade-point average of an undergraduate student. The grade of "H" is given for satisfactory completion of freshman honor elective courses.

"Conditions" indicate deficiencies that may be made up without actually repeating the subject. A grade of "D" is given when the work is completed.

The grade *"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

*Except that C— is considered poor.

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

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 units for honor elective courses are not in-

*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.

cluded in computing grade-point average. A grade of Pass may be given for courses numbered 200 or greater, Ph 172, research conferences, and undergraduate research. A grade of Pass or Fail is always given in the laboratory course EE 90.

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 under the same regulations that apply to adding courses.

(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.

If you wish to take advantage of this opportunity, please process the *Pass-Fail Course Selection Card* as indicated. These grades are not used in computing the grade-point average. Grade-point averages are not computed for freshmen.

Ineligibility for registration. Freshmen who receive no "Fail" grades 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 "Fail" grades 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 205.)

(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 whose grade-point average is 2.3 or more. 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*

*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 Humanities.
Division of Physics, Mathematics and Astronomy.

may, at the discretion of his department, be refused permission to continue the work of that option. (See note at head of each option in schedule of undergraduate courses, for special departmental applications of this rule.) 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 prescribed work in one of the options with a passing grade in each required subject and with a grade-point average of 1.9. A grade of "F" in an elective course need not be made up, provided the student has received passing grades in enough other accepted units to satisfy the minimum total requirements of his option. In addition to the above requirement, a member of the Air Force ROTC unit must satisfactorily complete the basic course unless relieved of this obligation by the Air Force. If a member of the AFROTC has entered the advanced course or if he has at any time at the California Institute secured deferment under Selective Service by reason of his membership in the AFROTC, he must satisfactorily complete the AFROTC course and must accept a commission in the Air Force if one is offered unless excused from these obligations by action of the Air Force.

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 45 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. A list of these students attaining Honor Standing on the basis of their academic records 1966-67 appears on page 394.

Graduation with honor. Graduation *with honor* will 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.

*No honor standing will be granted for the freshman class since grades in all freshman courses are only "P," indicating passed, or "F," indicating failed.

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 Advisor and the approval of the Undergraduate Academic Standards and Honors Committee. Master's candidates, see page 232. Petitions to carry excess units will not be accepted later than the last day of pre-registration.

Registration for fewer than 36 units must be approved by the Undergraduate Academic Standards and Honors Committee. See page 226 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 acceptable. 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 advisor 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 45 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.

STUDENT HEALTH AND PHYSICAL EDUCATION

PHYSICAL EDUCATION

Starting with the freshman year, all undergraduate students are required to enroll in and successfuly 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 193). 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 vacation periods (Thanksgiving, Christmas, and spring recesses) and 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 by a Health Fee. During the summer, a special health fee of $9.00 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. Supplementary fees are charged for certain services during the summer months only.

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. Workmen'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 freshmen and transfer students, there is a $10.00 Registration Fee payable upon notification of admission, not refundable if admission 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.

ANNUAL EXPENSE SUMMARY

Tuition (3 terms)		$2,100.00	
General Deposit		25.00	$2,125.00
Health Fee		40.00	
Student Body Dues, including *California Tech*		22.00	
Asesssment for Big T		6.00	68.00
Books and Supplies (approx.)			130.00
Student House Living Expenses (21 meals per week)			
Board	$665.00		
Room[1]	435.00	$1,100.00	
Dues		30.00	1,130.00
			$3,453.00

The following is a list of undergraduate student expenses at the California Institute of Technology for the Academic Year 1968-69, together with the dates on which the various fees are due. These charges are subject to change at the discretion of the Institute.

	First Term	*Fee*
September 26, 1968	General Deposit	$ 25.00
Freshmen	Tuition	700.00
September 30, 1968	Board and Room	397.00
All Others	Health Fee	40.00
	Incidental Fees:	
	Associated Student Body Dues	7.00
	Assessment for *Big T*	2.00
	Student House Dues	10.00
	Second Term	
January 6, 1969	Tuition	700.00
	Board and Room	359.00
	Incidental Fees:	
	Associated Student Body Dues	7.50
	Assessment for *Big T*	2.00
	Student House Dues	10.00
	Third Term	
March 31, 1969	Tuition	700.00
	Board and Room	344.00
	Incidental Fees:	
	Associated Student Body Dues	7.50
	Assessment for *Big T*	2.00
	Student House Dues	10.00

Tuition Fees for fewer than normal number of units:

Over 35 units	Full Tuition
Per unit per term	$ 20.00
Minimum per term	$200.00
Auditor's Fee (p. 200)	$30.00 per term, per lecture hour

[1]There are a few single rooms available which will rent for $500.00 per year. Rates for room and board are subject to revision prior to August 1st of any year.

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] No portion of the Student Body Dues, or subscription to *California Tech,* is refundable upon withdrawal at any time. Room contracts are for one year except for Seniors who may contract for one term. 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 $22.00 are payable by 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 $2.00 per term 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 180). All applications shall be accompanied by a $50.00 deposit.

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.

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]Pro 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.

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's graduation, interest is charged at the rate of 3 percent per annum, but no repayment on 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 per cent 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 221.

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 263.

Students with exceptional financial need may qualify for an Educational Opportunity Grant which was authorized by the Higher Education Act of 1965. To qualify, students must either be accepted for enrollment or be in good standing at the Institute, yet be financially unable to attend without an opportunity grant. The amount of financial assistance a student may receive depends upon his need taking into account his financial resources, those of his parents, and the cost of attending the Institute. First-year grants range from $200 to $800 and cannot be more than one-half the amount of assistance the student receives from other sources such as National Defense Student Loans or state or private scholarships. A grant may be increased by $200 for any student ranking in the upper half of his class during the preceding year.

3. The Higher Education Act of 1965 also contains provisions for student assistance through state and private non-profit insured loan programs (Title IV, Part 3). The California State Scholarship and Loan Commission guarantees loans ranging from $300 to $1,000 to California resident students. Students from out of state may apply for a loan directly to their own state agency.

If a student's adjusted family income is less than $15,000 a year, the federal government pays to the lender the entire interest charge up to 6 percent a year on the unpaid balance while the student is in school and 3 percent interest during the repayment period.

The terms and conditions of this program vary from state to state. Generally undergraduate and graduate students may borrow from $1,000 to $1,500 per year for at least six academic years.

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 rate of 7½ percent per annum payable quarterly. The interest is the only payment made on this plan during the undergraduate years. On November 1 following his class's graduation the student commences repayment on the deferred portion at the rate of $85.00 a month including interest at 7½ percent 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 $6,000).

Entirely aside from loans and the Deferred Payment Plan another source of aid to the student is a monthly budget payment program permitting payments of from one to four years educational expense over periods as long as 60 months in amounts up to $14,000. The plan is administered by Educational Funds, Inc., 10 Dorrance Street, Providence, Rhode Island 02901.

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 Admissions 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 the 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 217-221.

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 where 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 190. 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 190) 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.

Parents' Confidential Statement forms must be sent to the appropriate College Board office not later than February 15 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.*

HONORARY SCHOLARSHIPS

In addition to the above, there are three honorary awards which carry stipends. The Sloan Scholarships, the General Motors Scholarships, and the California Institute National Prize Scholarships described on following pages are given without consideration of financial need. All applicants for admission are automatically considered for these scholarships. Only when need exists is it necessary to file a *Parents' Confidential Statement* in connection with these awards.

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 honorary scholarships and 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 other 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 in general expected 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. Most awards are for full or part tuition. When individual scholarships carry amounts in excess of full tuition, 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 may 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. Grants from these funds are usually for full tuition, or less if the need of the recipient is less. 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. For Honorary Scholarships see above.

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 Institute National Prize Scholarships: Seven National Prize Scholarships not related to need and amounting to $1000 for the freshman year may be awarded at the discretion of the Admissions Committee.

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.

Crown Zellerbach Foundation Scholarships: The Crown Zellerbach Foundation of San Francisco provides two scholarships of $1200 each for juniors or seniors majoring in a science option.

Cyprus Mines Corporation Scholarships: The Cyprus Mines Corporation of Los Angeles gave $1000 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.

Douglas Aircraft Company Scholarship: The Douglas Aircraft Company of Los Angeles made provision for a $1500 scholarship to be awarded to a junior or senior in engineering or physics, in that order of preference.

Drake Scholarships: Mr. and Mrs. A. M. Drake of Pasadena made provision 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.

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 the holder's grades and conduct remain satisfactory.

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 provision 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.

Hewlett-Packard Scholarship: The Neely Sales Region of Hewlett-Packard gave $2000 for undergraduate scholarships with preference to be given to sophomores.

The Holly Scholarship: The Holly Manufacturing Company has established a half-tuition scholarship to be awarded to a senior in the engineering option.

The International Nickel Company Scholarship: The International Nickel Company of New York established a four-year scholarship of $1900 a year for a student entering the freshman year in 1962, and another four-year award for a student entering in 1966.

Earle M. Jorgensen Scholarship: Mr. Earle M. Jorgensen has made possible the award of two 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.

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 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 National Engineering 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. 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. Not open to freshmen.

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.

Dorothy D. and Seeley G. Mudd Scholarship: Members of the family of Mrs. Dorothy D. and Dr. Seeley G. Mudd have given a fund for undergraduate scholarships in their names.

Seeley Mudd Scholarships: The Seeley W. Mudd Foundation of Los Angeles provided funds for scholarships to cover non-tuition expenses of a student in the geology option and a student in the engineering 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 differences 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.

Procter and Gamble Scholarship: The Procter and Gamble Fund provides a four-year undergraduate scholarship covering tuition and certain other expenses. This four-year award is open to entering freshmen only.

Radio Corporation of America Scholarship: The Radio Corporation of America provided funds for an $800 undergraduate scholarship.

Alfred P. Sloan National Scholarships: The Alfred P. Sloan Foundation of New York established at the California Institute a minimum of six scholarships to be awarded to entering freshmen without restriction as to the field of study to be pursued. Original selection of the holders of these scholarships is made without regard to financial need. Once selection has been made, awards will range from a prize scholarship of $200 per year for students not in need of financial assistance to amounts as high as $2400 per year to those whose need warrants such consideration. Holders of these scholarships may expect them to be renewed in each of the three upperclass years provided the conduct and grades of the holders remain satisfactory.

Standard Oil Company of California Scholarships: The Standard Oil Company of California provided two scholarships for undergraduates majoring in engineering.

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.

Systems Technology Scholarship: Systems Technology, Inc. has provided money for an undergraduate scholarship.

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.

Western Electronic Manufacturers Association Scholarship: Western Electronic Manufacturers Association of Los Angeles provided for one or more scholarships for junior and senior students in engineering. The purpose of these scholarships is to promote interest in the electronics field.

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
Crown Zellerbach Foundation
Cyprus Mines Corporation
Douglas Aircraft Company, Inc.
General Motors Corporation
Goodyear Foundation, Inc.
International Nickel Co., Inc.
Kennecott Copper Corporation
Lockheed Leadership Fund
The Procter & Gamble Fund
Radio Corporation of America
Alfred P. Sloan Foundation
Texaco Inc.

4. Student Aid Loan Funds

(See also page 212)

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 212-214. 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
Eugene Kirkeby Loan Fund
The Gustav D. Koehler Loan Fund
Private John Larrecq 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

(See page 213)

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 pages 213-214.

STUDENT EMPLOYMENT

The Institute tries to help students to find suitable employment when they cannot continue their education without thus supplementing their incomes. The requirements of the courses at the Institute are so exacting, however, that under ordinary circumstances students who are entirely or largely self-supporting should not expect to complete a regular course program satisfactorily in the usual time. It is highly inadvisable for freshman students to attempt to earn their expenses. Students wishing employment are advised to write, before coming to the Institute, to the Director of Placements.

PLACEMENT SERVICE

The Institute maintains a Placement Office under the direction of a member of the Faculty. With the services of a full-time staff, this office assists graduates and undergraduates to find employment.

Interviews with candidates for the Ph.D. degree are arranged during any term. Interviews with candidates for other degrees are arranged during the second and third terms. Students, both graduate and undergraduate, wanting part-time employment during the school year or during vacations, should register at the Placement Office. Assistance will be given whenever possible in securing employment for summer vacations. Alumni who are unemployed or desire improvement in their positions should register at the Placement Office.

A large number of brochures published by industrial organizations and government agencies are available. These show placement opportunities in the fields of science and engineering. The Director of Placements is always available for consultation and guidance on placement problems.

The Placement Office maintains information on fellowships and scholarships offered by universities, foundations, and industry throughout the world.

It should be understood that the Institute assumes no responsibility in obtaining employment for its graduates, although the Placement Office will make every effort to find 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 welfare of 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 a public contest. The contest is under the direction of representatives of the Division of the Humanities.

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.

TRAVEL PRIZE

Each year those juniors who are in the top 15-20% of their class, scholastically, are eligible to compete for a Travel Prize. This prize provides funds for the winners (about three annually) to travel during the summer between their junior and senior years almost anywhere to pursue individual vocational or avocational interests.

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.

Section IV

INFORMATION AND REGULATIONS FOR THE GUIDANCE OF GRADUATE STUDENTS

A. General Regulations

I. REQUIREMENTS FOR ADMISSION TO GRADUATE STANDING

1. The Institute offers graduate work leading to the following degrees: Master of Science, after a minimum of one year of graduate work; Aeronautical Engineer, Civil 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.

2. 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.

3. At the graduate level the California Institute of Technology accepts applications from both men and women. 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. 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. Students applying for assistantships or fellowships (see page 258) need not make separate application for admission to graduate standing, but should submit their applications before February 15. For requirements in regard to physical examination, see pages 193 and 208.

4. 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.

5. Students from non-English speaking countries are expected to read, write and speak English and comprehend the spoken language. 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 the International Desk. Students who

wish to test their knowledge of English are encouraged to take the Test of English as a Foreign Language (TOEFL). For information, write to Educational Testing Service, Princeton, New Jersey 08540.

6. Special students, not working for degrees, are admitted only under exceptional circumstances.

II. GRADUATE RESIDENCE

1. 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 larger number of units in any one term will not be regarded as increasing the residence. See pages 228, 232 for special requirements for residence.

2. 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 graduate student.

3. Graduate students expecting to receive a degree will be required to maintain their admission status until the degree is obtained, either 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 the degree may be conferred.

4. 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 19. 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 $200 if Ph.D. or engineer's degree thesis requirements are completed during the summer.

III. REGISTRATION

1. 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.

2. 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.

3. The number of units allowed for a course of study or for research is so chosen that one unit corresponds roughly to one hour a week of work throughout the term for a student of superior ability.

4. 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 regular assignment card for the course, obtained on registration. *The student himself is charged with the responsibility of making certain that all grades to which he is entitled have been recorded.*

5. 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.

6. 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 the research does not justify the full number originally registered for.

7. 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 prior approval therefor 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.

8. Registration, with at least minimum tuition (see page 231), 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 thesis. Registration with minimum tuition will be allowed for at most one term, except for summer registration.

9. A graduate student doing unsatisfactory work may be declared ineligible to register at the beginning of any term.

10. 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.

IV. GRADES IN GRADUATE COURSES

1. 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.

2. Grades for all graduate work are reported to the Registrar's office at the close of each term.

3. 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 201), 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.

V. TUITION AND OTHER FEES

The tuition charge for all students registering for graduate work is currently $2,100 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 $20 a unit for fewer than 36 units with a minimum of $200 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 208. A summer fee of $9 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 any 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.

Information regarding fellowships, scholarships, and assistantships is discussed on page 258 of the catalog. Students of high scholastic attainment may be awarded graduate scholarships covering the whole or a part of the tuition fee. Loans may also be arranged by making an application to the Scholarships and Financial Aid Committee.

Graduate students are eligible to borrow from certain funds under the jurisdiction of the Committee on Student Aid (see page 263).

Graduate students are eligible for membership in the Associated Student Body of Caltech, pursuant to the By-Laws thereof. Dues are $22.00 annually (see page 182).

VI. OPTION REPRESENTATIVES

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 1968-69 are as follows:

Mathematics: Prof. R. P. Dilworth
Physics: Prof. Ward Whaling
Astronomy: Prof. J. B. Oke
Geology: Prof. A. L. Albee
Biology: Prof. R. S. Edgar
Chemistry: Prof. R. E. Dickerson
Chemical Engineering: Prof. C. Pings
Electrical Engineering: Prof. R. W. Gould
Aeronautical Engineering: Prof. E. E. Sechler
Other Engineering: Prof. F. S. Buffington
Applied Mathematics: Prof. G. B. Whitham

GRADUATE EXPENSES

Tuition (3 terms)	$2,100,00	
General deposit	25.00	
Health Fee	40.00	$2,165.00
Books and Supplies (approx.)		80.00

Graduate House Living Expenses (see page 257 for details)

[1]Room—$436.50 to $504.00 per academic year (Rates are subject to revision prior to August 1 of any year)

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

		Fee
	First Term	
September 30, 1968	General Deposit (see page 212)	$ 25.00
	Tuition	700.00
	Health Fee	40.00
	Second Term	
January 6, 1969	Tuition	700.00
	Third Term	
March 31, 1969	Tuition	700.00
[2]Summer Accident Insurance Fee		9.00

Tuition fees for fewer than normal number of units:

Over 35 units	Full Tuition
Per unit per term	$ 20.00
Minimum per term	200.00

Auditor's Fee (p. 200) .... $30.00 per term, per lecture hour

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% and a pro rata charge of time in attendance.

B. REGULATIONS CONCERNING WORK FOR THE DEGREE OF MASTER OF SCIENCE

1. 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. Regulations governing registration will be found on page 227.

[1]Room rent is billed one month in advance and is payable upon receipt of the monthly statement.

[2]An Accident Insurance Fee of $9.00 will be charged to all students taking summer research who were not enrolled during the previous academic year.

2. *Residence.* At least one academic year of residence at the Institute (as defined on page 227) 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. A student will not, in general, be admitted to graduate standing until he has completed work equivalent to that required for the bachelor's degree.

To qualify for a master's degree, a student must complete the work indicated in the schedule of first-year graduate courses (see pages 283-294) 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.

3. *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. 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.

4. *Special Requirements for the Master's Degree*

(a) Students admitted to work toward the master's degree in the Division of Chemistry and Chemical Engineering are required to take placement examinations. See pages 285-286.

(b) Students admitted to work toward the degree of Master of Science in Electrical Engineering are required to take a placement examination in the subject of engineering mathematics and complex variables. This examination is given on the Friday of the week preceding registration, and will be concerned primarily with subject matter of the undergraduate course, AM95abc. 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 AM113ab, 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.

(c) A written placement examination is required of incoming graduate students in the Division of Geological Sciences. For details see page 248. Candidates for the master's degree in the Division of Geological Sciences should familiarize themselves with, and are expected to meet, certain special requirements concerning basic sciences and field geology. Detailed information on these requirements may be obtained from the Division Secretary.

(d) Students admitted to work toward the master's degree in the Division of Physics, Mathematics and Astronomy are required to take placement examinations to be used as a guide in selecting the proper course of study. See page 251.

(e) In the case of a required thesis two final copies must be filed with the Division concerned ten days before the degree is to be conferred. Instructions for the preparation of theses may be obtained from the respective departments.

C. Regulations Concerning Work for the Engineer's Degree

1. 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 226. Regulations governing registration will be found on page 227. 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.

2. *Residence.* At least six terms of graduate residence (as defined on page 227) 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 grade-point 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.

3. *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 cer-

tify to its satisfactory completion. One of the members of the committee must be in a field outside of 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.

4. *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.

5. *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.

Special Requirements for the Degree of Aeronautical Engineer. In the program for this degree, not less than 60 units shall be for research and thesis. The thesis may consist of the results of a theoretical and/or experimental investigation or may be a literature survey combined with a critical analysis of the state-of-the-art in a particular field.

Special Requirements for the 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 on page 247.

Special Requirements for the Degree of Mechanical Engineer. Each student admitted to work for the degree of Mechanical Engineer shall meet with a committee before registration for the purpose of planning the student's work.

Not less than a total of 55 units of this work shall be for research and thesis, the exact number of units to be left to the discretion of the supervising committee appointed by the Dean of Graduate Studies. 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 each candidate shall be determined by the supervising committee, but 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 will be found on page 291.

D. Regulations Concerning Work for the Degree of Doctor of Philosophy

I. GENERAL REGULATIONS

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 238-257.

With the approval of the Committee on Graduate Study, any student studying for the doctor's degree 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.

II. REQUIREMENTS FOR ADMISSION TO WORK FOR DOCTOR'S DEGREE

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.

III. GENERAL REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

1. *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 and engineering, called the major program of study; and of additional advanced work outside of this branch, called the minor 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 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 either 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 238-257, 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 item 5, page 238). 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.

2. *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 227 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.

3. *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 238-257. 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.

4. *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 236) 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.

5. *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. This 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 examinations, see pages 238-257.

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.

6. *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 238-257.

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 others. In any case, however, a substantial portion of the thesis must be the candidate's own exposition of his work. For regulations regarding use of "classified" material see page 234.

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.*

IV. SPECIAL REQUIREMENTS FOR THE DOCTOR'S DEGREE

In agreement with the general requirements for the doctor's degree adopted by the Committee on Graduate Study, as set forth in III, page 236, the various divisions of the Institute have adopted the following supplementary regulations.

DIVISION OF BIOLOGY

1. *Aims and Scope of Graduate Study in Biology.* Graduate students in biology come with very diverse undergraduate preparation—majors in physics,

chemistry, and mathematics, as well as in biology and its various branches. The aims of the graduate program are to provide, for each student, depth of experience and competence in his particular chosen major specialty; perception of the nature and values of biology as a whole; sufficient strength in the basic sciences to allow him to continue self-education after his formal training has been completed and keep in the forefront of his changing field; and the motivation and training to serve that field productively through a long career. In accordance with these aims the graduate study program in biology leading to the doctor's degree 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,* 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 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.

2. *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 of the Biology Division is diverse, and in particular fields such as psychobiology 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 the Biology Division.

3. *Placement Examinations.* All students admitted to graduate work toward the Ph.D. in the Division of 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.

4. *Advisory Committee.* During the week preceding registration for the first term, each entering student confers with his Advisory Committee. The com-

mittee 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. Its chairmanship and constitution may, however, change as the student ascertains the subject of his specialization or changes it. Such changes are readily made.

5. *Teaching Requirements for Graduate Students.* All students must acquire some teaching experience.

6. *Major Subjects of Specialization.* A student may pursue major work leading to the doctor's degree in the Division of Biology in any of the following disciplines:

Biochemistry	Genetics
Biophysics	Neurophysiology
Cell Biology	Plant Physiology
Developmental Biology	Psychobiology

7. *Minor Subjects.* A student majoring in one of the above disciplines may elect to take a minor in any of the following ways, subject to the approval of his advisory committee: (a) a subject minor in another discipline of biology, which must be markedly different in content and techniques from the major; (b) a subject minor in another division of the Institute, or (c) a general minor consisting of not less than 45 units of advanced course work in one or more disciplines in the humanities, sciences (other than biology), or engineering. When a student takes a subject minor, his degree designates the disciplines of his major and minor (e.g., Biophysics and Psychobiology or Cell Biology 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.

A student majoring in another division of the Institute may, with the approval of the Biology Division and his major division, elect a subject minor in any one of the disciplines listed in section 6. The requirements for such a minor consist of (a) passing the placement examination in cell biology or organismic biology, and (b) passing the qualifying examination in the discipline elected. There is no program for a minor in General Biology, but 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 arrange to have his minor designated as Biology rather than with the name for his minor discipline. The Institute's general requirements for major and minor programs of study are noted on pages 236-238.

8. *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 subject minor in the Biology

Division is required to pass a candidacy examination in the minor field with a grade 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.

Students majoring in other divisions and electing a subject minor in the Biology Division see paragraph 2 of section 7 above.

9. *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 corrections, 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. 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.

DIVISION OF CHEMISTRY AND CHEMICAL ENGINEERING

1A. *Chemistry.* On Monday and Tuesday of the week preceding General Registration for the first term of graduate study, graduate students admitted to work for the Ph.D. degree will be required to take three written placement examinations, one each in the fields of physical chemistry, organic chemistry, and inorganic/analytical chemistry. An optional fourth examination in chemical physics is available for those interested in this field (see sec. 1B). 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 the student possesses an understanding of general principles and a power to apply these to specific problems, rather than a detailed informational knowledge. Graduate students are expected to demonstrate a proficiency in the subjects of the first three examinations 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.

In the event that a student fails to show satisfactory performance in one or more of the placement examinations he may be required to register for a prescribed course, or courses, in order to correct the deficiency promptly. In general no graduate credit will be allowed for these prescribed courses. These courses must be completed in a satisfactory manner before the graduate student can be admitted to candidacy.

To be recommended for candidacy for the doctor's degree in chemistry the applicant, in addition to demonstrating his understanding and knowledge of the fundamentals of chemistry, must give satisfactory evidence of his proficiency at a higher level in that field of chemistry elected as his primary field of interest and approved by the Division of Chemistry and Chemical Engineering. In general the applicant will be required to pass an oral examination and to submit to his examining committee and to the Divisional graduate secretary not less than one week prior to his examination (1) a written progress report giving evidence of his industry and ability in research and of his power to present his results in clear, concise language and with discrimination as to what is essential in scientific reports, and (2) three propositions (as described under 5 below) which the applicant is prepared to defend during his oral examination.

In the event that any of the candidate's propositions is found to be unsatisfactory he will not be recommended for candidacy at that time, but will be required to submit and defend a set of new or revised propositions at an examination to be taken at least three terms prior to his final examination.

The divisional language requirements must also have been completed before admission to candidacy is complete.

Candidacy examinations are normally taken during the fifth term of graduate residence at the Institute. A student admitted to work for the Ph.D. degree in chemistry who fails to satisfy the requirements for candidacy, including languages and placement examination remedial courses, by the end of his sixth term of residence will not be allowed to register in subsequent terms except by special permission of the Division of Chemistry and Chemical Engineering. This permission, to be requested via 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.

1B. *Chemical Physics.* Students working for the Ph.D. degree in chemistry may elect to do research in chemical physics. Except for the differences mentioned below, all of the requirements regarding graduate students in chemistry are applicable to students who wish to work in the field of chemical physics.

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. These students must also take the placement examinations in inorganic, organic, and physical chemistry.

Students taking the chemical physics examination may, with permission, satisfy a placement examination deficiency in one other field by demonstration of proficiency in the chemical physics examination. Students who choose chemical physics as their primary field of interest will, in general, take a larger fraction of their graduate courses in mathematics and physics than students in other fields of chemistry.

1C. *Chemical Engineering.* 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 professors 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 allowed to take advanced courses; these courses include the Ch.E. 200-series along with other courses taught throughout the Institute.

To be recommended for candidacy the student must demonstrate proficiency at a graduate level in chemical engineering. This will be done in chemical engineering courses and in 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 three propositions and a written progress report on his research to his examining committee. The examination will cover the progress report and propositions. 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.

Applicable to All Chemistry and Chemical Engineering Students

2. 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 in the student's field of interest. 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.

3. 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. If a student elects a minor program of study of the general type, 45 units or more of advanced work are required and must represent an integrated program approved by the Division; for students in chemistry it must consist of courses other than chemistry; 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.

4. 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 proofread. One must be either the original ribbon copy or an electrostatic copy on 20-pound bond paper; the other may be an electrostatic vellum copy reproduced from the original. In addition, one reproduced copy, corrected after proofreading by the Graduate Office, is to be submitted to the Divisional Graduate

Secretary for the Divisional library. All reproduced copies may be either an electrostatic bond copy (Xerox or similar) or an electrostatic vellum (Xerox or similar).

5. The final examination will consist in part of the candidate's oral presentation and defense of a brief résumé of his research and in part of the defense of a set of propositions prepared by the candidate.

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 the candidate's 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, 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.

Chemistry as a Minor Subject

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.

Division of Engineering and Applied Science

1. *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 cancelled.

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.

2. *Applied Mechanics, Engineering Science, Materials Science, and Mechanical Engineering.* To be recommended for candidacy for the Ph.D. degree in Applied Mechanics, Engineering Science, Materials Science, or Mechanical Engineering, 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 relevant faculty in applied mechanics, engineering science, materials science, or mechanical engineering. If any course submitted for candidacy was taken elsewhere than at the Institute, the student may be required to pass special examinations indicating a satisfactory knowledge of the subject.

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 relevant faculty in applied mechanics, engineering science, materials science, or mechanical engineering. Such courses shall be in addition to requirement (b) above.

d. Complete at least 45 units of advanced courses in a single field (subject minor) as arranged by the student in conference with his advisor and approved by the relevant faculty in applied mechanics, engineering science, materials science, or mechanical engineering, and the faculty concerned with the subject minor, or 54 units in several fields (general minor) with faculty approval. The minor requirement may be satisfied in any one of the following ways: (i) a subject minor in another division of the Institute; (ii) a subject minor in another discipline of engineering, which must differ markedly in content from the major; (iii) a general minor consisting of courses listed as *Advanced Subjects* in the catalog, in one or more disciplines in the sciences, engineering, or the humanities.

A portion of the courses in a general minor should preferably be outside the Division of Engineering; the course used to satisfy the mathematics requirement (c) above may not be included. Courses for either a subject minor or a general minor may be included only if they differ from the field of the student's thesis research. The diploma designates the disciplines of both the major and the minor if the requirements for a subject minor have been satisfied. If a general minor is selected and approved, the diploma designates only the major discipline.

e. Pass an oral examination on the major subject, and if the student has a subject minor, examination on the subject of that program shall be included.

The student is encouraged to discuss with his advisor the desirability of taking foreign languages, which may be included in a general minor with the proper approvals. Foreign languages are not required.

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.

A student majoring in another branch of engineering, or another division of the Institute, may, with the approval of the relevant faculty in applied mechanics, engineering science, materials science, or mechanical engineering, elect a discipline in one of these fields as a minor subject, consisting of a group of courses that differ markedly from the major subject of study or research.

3. *Civil Engineering.* 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, in addition to general Institute requirements:

a. Pass the qualifying examination described above.

b. Pass a candidacy oral examination on the major subject, and minor subject (if the student has elected a subject minor).

c. Submit a satisfactory written progress report on his thesis research.

d. Pass the courses required for the M.S. degree (except Humanities elective) and other advanced courses as required by the staff.

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, AM 113 abc will be an acceptable substitution for the mathematics requirement.

Minor. 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 completion of at least 45 units of advanced courses arranged by the student in conference with his advisor, and approved by the faculty in civil engineering, in one of the three following ways:

(i) a subject minor in another division of the Institute;

(ii) a subject minor in another discipline of engineering, which must differ markedly in content from the major subject; or

(iii) a general minor consisting of courses listed as *Advanced Subjects* in the catalog in one or more disciplines; a portion of such courses should preferably be 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.

4. *Electrical Engineering.* 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 advisor.

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. Complete at least 45 units of advanced courses in a minor field. 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 with a grade of C or better one of the following subjects:

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.

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 one month after the doctoral thesis has been presented in final form, and prior to its approval.

Division of Geological Sciences

The following statement summarizes the regulations governing the doctoral program.

1. *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.

2. *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.

Each member of the Division faculty serves as an advisor to a small number of graduate students. Each graduate student will be notified, prior to his arrival, who his advisor will be, and prior to registration day the student should seek the counsel of his advisor in planning his program for each term. If the student has, or develops, an interest in a particular field, he should also consult with staff members in that field concerning his program of study and research.

Well-qualified graduate students are encouraged to apply for National Science Foundation Fellowships, but each student should consult with his advisor prior to making application for, seeking a renewal of, or terminating such a fellowship.

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 advisor 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 even an orientation toward Ph.D. thesis research.

3. *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 (see paragraph 5 following), 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 advisor.

4. *Proficiency in Mathematics.* For good work in most modern earth-science fields, a proficiency in mathematics equivalent at least to that represented by the course AM 113 abc (Engineering Mathematics) is essential. Students will be required to take that course or demonstrate equivalent training. Much higher proficiency is required in some fields, but a lesser proficiency is acceptable in certain fields such as paleontology.

5. *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 — Geophysics
Planetary Science

6. *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 subject. The Division prefers to have its students satisfy the minor requirement by work in other divisions of the Institute as prescribed on page 236 of this catalog. However, the student may propose a subject minor in one of the five fields listed in section 5 above, that is different from the major subject, or he may include Geology Division courses within a minor program of general type, if they are pertinent to an intelligently integrated program. However, Ch 124 ab will ordinarily not be acceptable toward the 45 units of minor work. Students from other divisions can obtain a subject minor in geology by offering a suitable combination of graduate-level Geology Division courses which can be, but need not be, concentrated solely in one of the five fields specified in section 5. All proposed minor programs are subject to review and approval by the Division and the Dean of Graduate Studies.

A proposed minor program for the Ph.D. must be submitted to the staff for preliminary evaluation before the end of the 6th term of residence, and preferably earlier.

7. Additional Requirements for Ph.D.

In Geochemistry: In addition to the general Institute and Division requirements, the candidate for the Ph.D. in Geochemistry must have as a minimum the equivalent of the courses that are required for the undergraduate curriculum in geochemistry. The candidate will be expected to take a minimum of 45 units of advanced courses in chemistry and geochemistry. These same courses cannot be presented to satisfy the requirements for a minor or for a distributed minor.

Substitution for courses equivalent to the undergraduate requirement may be permitted by the Division upon petition. The natures of the substitutions that are permitted will depend upon the abilities and interests of the student.

In Geophysics: Students entering work for a Ph.D. in Geophysics should have completed the following courses or their equivalents: Ph 106 abc, and either Ma 108 abc or AM 113 abc. If a student is not qualified in these courses, or their equivalents, he may have to spend extra time in residence to acquire this training. In addition, Ph.D. candidates in geophysics are required to take Ph 129 abc and 18 units of advanced (200 level) geophysics courses, plus at least 100 units of advanced course work elected from the following disciplines: Electromagnetic Theory, Advanced Mechanics, Geophysics (200 level), Solid Mechanics—Elasticity, Quantum and Solid State Physics, Statistical Physics—Communication Theory, Applied Mathematics—Numerical Analysis, Thermodynamics, Linear Systems—Signal Analysis, Geology (100 and 200 level courses) including the field courses specified in item 3. The study program is subject to approval by the student's advisor and faculty members supervising his work.

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 requirement (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.

8. *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.

9. *Admission to Candidacy.* A student admitted to work for the Ph.D. degree will be required to file with the Division before the end of the ninth term of residence the regular form for application for admission to candidacy with specification of major field, the Ph.D. work, a minor program, and evidence of having satisfied the language requirement.

10. *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 must also prepare a paper for publication embodying the results of his thesis work in whole or in part. He should consult with the member of the staff supervising the major research on the choice of subject and on the scope of the paper.

11. *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.

Division of Physics, Mathematics and Astronomy

The disciplines offered by the Division in which major or minor work may be undertaken, as specified on page 236, are Astronomy, Mathematics, and Physics.

1. PHYSICS

a. *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, and Quantum Mechanics, approximately as covered in Ph 106, Ph 102, and Ph 125. In general, they will be designed to test whether the student possesses an understanding of general principles and a power 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.

b. *Courses Required.* In the statement below of courses required, the following courses are considered:

Ph 201	Analytical Mechanics
Ph 203	Nuclear Physics
Ph 204	Low Temperature Physics
Ph 213	Nuclear Astrophysics
Ph 214	Introduction to Solid State Physics
Ph 216	Introduction to Plasma Physics
Ph 221	Topics in Solid State Physics
Ph 227	Thermodynamics, Statistical Mechanics and Kinetic Theory
Ph 230	Elementary Particle Theory
Ph 231	High Energy Physics
Ph 234	Topics in Theoretical Physics
Ph 236	Relativity
Ph 240	Current Theoretical Problems in Particle Physics
Ay 131	Astrophysics I
or	
Ay 132	Astrophysics II
Ay 133	Radio Astronomy

Note that the three basic graduate courses, 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 (Section c below), 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.

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 in 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.

c. *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, Ph 172, or Ph 173 before taking his candidacy oral examination.

Candidates who have selected a minor subject must pass a special oral examination in their minor subject. It is the responsibility of the candidate to make arrangements for this examination. It should be held as soon as possible after completion of the required course work in the minor.

d. *Admission to Candidacy*. To be recommended for candidacy for the Ph.D. degree in physics, a student must, in addition to the general Institute requirements, pass the written and oral candidacy examinations in physics. 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.

e. *Further Requirements for the Ph.D. Degree*. 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 Section b above. 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.

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 the impossibility of scheduling by the Division of more than one final oral examination per day.

f. *Subject Minor*. A subject minor program in physics (see page 236) will be approved by the minor division if it includes at least 18 units of physics courses, chosen from Ph 205, Ph 209, and the list in Section b above, but excluding 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 but for which reduced units are given to graduate students in physics will be allowed for the subject minor, but 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 arrange for this examination.

2. MATHEMATICS

a. Each new graduate student admitted to work for an advanced degree in mathematics will be given an informal 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.

b. 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.

c. To be recommended for candidacy for the degree of Doctor of Philosophy in Mathematics the applicant must satisfy the general requirements, including language, and pass an oral candidacy examination.

This examination will usually be held at 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 up to date, including independent work done by the candidate during his first year. On the basis of the performance, the examining committee will map out the further program of study of the student and 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.

d. 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 the 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.

e. The final oral examination in mathematics will be held as closely as possible 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.

f. Candidates who have selected a subject minor must pass a special examination in their minor subject. It is the responsibility of the candidate to make arrangements for this examination. It should be held as soon as possible after admission to candidacy and completion of the course work in his minor subject.

g. Subject minor in Mathematics. Students majoring in other fields may take a subject minor in mathematics (see page 236) provided their program consists of 45 units or more units of 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.

3. APPLIED MATHEMATICS

a. *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.

b. *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 Algebra
AMa 105	Introduction to Numerical Analysis
Ma 109	Delta Functions and Generalized Functions
Ma 137	Introduction to Lebesgue Integrals
Ma 143	Functional Analysis and Integral Equations
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 151	Perturbation Methods
AMa 152	Linear and Non-Linear Wave Propagation
AMa 153	Stochastic Processes
AMa 251	Applications of Group Theory
IS 181	Linear Programming

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.

c. *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.

d. *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.

e. *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.

f. *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.

g. *The Minor.* The minor requirement for students majoring in Applied Mathematics will be satisfied by 45 units of study in a field or fields sufficiently far removed from the candidate's major field of study. 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. It should be held as soon as possible after completion of course work in the minor subject.

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.

4. Astronomy

Placement Examinations. Each student admitted to work for an advanced degree in astronomy is required to take the Placement Examinations in physics, page 251, Section 1a, 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, mathematical physics, and astronomy is sufficiently strong to permit advanced study in these subjects. If not, students will be required to pass the appropriate courses.

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 ab, Ay 132 ab, 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. Fields in which subject minors are usually taken include physics, geology, or engineering, dependent on the student's field of specialization. See page 253 for the physics subject minor.

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 ab, Ay 132 ab, Ay 133 ab, Ay 138, and Ay 139, (3) pass an oral examination (see below), and (4) be accepted for thesis research by a staff member. Students in radio astronomy may substitute Ay 234 for Ay 132 b. 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 advisors 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. 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.

E. Living Accommodations for Graduate Students

Housing Facilities. The Institute has four resident houses providing single rooms for 166 male graduate students. These handsome and comfortable residences, located on the 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 from $436.50 to $504.00, 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 available on the campus at present for married graduate students. They should write to the Off-Campus Housing Office, California Institute of Technology, for assistance in finding suitable accommodations in the community.

Dining Facilities. Graduate students are privileged to join the Athenaeum (Faculty Club), which affords the possibility of contact not only with fellow graduate students but also 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 from 7 a.m. to 4 p.m. and 5:30 p.m. to 7:30 p.m.; Saturday and Sunday from 9 a.m. to 1 p.m. and 5:30 p.m. to 7:30 p.m.; serving breakfast, lunch, dinner, and snacks, cafeteria style.

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

F. 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 (see page 263).

In addition to loans, the Deferred Payment Plan is also available to graduate students (see page 263).

I. 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.

II. 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 Scholarship: A fund has been established by Mr. Earle C. Anthony for scholarships 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 scholarships.

Meridan Hunt Bennett Scholarships: The scholarships for graduate students are granted from the Meridan Hunt Bennett Fund as stated on page 217.

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.

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 as 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.

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.

The following prize awards are offered:

The Daniel Guinier Memorial Fellowship for travel in France: Given by Prof. and Mrs. Andre Guinier of Paris, in memory of their son.

Metabolic Dynamics Foundation Award: Given by the Foundation to the graduate student who has contributed most to the field of Homeostatic Control Systems.

III. 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 Woodrow Wilson Foundation, and the Ford Foundation, the following corporations, foundations and individuals contribute funds for the support of Graduate Fellowships which are administered by the Institute:

Atlantic Richfield Company
R. C. Baker Foundation
Bell Telephone Laboratories
The Boeing Company
Douglas Aircraft Company
E. I. du Pont de Nemours Company
Fairchild Camera and Instrument Corporation
Fluor Foundation
General Dynamics Corporation
General Electric Foundation
General Telephone and Electronics Corporation
Gillette Paper-Mate Manufacturing Company
Gulf General Atomic Corporation
Fannie and John Hertz Foundation
Hughes Aircraft Company
International Business Machines Corporation
Kennecott Copper Corporation
Paul E. Lloyd
Lockheed Leadership Fund
Arthur McCallum Fund
North American Aviation, Inc.
Radio Corporation of America
Rand Corporation
Schlumberger Foundation
Shell Companies Foundation
Alfred P. Sloan Foundation
Standard Oil Company of California
John Stauffer
Stauffer Chemical Company
Tektronix Foundation
Title Insurance and Trust Company Foundation
Union Carbide Corporation
United States Steel Foundation
Xerox Corporation, Electro-Optical Systems, Inc.
TRW Systems

A number of governmental units, industrial organizations, educational foundations, and private individuals have contributed funds for the support of fundamental researches 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 292, and note under Engineering Science, page 172.

IV. 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, the conditions being similar to those of Guggenheim Fellowships. The stipend varies with the experience of the Fellow.

Harry Bateman Research Fellowship: In honor of Professor Harry Bateman, the Institute offers a research fellowship in pure mathematics to a candidate holding the doctorate. The recipient will devote the major part of his time to research, but will be expected to teach one course in mathematics. The appointment is normally made for one year, but may be renewed for a second year.

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 Fellowship: A fellowship in theoretical physics established in honor of Dr. Tolman, late Professor of Physical Chemistry and Mathematical Physics.

V. 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 212 and 221, except that the maximum amount which may be borrowed under the NDEA by a qualified graduate student is $2500. The total of loans made to such a student from this source for all years, including any loans made to him as an undergraduate, may not exceed $10,000. Loans and the deferred payment plan may also be used in combination, but the total amount from all sources may not exceed $2500 in any one year of graduate study. Loans from Institute 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 214.

VI. 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

SCHEDULES OF THE COURSES

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]

Students are required to take physical education[2] in each term of the freshman and sophomore years.

KEY TO ABBREVIATIONS

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

1The 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.

2See page 208 for rule regarding excuses from physical education.

SCHEDULES OF UNDERGRADUATE COURSES

FIRST YEAR, ALL OPTIONS

The subjects listed below are taken by all students during their first year. 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	Literature of the Modern World (3-0-6) or An Introduction to Modern Europe (3-0-6) or Modern Themes in United States History (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 may be chosen from Bi 1, Ch 3 ab, E 5 ab, EE 9, Ge 1, Ph 3, Ph 4.

A partial list of other electives available to freshmen includes the following: Ay 1, Bi 2, Bi 3, EE 3, EE 5, Gr 1, IS 10 a, Ph 10 ab, and Freshman Honors (non-credit) all divisions.

HUMANITIES—SOCIAL SCIENCE REQUIREMENTS

The general requirements for graduation are 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 total, 27 units must be in English, En 1 abc if taken in freshman year, En 7 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*: Ec 13, En 12, En 13, En 15, En 20, H 40, H 41, L 1, L 32, L 33, L 35, L 39, L 50, Mu 1, Pl 7, Pl 13.

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 203.

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 (4-0-8)	12	12	12
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 should 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	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 125abc[2]	Quantum Mechanics (4-0-5)	9	9	9
Ay 131 ab[2]	Stellar Atmospheres (3-0-6)	9	9	.
Ay 132 ab[2]	Stellar Interiors (3-0-6)	9	9	.
Ay 133 ab[2]	Radio Astronomy (3-0-6)	9	9	.
Ay 141abc	Research Conference in Astronomy (1-0-1)	2	2	2

[1]For rules governing Humanities electives see page 265. Note special regulation on English, page 265, 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 advisors.

BIOLOGY OPTION

(For First Year see page 265)

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 203.

Only the first term of Freshman Chemistry Laboratory is specifically required for graduation in the Biology Option. None of the freshman or sophomore physics laboratory courses are required for graduation in the Biology Option. Students are urged, however, to take as many of these laboratory course electives as possible.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
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]	16	18	18
		49	51	51

Electives

[1]For rules governing Humanities electives, see page 265.

[2]The following Sophomore electives are recommended* for Biology majors:

Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
Ch 46 a	Experimental Methods of Covalent Chemistry (1-6-0)	7	.	.
Bi 1	Introduction to Biology (3-3-3)	.	9	.
Bi 9	Cell Biology (3-3-3)	.	.	9

*Biology majors not electing Ch 41 abc in the second year are required to take this course in the third year. Biology majors who have not elected Bi 1 and Bi 9 in the first or second year are expected to elect them or approved alternatives in the third or fourth year.

THIRD YEAR

	Humanities Electives[3]	9	9	9
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Bi 6	Organismic Biology (4-8-10)	22	.	.
Bi 110	Biochemistry (4-0-8)	.	12	.
Bi 111	Biochemistry Laboratory (0-8-2)	.	10	.
Bi 122	Genetics (4-0-8)	.	.	12
	Electives[4]	6-12	6-12	16-22
		46-52	46-52	46-52

[3]For rules governing Humanities electives, see page 265.

[4]The courses in Organismic Biology (Bi 6, Bi 8), Biochemistry (Bi 110, Bi 111, Bi 112), and Genetics (Bi 122, Bi 123, Bi 124) respectively are designed to be taken by Biology majors for full credit (34 units in each course-group), although this is not mandatory. Alternatively, electives may, with the approval of the student's advisor, be selected from the following courses (in addition to those recommended for the sophomore year).

Electives

		Units per Term 1st	2nd	3rd
Bi 8	Special Problems in Organismic Biology (units to be arranged)	7-12	.	.
Bi 22	Special Problems (units to be arranged)	x or	x or	x
Bi 106	Introductory Developmental Biology of Animals (2-6-4)	.	12	.
Bi 112	Biochemistry Colloquium (2-0-10)	.	12	.
Bi 114	Immunology (2-4-3)	9	.	.
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)	.	.	6-16
Bi 128	Advanced Microtechnique (1-4-1)	.	.	6
Ch 46 bc	Experimental Methods of Covalent Chemistry (1-6-0)	.	7	7
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 118	General Physiology (3-3-4)	10	.	.
	Electives	27-32	37-42	37-42
		46-51	46-51	46-51

Electives

In addition to those listed for the third year:

Bi 116	Behavioral Biology	.	6	.
Bi 117	Psychobiology (2-4-3)	.	.	9
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 208	Selected Topics in Neurobiology	.	2-3	2-3
Bi 209	Psychobiology Seminar (units to be arranged)	x or	x or	x
Bi 214 abc	Chemistry of Bio-organic Substances (1-0-2)	3	3	3
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	.
Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Ch 144	Advanced Organic Chemistry (3-0-6)	9	9	9
Ch 244	Molecular Biochemistry (3-0-3)	6	6	.
Ge 5	Geobiology (3-0-6)	.	.	9
	Any advanced course offered by another Division, subject to approval by the student's advisor.			

[1]For rules governing Humanities electives, see page 265.

CHEMICAL ENGINEERING OPTION

Any student of the chemical engineering option whose grade-point average in the required chemistry and chemical engineering subjects of any year is less than 1.9 will be admitted to the required chemistry and chemical engineering 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
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
Ph 2 abc	Sophomore Physics (4-0-5)	9	9	9
Ch 41 abc	Sophomore Chemistry (3-0-6)	9	9	9
	Electives in Science or Engineering[1,2,3]	9	9	9
	Electives[4]	9	9	9
PE 2 abc	Physical Education (0-3-0)	3	3	3
		51	51	51

THIRD YEAR

		1st	2nd	3rd
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
ChE 63 abc	Chemical Engineering Thermodynamics (2-0-5)	7	7	7
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ch 114	Quantitative Analysis (2-0-2)	4	.	.
	Electives[1,2,3,4,5]	15-18	21-24	21-24
		47-50	49-52	49-52

FOURTH YEAR

		1st	2nd	3rd
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
ChE 110 abc	Optimal Design of Chemical Systems (3-0-9)	12	12	12
ChE 126 ac	Chemical Engineering Laboratory (7-0-2)	9	.	9
Ch 26 a	Physical Chemistry Laboratory	.	8	.
	Electives[1,2,3,4,5]	18-21	18-21	18-21
		48-51	47-50	48-51

[1]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.

[2]In addition to EE 90, other courses which include circuit analysis, such as EE 5, are recommended.

[3]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.

[4]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.

[5]In addition to approved elective courses listed on page 270, any science and engineering course will be accepted if approved by the advisor. 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.

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 advisor. The student must meet any prerequisites required for a course.

		Units per Term 1st	2nd	3rd
Ch 3 ab	Experimental Chemical Science (0-3-0 or 0-6-0)	.	3-6	3-6
Ch 16	Chemical Instrumentation (0-6-2)	8	.	.
Ch 24 c	Elements of Physical Chemistry (3-0-6)	.	.	9
Ch 46 abc	Experimental Methods of Covalent Chemistry (1-6-0)	7	7	7
Ch 113 ab	Advanced Inorganic Chemistry (3-0-6)	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 (3-3-6)	12	12	.
Ch 129 abc	Structure of Crystals (3-0-6)*	9	9	9
Ch 130	Photochemistry (2-0-4)*	.	.	6
Ch 144 abc	Advanced Organic Chemistry (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 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	Feedback Control Systems (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 1968-69.

CHEMISTRY OPTION

(For First Year see page 265)

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 (4-0-8)	12	12	12
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
	Electives[2,3,4]	15-18	15-18	15-18
PE 2 abc	Physical Education (0-3-0)	3	3	3
		48-51	48-51	48-51

THIRD YEAR

		1st	2nd	3rd
Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ch 46 abc[5]	Experimental Methods of Covalent Chemistry (1-6-0)	7	7	7
Ch 90	Oral Presentation (1-0-1)	2	.	.
Ec 4 ab	Economic Principles and Problems (3-0-3)	.	6	6
L 32 abc[6]	Elementary German (4-0-6)	10	10	10
	Electives[2,3]	9-13	15-19	15-19
		47-51	47-51	47-51

FOURTH YEAR

		1st	2nd	3rd
Ch 26 ab[7]	Physical Chemistry Laboratory (0-6-2)	.	8	8
	Electives[2,3]	47-51	39-43	39-43
		47-51	47-51	47-51

[1]A minimum of 9 units of elective laboratory work is required for the year. Students intending to enter the chemistry option are encouraged, but not required, to elect Ch 3 a and Ch 3 b.

[2]A minimum of 140 units of science and/or engineering electives are required for graduation in the chemistry option and there is an Institute requirement of a minimum of 108 units of humanities and/or social science. Among the science electives must be the prerequisites for Ch 26 ab specified in footnote 7. In addition to the approved science and engineering elective courses listed on pages 272-273 any science and engineering course will be accepted if approved by the advisor.

[3]If Ch 80 units are to be used as electives in the chemistry option, a thesis describing the research or a portion of it and approved by the research director must be submitted in duplicate before May 10 of the year of graduation. No more than 60 units of undergraduate research may be used as chemistry electives without special permission.

[4]If Ch 46 abc is not elected it must be taken in the third year.

[5]If Ch 46 was taken as an elective in the second year, an equivalent number of elective units should be taken in the third year.

[6]May be taken in either third or fourth year. L 33 abc or L 50 abc may be substituted for L 32 abc.

[7]Prerequisites are two terms of EE 90, or EE 9, or equivalent (e.g., suitable physics laboratory courses). Ch 26 ab may be taken in either the third or fourth year.

APPROVED ELECTIVE COURSES FOR THIRD AND FOURTH YEARS IN THE CHEMISTRY OPTION

No more than 60 units of undergraduate research may be used as chemistry electives without special permission. Other courses may be taken as electives provided they are in science or engineering subjects and are approved by the advisor. Students must meet any prerequisites required by a course.

		Units per Term 1st	2nd	3rd
Ch 3 ab	Experimental Chemical Science (0-3-0 or 0-6-0)	.	3-6	3-6
Ch 16	Chemical Instrumentation (0-6-2)	8	.	.
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 ab	Advanced Inorganic Chemistry (3-0-6)	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)	12	12	.
Ch 129 abc	Structure of Crystals (3-0-6)*	9	9	9
Ch 130	Photochemistry (2-0-4)*	.	.	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 abc	Advanced Organic Chemistry (3-0-6)	9	9	9
Ch 145	Advanced Organic Chemistry Laboratory (1-5-1)*	7	.	.
Ch 148	Separation and Identification of Organic Compounds (3-0-3)*	.	6	.
ChE 10	Chemical Engineering Systems (3-3-3)	.	.	9
ChE 63 abc	Chemical Engineering Thermodynamics (2-0-5)	7	7	7
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 10 7abc	Polymer Science (3-0-6)	9	9	9
ChE 172 abc	Feedback Control Systems (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	Biochemistry (4-0-8)	.	12	.
Bi 119	Advanced Cell Biology (3-4-5)	.	12	.
Bi 122	Genetics (4-0-8)	.	.	12
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
Ge 1	Physical Geology (4-2-3)	9	.	.
Ge 130 ab	Introduction to Geochemistry (2-0-4)	6	6	.
Ge 151	Laboratory Techniques in the Earth Sciences (0-5-0)	.	5	.
L 35	Scientific German (0-0-10)	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	.	.

*Not offered in 1968-69.

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

ECONOMICS OPTION

(For First Year see page 265)

SECOND YEAR

Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
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 *	15	15	21
		45	45	45

THIRD YEAR

Ec 126 ab	Money, Income, and Growth (3-0-6)	9	9	.
Ec 120	International Economic Theory (3-0-6)	.	.	9
	Electives, not less than *	36	36	36
		45	45	45

FOURTH YEAR

Ec 121 a	Price Theory (3-0-6)	9	.	.
Ec 122 a	Econometrics (3-0-6)	.	9	.
	Economics Electives *	9	9	18
	Electives, not less than *	27	27	27
		45	45	45

*Students in the Economics option must complete successfully:

a. 54 units of natural science, mathematics or engineering beyond the sophomore year, including 18 units in mathematics.

b. 36 units of Economics, chosen from Ec 98 abc, Ec 111, Ec 112, Ec 115, Ec 116, 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 advisor.

ENGINEERING OPTION

(For First Year see page 265)

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, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 203.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
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
		48-51	48-51	48-51

THIRD YEAR

		1st	2nd	3rd
	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

		1st	2nd	3rd
	Humanities Elective[2] (3-0-6)	9	9	9
E 10 ab or E 11 ab	Technical Presentations (1-0-1)	2	2	.
	Electives[1]	34-40	34-40	34-40
		45	45	45

[1]The electives must include Ec 4 ab and at least 99 units of Engineering Division courses (Ae, AM, CE, EE, 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 engineering 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, it may be included in the 99 unit requirement. Electives must be approved by the student's advisor. A passing grade must be obtained in courses aggregating at least 417 units beyond the freshman year for graduation in the Engineering option.

Courses that may be used to satisfy the engineering 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 (6 units maximum)
EE 90 b	3 units	Laboratory in Electronics (6 units maximum)
EE 90 c	3 units	Laboratory in Electronics (6 units maximum)
EE 91 a	5 units	Experimental Projects in Electrical Engineering
EE 91 b	5 units	Experimental Projects in Electrical Engineering
EE 91 c	5 units	Experimental Projects in Electrical Engineering
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 265.

Note: A student who plans to apply for graduate study at the Institute in some field of Engineering should, before choosing his electives, consult Sections IV and V of this catalog for specific requirements for admission to graduate study in this field.

ENGLISH OPTION

(For First Year see page 265)

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 (4-0-8)	12	12	12
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 *	21	21	21
		45	45	45

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 265)

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 (4-0-8)	12	12	12
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 5. Different courses may be elected with the advice and consent of the student's advisor, 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 265.

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 advisors 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 advisor.

THIRD YEAR

Geology Option

		Units per Term 1st	2nd	3rd
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

		Units per Term 1st	2nd	3rd
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 ab is strongly recommended for geochemists. Other elective subjects include Ay 1, Ma 112, Ch 14, Ch 24 c, 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

		Units per Term 1st	2nd	3rd
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, AMa 105, Ch 21 abc, EE 5.

**Note Second year comments on choice of electives.

FOURTH YEAR

Common to All Options in the Division

		Units per Term 1st	2nd	3rd
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

		1st	2nd	3rd
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 ab, Ge 135, Ge 151. AM 95 abc is strongly recommended.
**Note Second year comments on choice of electives.

Geochemistry Option

		1st	2nd	3rd
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 151, Ge 212, Ge 215, Ph 102 abc, AM 95 abc.
**Note Second year comments on choice of electives.

Geophysics Option

	1st	2nd	3rd
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 265)

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

Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
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 *	21	21	21
		45	45	45

THIRD YEAR

	Electives, not less than *	45	45	45

FOURTH YEAR

H 101	Tutorial **	9	9	9
	Electives, not less than *	36	36	36
		45	45	45

*Students in the History option must complete successfully:

a. At least 54 units of natural science, mathematics, or engineering taken beyond the sophomore year.

b. At least 90 units of History, 27 of which will consist of History 101 Tutorial taken in the senior year. The remaining 63 will consist of courses chosen from among those listed as "Advanced Subjects." They must include 9 units in each of the three following major areas: early European *or* non-Western; modern European; and American. And of these 63 units, 27 must be completed by the end of the junior year.

c. A comprehensive oral examination to be given at the end of the second term of the senior year.

**History 101 Tutorial involves the writing of a research paper. Although students in the History option will take it in their senior year, they are strongly advised to select a subject before conclusion of their junior year.

MATHEMATICS OPTION

(For First Year see page 265)

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed under the division 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 203.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
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 265.

PHYSICS OPTION

(For First Year see page 265)

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 203.

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 (4-0-8)	12	12	12
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

		1st	2nd	3rd
Ph 3	Physics Laboratory (sophomores only)	6[3]	.	.
	(freshmen only)	.	6	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.

		1st		2nd		3rd
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	Introduction to Design (0-9-0)	9	or	9	or	9
ME 3	Materials and Processes (3-3-3)	9	or	9	or	9
ME 17 ab	Thermodynamics (3-0-6)	9		9		.
EE 5	Introductory Electronics (3-0-6)	.		.		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 abc	Experimental Methods of Covalent Chemistry (1-5-0)	6		6		6
L 32 abc	Introductory 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 265.

[3]Students who have successfully completed the former Ph 1 abc laboratory need not register for Ph 3. Ph 3 will not be offered the first term of 1968-69. Students who have failed two or more terms of Ph 1 laboratory must pass Ph 4, which will be offered in the third term.

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
	Electives[4] not less than	23	23	23
		41	41	41

Suggested Electives

Ph 77 ab	Advanced Physics Laboratory	.	6	6
Ph 125 abc	Quantum Mechanics[5] (4-0-5)	9	9	9
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
Ge 171	Applied Geophysics (4-0-6)	.	10	.
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)	.	9	.
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 35	Scientific German (4-0-6)	10	.	.
L 50 abc	Elementary Russian (4-0-6)	10	10	10
L 1 ab	Elementary French (4-0-6)	10	10	.

[4]Students should note that EE 13 abc is prerequisite to most advanced electrical engineering courses, and that Ma 108 abc is prerequisite to most advanced mathematical courses.
[5]To be taken by juniors with permission of the instructor only.

FOURTH YEAR

Ph 77 ab	Advanced Physics Laboratory	.	6	6
	Senior Physics Electives	18	18	18
	Humanities Elective[1]	9	9	9
	Electives	17	17	11
		44	50	44

Senior Physics Electives

Ph 93 abc	Topics in Contemporary 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
Ph 203 ab	Nuclear Physics (3-0-6)	.	9	9
Ph 209 abc	Electromagnetism and Electron Theory (3-0-6)	9	9	9
Ph 213 ab	Nuclear Astrophysics (3-0-6)	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
Ph 231 abc	High Energy Physics (3-0-6)	9	9	9
Ph 236 abc	Relativity (3-0-6)	9	9	.

[1]For rules governing Humanities electives, see page 265.

SCHEDULES OF GRADUATE COURSES

GRADUATE HUMANITIES ELECTIVES

Any Humanities course numbered 100 or higher may be used as a Graduate Humanities Elective. See listings under Advanced Subjects in Economics, English, History, Languages, Philosophy, and Political Science.

AERONAUTICS

Program for degree of Master of Science in Aeronautics

		Units per Term 1st	2nd	3rd
Ae 101 abc	Basic Fluid and Gasdynamics			
or		9	9	9
Hy 101 abc	Fluid Mechanics			
Ae 102 abc	Basic Solid Mechanics	9	9	9
Ae 104	Experimental Techniques	6	.	.
Ae 105 bc	Fluid Mechanics Laboratory			
or		.	6	6
Ae 106 bc	Solid Mechanics Laboratory			
Ae 150 abc	Aeronautical Seminar	1	1	1
	Electives (not less than)	20	20	20
		45	45	45

Program for degree of Aeronautical Engineer

Prerequisite, one year of graduate study covering the equivalent of the above M.S. degree program.

		Units per Term 1st	2nd	3rd
Ae 200 abc	Research in Aeronautics			
or		20	20	20
JP 280 abc	Research in Jet Propulsion			
	Seminar[1]	1	1	1
	Electives[2] (not less than)	27	27	27
		48	48	48

[1]Any advanced seminar such as Ae 208 (Fluid Mechanics), Ae 209 (Solid Mechanics), JP 290 (Jet Propulsion).

[2]Not less than 9 units per term shall be taken in the following subjects: Ae 201 Advanced Fluid Mechanics, Ae 203 Applied Aerodynamics and Flight Mechanics II, Ae 210 Advanced Solid Mechanics.

APPLIED MECHANICS

Program for degree of Master of Science in Applied Mechanics

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar	1	1	1
AM 125 abc	Engineering Mathematical Principles[1]	9	9	9
	Electives as below[2]*	Minimum 54 per year		
	Free electives[3]*	Minimum 27 per year		
	Total	Minimum 135 per year		

Electives

(See Notes 1 and 2 below)

		Units per Term 1st	2nd	3rd
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

[1]With Faculty approval, AM 125 abc may be replaced by Ma 108 abc (Advanced Calculus), AMa 101 abc (Methods of Applied Mathematics I), or other satisfactory substitute.

[2]Substitution for electives listed above may be made with the approval of the student's advisor and the Faculty in Applied Mechanics.

[3]Students are encouraged to consider a Humanities elective as part of their free elective.

*The elective units may be divided among the 3 terms in any desired manner.

ASTRONOMY

Program for degree of Master of Science in Astronomy

Science electives at least 108 units.

Humanities electives at least 27 units.[1]

The choice of astronomy and other science elective courses must be approved by the department. At least 36 units of these 135 units must be selected from Ay 131, Ay 132, Ay 133, Ay 134, Ay 136, Ay 138, Ay 139, Ay 201. Placement examinations in astronomy and physics will be required. See catalog pages 143 and 256. 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.

[1]For information concerning Humanities electives, see page 283.

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 that the student has completed at least one year of residence and 135 units of graduate work, which shall include at least 81 units of professional work at an advanced level and at least 27 units of free electives. He must have 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.

CHEMICAL ENGINEERING

Program for degree of Master of Science in Chemical Engineering

	Units per Term 1st	2nd	3rd
ChE 126 abc Chemical Engineering Laboratory (0-12-3)[1]	15	15	15
Electives,[2] at least	30	30	30
	45	45	45

A minimum of 135 units of graduate subjects, with three terms of graduate registration at the Institute, is required for master's degree. Of the 135 units, 81 must be in advanced professional subjects.

Students admitted to work toward the M.S. degree in chemical engineering will be required to take three placement examinations, one each in industrial chemistry and engineering and applied chemical thermodynamics, one in transport phenomena and equilibrium stage operations of chemical engineering, and another in applied chemical kinetics. (See page 242.) The results of these examinations will form the basis for prescribing any remedial work and serve as a guide for establishing the student's program of study.

[1]The student who has taken any part or all of ChE 126 abc or its equivalent as an undergraduate will substitute an equal amount of research, ChE 280, and must submit a research report in thesis form and have it accepted by the chemical engineering faculty. 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 chemical engineering faculty.

[2]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 the 81 units of advanced professional subjects, AM 113 abc must be taken if the equivalent has not been studied previously.

CHEMISTRY

Program for degree of Master of Science in Chemistry

During the week preceding General Registration for the first term of graduate study, graduate students admitted to work for the M.S. degree 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 and in general will be designed to test whether the student possesses an understanding of general principles and a power to apply these to specific problems, rather than a detailed informational knowledge. Graduate students are 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.

In the event that a student fails to show satisfactory performance in any of the placement examinations, he will be required to register for a prescribed course, or courses, in order to correct the deficiency promptly. In general no graduate credit will be allowed for prescribed undergraduate courses. If the student's performance in the required course or courses is not satisfactory, he will not be allowed to continue his graduate studies except by special action of the Division of Chemistry and Chemical Engineering on receipt of his petition to be allowed to continue.

The needs of chemistry majors vary so widely in specialized fields of this subject that no specific curricula can be outlined. Before registering for the first time, a candidate for the master's degree should consult a member of the Committee on Graduate Study of the Division.

All masters' programs at the Institute require at least one year of residence and 135 units of graduate work, of which 81 units must be at an advanced professional level. For the degree in chemistry, these 81 units must include at least 40 units of chemical research and at least 30 units of advanced courses in science. The remaining 54 units are electives which 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 Chairman of the Division 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.

CIVIL ENGINEERING

Program for degree of Master of Science in Civil Engineering

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; or 4-0-6)[1]	9(or 10)	9(or 10)	9(or 10)
CE 130 abc	Civil Engineering Seminar (1-0-0)	1	1	1
	Electives (minimum total for year, 108)	36	36	36
	Total (minimum for M.S., 138)	46	46	46

Electives

Courses are grouped into five general areas. A program for the M.S. degree should include electives from at least three areas and must be approved by the advisor. 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.

[1]For information concerning Humanities electives, see page 283.

Electives in Structures

Ae 102 abc	Basic Solid Mechanics (3-0-6)	9		9		9
AM 111	Experimental Stress Analysis (1-6-2)	.		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	Dynamics Measurements Laboratory (1-6-2)	9		.		.
CE 121	Analysis and Design of Structural Systems (0-9-0)	.		.		9
CE 124	Special Problems in Structures (3-0-6)	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

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

CE 160	Advanced Hydrology[2]	.	.	.
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[3]			
Hy 112 ab	Hydrologic Transport Processes (3-0-6)	.	9	9
Hy 113	Coastal Engineering (3-0-6)	.	.	9
Hy 121	Advanced Hydraulics Laboratory[2]	.	.	.

Electives in Environmental Health Engineering

CE 141	Applied Aqueous Solution Chemistry (3-3-3)	9	.	.
CE 142 ab	Applied Chemistry of Natural Water Systems (2-3-4)	.	9	9
CE 145 ab	Environmental Health Biology (2-4-4; 2-3-4)	.	10	9
CE 146 abc	Analysis and Design of Environmental Systems (3-0-6)	9	9	9
CE 152 ab	Environmental Radiation (2-3-4)	.	9	9
CE 153	Seminar in Environmental Health Eng. (2-0-1)	.	.	3
CE 156	Industrial Wastes (3-0-6)	.	.	9
CE 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
Bi 107 abc	Biochemistry (3-0-7; 0-8-2)	10	10	10

Electives in Mathematics

AMa 101 abc	Methods of Applied Mathematics	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 (4-0-5)	12		12	12
AM 125 abc	Engineering Mathematical Principles	9		9	9
Ma 112	Elementary Statistics	9	or	9	.

[2]Six or more units as arranged, any term.

[3]Six or nine units as arranged, second or third term.

ELECTRICAL ENGINEERING

Program for the degree of Master of Science in Electrical Engineering

E 150 abc	Engineering Seminar	3 units
	Electives as below[1]	Minimum 102 units
	Free electives[2]	Minimum 27 units
	TOTAL	Minimum 135 units

Suggested Electives[1]

EE 112 abc	Network Synthesis (3-0-6)	9	9	9
EE 113 abc	Modern Optics (3-0-6)	9	9	9
EE 114	Electronic Circuit Design (3-0-6)	.	.	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 162	Stochastic Processes in Communication and Controls (3-0-6)	9	9	.
EE 163 abc	Statistical Communication Theory (3-0-6)	9	9	9
EE 164	Information Theory (3-0-6)	9	.	.
EE 165	Pattern Recognition and Learning (3-0-6)	.	.	9
EE 166	Special Topics in Stochastic Processes (3-0-6)	.	.	9
EE 172 abc	Feedback Control Systems (3-0-6)	9	9	9
EE 174	Control Systems (3-0-6)	9	.	.
EE 175	Optimization in Control (3-0-6)	.	9	.
EE 176	Stochastic Problems in Control (3-0-6)	.	.	9
EE 194	Microwave Laboratory (1-4-4)	.	.	9
EE 225 abc	Solid State Device Theory (3-0-6)	9	9	9
EE 291	Advanced Work in Electrical Engineering	.	.	.
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
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
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
IS 181 ab	Linear Programming (3-0-6)	.	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)	.	9	9
AMa 153 abc	Stochastic Processes (3-0-6)	9	9	9
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
	Other electives as approved by Electrical Engineering faculty.			

Notes

[1]If, as a result of the placement examinations (see page 232), 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.

[2]Students are urged to consider including a humanities course in the free electives.

ENGINEERING SCIENCE

Program for degree of Master of Science in Engineering Science

AMa 101 abc or AM 125 abc or Ph 129 abc	Methods of Applied Mathematics I or Engineering Mathematical Principles or Methods of Mathematical Physics	9	9	9
	Electives as below	18	18	18
	Free Electives (minimum total for year, 54 units)	18	18	18
		45	45	45

Electives

AMa 104	Matrix Algebra	9	.	.
AMa 105 ab	Introduction to Numerical Analysis	.	11	11
AM 135 abc	Mathematical Elasticity Theory	9	9	9
EE 133 abc	Interaction of Radiation and Matter	9	9	9
EE 135 abc	Ferromagnetism	9	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

NOTES

Students in Information Science may substitute Ma 108 abc or AMa 153 abc for the above requirement in applied mathematics.

Substitution for electives listed above may be made with the approval of the student's advisor and the faculty in Engineering Science.

GEOLOGY

Requirements for M.S. Degree in Geology, Geochemistry, Geophysics, and Planetary Science

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 248, and 276-278). 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 advisor, 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.

Only in exceptional cases will the Division permit a student to undertake work leading to an Engineer's Degree in the Geological Sciences. If such instances arise, a program of prescribed study will be worked out with each student on an individual basis.

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 requirements may be satisfied by evidence of equivalent training obtained elsewhere.

MATERIALS SCIENCE

Program for degree of Master of Science in Materials Science

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
MS 104 abc	Materials Science Laboratory (0-6-3)	9	9	9
	Electives as below*[2]	Minimum	48 per year	
	Free Electives*[3]	Minimum	27 per year	
	Total	Minimum	135 per year	

Electives

(See Notes 1 and 2 below)

		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
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 131abc	Introduction to Classical Theoretical Physics II (3-0-6)	9	9	9
MS 101 abc	Physical Metallurgy (3-0-6)	9	9	9
MS 102	Pyrometry (1-6-2)	.	.	9
MS 103 ab	Physical Metallurgy Laboratory (0-9-0) (0-6-0)	9	6	.
MS 104 abc	Materials Science Laboratory (0-6-3)	9	9	9
MS 105	Mechancal 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	Elementary Statistics (3-0-6)	9 or	9	.
ME 101 abc	Advanced Design (1-6-2)	9	9	9

*The elective units may be divided among the 3 terms in any desired manner.

[1]Students who have not had the equivalent of AM 95 abc are required to take AM 113 abc, which may not be included in the non-free electives.

[2]Substitution for electives listed above may be made with the approval of the student's advisor and the Faculty in Materials Science.

[3]Students are urged to consider including a humanities course in the free electives.

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 125 abc	Quantum Mechanics (4-0-5)	9	9	9

MATHEMATICS AND APPLIED MATHEMATICS

As nearly all mathematics and applied mathematics students are working for the doctor's degree, and follow programs arranged by the student in consultation with members of the staff, no specific master's degree curriculum is outlined. Additional information is given on page 157.

MECHANICAL ENGINEERING

Program for degree of Master of Science in Mechanical Engineering

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
	Electives as below*[2]	Minimum	75 per year	
	Free electives*[3]	Minimum	27 per year	
	Total	Minimum	135 per year	

Electives (See Notes 1 and 2 below)

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
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 170	Jet Propulsion Laboratory (0-9-0)	.	.	9
MS 101 abc	Physical Metallurgy (3-0-6)	9	9	9
MS 102	Pyrometry (1-6-2)	.	.	9
MS 104 abc	Materials Science Laboratory (0-6-3)	9	9	9
Ma 112	Elementary Statistics (3-0-6)	9 or	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

*The elective units may be divided among the 3 terms in any desired manner.

[1]Students who have not had the equivalent of AM 95 abc are required to take AM 113 abc, which may not be included in the non-free electives.

[2]Substitution for electives listed above may be made with the approval of the student's advisor and the Faculty in Mechanical Engineering.

[3]Students are urged to consider including a humanities course in the free electives.

MECHANICAL ENGINEERING
(JET PROPULSION OPTION)

Program for degree of Master of Science in Mechanical Engineering

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
JP 120 abc	Thermodynamics of Propulsion Systems	9	9	9
JP 121 abc	Jet Propulsion Systems and Trajectories	9	9	9
	Electives as below*[2]	Minimum 21 per year		
	Free electives*[3]	Minimum 27 per year		
	Total	Minimum 135 per year		

Electives (See Notes 1 and 2 below)

		1st	2nd	3rd
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
ME 126	Fluid Mechanics and Heat Transfer Laboratory (0-6-3)	.	.	9

*The elective units may be divided among the 3 terms in any desired manner.
[1]Students who have not had the equivalent of AM 95 abc are required to take AM 113 abc, which may not be included in the non-free electives.
[2]Substitution for electives listed above may be made with the approval of the student's advisor and the Faculty in Mechanical Engineering.
[3]Students are urged to consider including a humanities course in the free electives.

MECHANICAL ENGINEERING
(NUCLEAR ENERGY OPTION)

Program for degree of Master of Science in Mechanical Engineering

		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 (See Notes 1 and 2 below)

		1st	2nd	3rd
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 151 abc	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	Elementary Statistics (3-0-6)	9	or 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

NOTES

*The elective units may be divided among the 3 terms in any suitable manner.

[1]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.

[2]Electives may include graduate courses from any option, including humanities.

MECHANICAL ENGINEERING

Program for degree of Mechanical Engineer

Specific requirements for the degree of Mechanical Engineer are given on page 234. The following list will suggest possible subjects from which a program of study may be organized:

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
MS 101 abc	Physical Metallurgy (3-0-6)
MS 103 ab	Physical Metallurgy Laboratory
MS 104 abc	Materials Science Laboratory (0-6-3)
MS 112 ab	Advanced Physical Metallurgy
MS 205 ab	Theory of Mechanical Behavior of Metals
MS 217	X-Ray Metallography II
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

MECHANICAL ENGINEERING
(JET PROPULSION OPTION)

Program for degree of Mechanical Engineer (Jet Propulsion Option)

		Units per Term 1st	2nd	3rd
JP 280 abc	Jet Propulsion Research (Thesis)	18	18	18
	Electives (not less than)	30	30	30
		48	48	48

The list of subjects which could be chosen as electives for the sixth-year work is given above.

PHYSICS

Program for degree of Master of Science in Physics

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.

NOTE: Each program must be approved by the Departmental Representative. With his approval, students who have the proper preparation may substitute other graduate courses in science or engineering for some of those listed above.

Section VI

SUBJECTS OF INSTRUCTION

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 including elastic and inelastic behavior. Applications to engineering problems with a critical evaluation of available methods of solution. Instructor: Babcock.

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 areospace 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. Instructors: Harris, Lissaman.

Ae 104. Experimental Techniques. *6 units (3-0-3); first term.* Properties of materials and of mechanical, electrical and electronic devices; design and use of instruments, with emphasis on digital methods. Instructor: Coles.

Ae 105 bc. Fluid Mechanics Laboratory. *6 units (1-3-2); second and third terms. Prerequisite: 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 non-steady gasdynamics, analogies. Instructors: Sturtevant, Coles.

Ae 106 bc. Solid Mechanics Laboratory. *6 units (1-3-2); 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 laws 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. Instructors: Lees, Saffman.

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; hydro foils and gems. Instructor: Lissaman.

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 dimension; Kolosov-Muskhelishvile method of complex variables; integral transforms and integral equation methods. Anistropic 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. Micrometeroid 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 240 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 1968-69 are indicated.

Ae 231. Molecular Theory of Fluid Motion. *(3-0-6); offered second term 1968-69. Prerequisites: Ae 101, AM 125 or equivalent.* Distribution function, characteristic function. Law of large numbers, central limit theorem. Random walk. Fokker-Planck equation. Elementary kinetic theory and application to simple flows. Boltzmann equation and its extension to liquids and plasmas. Krook's model, moment equations, etc. Instructor: Liepmann.

Ae 232 abc. Ionized Gas Theory. *6 units (2-0-4); each term. Prerequisites: Ae 101, AM 95 or equivalent, AM 130 or permission of the instructor.* Introduction to the subject, stressing physical understanding. Review of electromagnetic theory. Elastic binary collisions and collision cross sections. Kinetic theory concepts, distribution functions, average properties. Boltzmann equation. Moment equations for component species and the plasma as a whole. Methods of obtaining a closed set of equations. The Chapman-Enskog procedure for a simple gas. Transport properties of simple gases and mixtures. Coulombic interactions. Debye screening, Fokker-Planck equation. Relaxation processes. Classification of plasmas on the basis of collisional interaction between species. Weakly and fully ionized gases. Discussion of boundary effects, impact and emission phenomena on solid surfaces. The fluid dynamics of collision dominated, weakly ionized gases. Very low density plasma flows. Some aspects of reentry shock and boundary layers, rocket exhausts, satellite-ionospheric interactions. Instructor: Sajben.

Ae 233. Topics in High Temperature Gasdynamics. *9 units (3-0-6); offered first term 1968-69. 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. Instructor: Lees.

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 experiments. Text: *Hypersonic Flow Theory,* Hayes and Probstein. Instructor: Kubota.

Ae 235. Magneto-Fluid Dynamics. *9 units (3-0-6); one term (offered first term 1968-69). 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. Instructor: Shercliff.

Ae 236. Rotating and Stratified Fluids. *9 units (3-0-6); one term. To be offered 1969-70. 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. Instructor: Saffman (not offered 1968-69).

Ae 237. Shock Tube Theory and Techniques. *9 units (3-0-6). 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; various shock tube parameters. Reflected shock waves. Effects of area change. Driver types and characteristics. Non-ideal behavior in shock tubes; diaphragm opening effects, boundary layer effects. Shock tube techniques and measurements. 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. Instructor: Roshko.

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. Magneto-hydrodynamic turbulence. Analytical theory of homogeneous turbulence. Instructor: Saffman.

Ae 239. Turbulent Shear Flows. *9 units (3-0-6); offered third term 1968-69. Prerequisites: Ae 101, AM 113.* Equations of mean motion and review of boundary layer concepts. Similarity arguments for turbulent shear flows and extension to energy processes. Integral methods; single and multi-parameter methods of calculation. Discussion of transition, roughness, heat and mass transfer. Applications in geophysics and astrophysics. Wakes, free shear layers, separated flows. (Subject matter will vary from year to year.)

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 354-355)

Air Force—Aerospace Studies

AS 300 abc. Growth and Development of Aerospace Power. *7 units (3-0-4); three terms. Prerequisite: Satisfactory completion of the six-week Air Force summer field training.* Development of air power, areospace power today and future of manned aircraft in terms of doctrine, technology, organization, and employment; astronautics and space operations, evolution of national space program, planned capabilities for space operations and operating principles, characteristics and problems of space vehicle systems. Instructors: Air Force Staff.

AS 400 abc. The Professional Officer. *7 units (3-0-4); three terms. Prerequisite: AS 300 abc.* Need for and variables affecting leadership, command and staff roles, human behavior and human relations concepts related to Air Force leadership; professional self-discipline, military discipline, principles, and functions of management, problem solving, management tools, practices and controls. Instructors: Air Force Staff.

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: Lagerstrom.

AMa 104. Matrix Algebra. *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: Franklin.

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: Schultz.

AMa 110. Introduction to the Calculus of Variations. *9 units (3-0-6); first term. 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. 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 gas dynamics, water waves, plasma physics, electromagnetism. Not offered in 1968-69.

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. Instructors: Cole, Whitham.

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. Instructor: Knowles.

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 105a, 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. Instructor: Keller.

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 in 1968-69.

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 143	Functional Analysis and Integral Equations
Ma 144	Probability
Ma 205	Numerical Analysis

AM 135	Mathematical Theory of Elasticity I
AM 136	Mathematical Theory of Elasticity II
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
IS 181	Linear Programming
Ph 125	Quantum Mechanics
Ph 209	Electromagnetism and Electron Theory
Ph 227	Thermodynamics, Statistical Mechanics, and Kinetic Theory
EE 163	Statistical Communication Theory

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. Text: *Differential Equations Applied in Science and Engineering,* Wayland. Instructors: Knowles, Wayland, and staff.

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. Instructors: Knowles, Miklowitz, Wayland, and staff.

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. Instructors: Knowles, Shield, Sternberg.

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 in elasticity; elastic instability. Introduction to the nonlinear theory and applications. Instructors: Knowles, Shield, 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. Instructor: Shield. Not offered in 1968-69.

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 viscoelastic 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, Sternberg.

AM 155. Dynamic Measurements Laboratory. *9 units (1-6-2); first term.* Experimental studies of the behavior of dynamic systems, using the latest electric analog techniques. Free oscillations, and steady state and transient-forced oscillations of linear and nonlinear systems are considered. 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); third 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 10. Introduction to Astrophysics. *8 units (2-2-4); second 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, 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, Sargent.

Ay 131 ab. Stellar Atmospheres. *9 units (3-0-6); first and second terms. Prerequisites: Ay 112 abc, Ph 102 abc, or equivalents.* Atomic spectroscopy. The theory of radiative equilibrium in stellar atmospheres. The continuous spectrum of the stars; the line absorption coefficient and spectral lines. Line broadening theory. Analysis of stellar spectra. Abundances of the elements and nucleo-synthesis theory. Instructor: Münch.

Ay 132 ab. Stellar Interiors. *9 units (3-0-6); first and second terms. Prerequisites: Ay 112 abc, Ph 102 abc, or equivalents.* Introduction to the study of stellar interiors; polytropes; opacity and energy generation. Stellar models. Red giants and white dwarfs. Stellar evolution. Pulsating stars. Problems of stellar rotation, convection, and stability. Not given in 1968-69.

Ay 133 ab. Radio Astronomy. *9 units (3-0-6); first and second terms. For seniors and graduate students only. Prerequisites: Ay 112, may be taken concurrently.* Radio measurements of the flux and brightness of celestial radio sources. Principles of receivers, antennae and interferometers. Solar noise, bursts, the normal and disturbed sun. Theory of thermal emission. Galactic noise. Theory of nonthermal emission, cosmic rays. Discrete sources and their identification. Radio galaxies and quasi-stellar sources. The 21-cm hydrogen line in absorption and emission and galactic structure. Instructors: Moffet, Cohen.

Ay 134. The Solar Atmosphere. *9 units (3-1-5); first 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. Instructor: Zirin.

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 data. Instructor: Oke.

Ay 136. Planetary Atmospheres. *9 units (3-0-6); third term.* Invariant imbedding problems in radiative transfer. Diffuse reflection and transmission of radiation by finite scattering atmospheres. Planetary illumination. Composition and structure of planetary atmospheres inferred from spectroscopic, polarimetric and radiometric observations. Evolution and origin of planetary atmospheres. Instructor: Münch.

Ay 137. Topics in Space Astronomy and Physics. *6 units (2-0-4); first 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. Not given in 1968-69.

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. Not given in 1968-69.

Ay 139. Stellar Dynamics and Galactic Structure. *9 units (3-0-6). 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 external systems. Not given in 1968-69.

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 advisor 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 the 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 advisor must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy.

Ay 201 ab. Astronomical Instruments and Radiation Measurement. *9 units (3-1-5), (3-2-4); first and second 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 spectrographs. Photoelectric detectors, photometric systems and their applications. Instructor: Oke.

Ay 208. Modern Observational Astronomy. *6 units (1-5-0); 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 212. Content and Evolution of Our Own and Other Galaxies. *6 units (2-0-4); third term.* The emphasis in this course will be on radio galaxies. Instructor: Lequeux.

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. Instructors: Sargent, Goldreich.

Ay 217. Theoretical Astrophysical Spectroscopy. *9 units (3-0-6); second 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. Instructor: Zirin.

Ay 234. Seminar in Radio Astronomy. *6 units (2-0-4); second term. Prerequisite: Ay 133 ab.* Recent developments in radio astronomy for the advanced student. Current publications and research in progress will be discussed by students and staff. Instructors: Schmidt, Lequeux.

The following courses will be offered from time to time by members of the Institute and Observatories staffs:

Ay 203. Magnetohydrodynamic Problems.

Ay 204. Advanced Spectroscopy.

Ay 206. Variable Stars.

Ay 213. Selected Topics in Observational Cosmology.

Ay 214. Theoretical Cosmology.

Ay 216. Equilibrium and Stability of Self-Gravitating Masses.

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: Edgar, 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. Special Topics in Biology. *6 units (2-0-4); third term. An elective course, open only to freshmen.* One or two topics, selected primarily in terms of student interest, will be discussed in some depth on the basis of student reading and investigation. Instructors: Owen, and staff.

Bi 6. Organismic Biology. *22 units (4-8-10); first term. Prerequisite: Bi 1 or consent of instructor.* A course of lectures, discussion, and laboratory covering relationships between structure, function, and developmental processes in organisms and ecosystems. Laboratory work will survey the diversity of animals, plants, and microorganisms. Instructors: Brokaw, McMahon, and staff.

Bi 7. Survey of Organismic Biology. *12 units (4-4-4); first term.* A shorter version of Bi 6, intended for non-majors in biology and graduate students desiring a survey course. Instructors: Brokaw, McMahon, and staff.

Bi 8. Special Problems in Organismic Biology. *Units to be arranged (7-12); first term. Prerequisite: Bi 1 or consent of instructor; to be taken only in conjunction with Bi 6.* This course is a device for increasing the number of units for Bi 6 from the minimum of 22 up to a maximum of 34, in order to allow students to devote a larger fraction of their time to intensive study of organismic biology. Registration for Bi 8 is not recommended for students who already have a normal number of units in other courses for the quarter. Students registering for Bi 8 will be expected to attain a higher level of understanding of the material covered in Bi 6, particularly by consulting more specialized reference material than would otherwise be possible. or to study intensively some selected subject relevant to organismic biology. Instructors: Brokaw, McMahon, and staff.

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 in one of the fields represented in the undergraduate biology curriculum; to be arranged with instructors before registration. Instructors: Biology teaching staff.

ADVANCED SUBJECTS

[A] Subjects open to graduate students, but not to be counted toward a major for the degree of Doctor of Philosophy.

Bi 106. Introductory Developmental Biology of Animals. *12 units (2-6-4); second term. Prerequisite: Bi 6 or 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. Instructor: Tyler.

Introductory Biochemistry Courses. *Second term. Prerequisite: Ch 41 abc.* Bi 110, 111, and 112 are designed to be taken together as a unit, providing an intensive introduction to the molecular basis of cellular metabolism through lectures, laboratory projects, individual reading, and student seminars. Biology majors and others interested in a comprehensive study of biochemistry are urged to enroll in all three. However, registration for Bi 110 only, or 110 and 111 only, is also permitted. (See also Bi 202, Bi 241, and Ch 244.)

Bi 110. Biochemistry. *12 units (4-0-8); second term. Prerequisite: Ch 41 a.* A lecture and discussion course in the principles of modern biochemistry with emphasis on the chemical mechanisms by which living cells store and utilize energy and information. Instructors: Wood, 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 112. Biochemistry Colloquium. *12 units (2-0-10); second term. Open to students enrolled in Bi 110 and 111; others require consent of instructor.* This course provides an opportunity for further study of selected topics encountered in Bi 110. Course content and procedure will be decided upon by the students enrolled, in consultation with the instructor. Instructors: Wood, and staff.

Bi 114. Immunology. *9 units (2-4-3); first term. Prerequisite: Ch 41 a.* A course on the principles and methods of immunology and their application to various biological problems. Instructor: Owen.

Bi 116. 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 117. Psychobiology. *9 units (2-3-4); third term.* An introduction to study of the brain and behavior. May be taken with or without laboratory. The laboratory provides a study of the vertebrate nervous system. Instructor: Sperry.

Bi 118. Neurophysiology. *10 units (3-3-4); first term.* A lecture and laboratory course on fundamental aspects of nervous excitation and conduction, synaptic transmission, inhibition, muscle contraction, sense organ physiology, etc. Instructors: Strumwasser, Van Harreveld, Wiersma.

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. Instructor: Attardi.

Bi 121. 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.

Introductory Genetics Courses. *Third term. Prerequisite: Bi 1 or Bi 9, or consent of instructor.* Bi 122, 123 and 124 are designed to be taken as a unit, providing an extensive introduction to basic mechanisms of inheritance in a variety of organisms and the application of genetic principles and methodology to a number of biological problems, including the biochemistry of gene action, problems of human genetics, etc.

Bi 122. Genetics. *12 units (4-0-8); third term. Prerequisite: Bi 1 or Bi 9, or consent of instructor.* A lecture and discussion course covering the basic principles of genetics. This course represents the core of the introductory courses in genetics and may be taken separately by those wishing only a survey of the subject. 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. Instructors: Edgar, Emerson, Horowitz, and Lewis.

Bi 124. Genetics Laboratory. *Units to be arranged; third term. To be taken simultaneously with Bi 122.* Research projects involving different organisms and different problems. Instructors: Lewis, Edgar, 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. Instructor: Tyler.

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 physico-chemical approaches to biology. Instructor: Delbrück.

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 the results. Topics covered include: polymer statistics and thermodynamics, sedimentation, light scattering, spectroscopy, X-ray diffraction, and electron microscopy. Offered 1968-69 and alternate years. Same as Ch 132 ab. Instructors: Davidson, Dickerson, Hodge, 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. The same one-quarter course is offered in both the winter and spring quarters 1968-69 and alternate years. Same as Ch 133. Instructor: Vinograd.

[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, Edgar, 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: Edgar, Lewis.

Bi 205. Experimental Embryology Seminar. *1 unit; all terms.* Reports on special topics in the field; meets twice monthly. In charge: Tyler.

Bi 207. Biophysics Seminar. *1 unit; all terms.* A seminar on the application of physical concepts to selected biological problems. Reports and discussions. Open also to graduate students in physics who contemplate minoring in Biology. Instructor: Delbrück.

Bi 208. Selected Topics in Neurobiology. *Units to be arranged with the instructors; 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.* An advanced seminar course in brain mechanisms and behavior. In charge: Sperry.

Bi 214 abc. Chemistry of Bio-Organic Substances. *3 units (1-0-2); first, second, and third terms. Prerequisite: Ch 41 abc.* A series of lectures on selected topics of organic chemistry that have special interest from a biological viewpoint. Instructor: Haagen-Smit. Not offered in 1968-69.

Bi 220 abc. Developmental Biology of Animals. *6 units (2-0-4); first, second, and 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, endrocrinological 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. Instructor: Tyler.

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. Instructor: Tyler.

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 280-290. 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).

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. Instructors: Corcoran, and staff.

ChE 63 abc. Chemical Engineering Thermodynamics. *7 units (2-0-5); first, second, third terms.* Lectures, discussions, and problems on the First and Second Laws of Thermodynamics, and their engineering applications to single and multicomponent systems. The thermodynamic properties of ideal and real substances will be considered. Closed and open systems will be investigated, including those involving physical and chemical equilibrium. Instructor: Friedlander.

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, third terms.* A study of homogeneous and heterogeneous kinetics with applications of combined reaction kinetics and transport phenomena in the analysis of engineering systems. Topics covered include: transition state theory, gas phase reactions, high temperature and free radical reactions. Adsorption and reaction on solid surfaces. Heterogeneous catalysts and reactions in porous catalysts. Reactions and diffusion in the solid state. Principles of chemical 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. 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.* Basic thermodynamic laws are applied to closed and open systems. Treatment covers ideal and real behavior of single and multicomponent systems. Criteria of equilibrium are discussed and applied to homogeneous and heterogeneous systems, including those involving chemical reactions. Elements of statistical thermodynamics, and irreversible thermodynamics, will be presented. Problems will emphasize applications to practical problems of current interest. Instructors: Cokelet, and staff.

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. Instructors: Tschoegl and Rembaum.

ChE 110 abc. Optimal Design of Chemical Systems. *12 units (3-0-9); 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 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, heterogeneous gas-solid interaction using a Knudsen reactor, homogeneous liquid-phase kinetics and control using a group of stirred-tank reactors in series. Instructors: Shair, Sabersky, Zukoski.

ChE 163 abc. Introduction to Thermodynamics. *5 units (3-0-2); first, second, third terms.* This subject is the same as ChE 63 abc but with reduced credit for graduate students. No graduate credit is given for this subject to students in chemical engineering.

ChE 172 abc. Feedback Control Systems. (Same as EE 172 abc.) *9 units (3-0-6); first, second, third terms. Prerequisite: AM 95 abc or equivalent.* Block diagram representation of control systems. Linear control systems. Frequency and time domain analysis. Stability. Synthesis using Bode diagrams, Nyquist plots, and root locus methods. Linear sampled data systems. Z-transform analysis. Analysis and synthesis of multi-variable systems. Statistical design. Applications of Wiener filtering. Nonlinear control systems. Phase plane and describing function techniques. Identification by cross-correlation techniques. Parameter optimization. Hill climbing methods. Applications of these methods in the analysis and synthesis of chemical, electrical, and mechanical systems will be discussed. Instructors: Gavalas, Seinfeld, Sridhar.

ChE 201 abc. Chemical Reactor Design. *9 units (2-0-7); first, second terms. Prerequisite: ChE 101 abc.* Detailed consideration is given to the design of chemical reactors with emphasis on optimization, stability, and the role of simultaneous energy, material, and momentum transport. Advanced design problems of current importance are solved by use of high-speed digital computing equipment available at the Computing Center. Instructor: Corcoran.

ChE 202. Advanced Problems in Transport. *9 units (2-0-7); third term. Prerequisite: ChE 103 abc.* Problems of some complexity of a quasi-research nature will be solved by group effort in the fields of material, thermal, and momentum transport. The field of interest to the student will be taken into account in establishing the problem or problems to be solved. Primary emphasis will be placed upon the synthesis of the student's background knowledge to arrive at an adequate solution to an engineering problem of some difficulty. Not offered in 1968-69. Instructor: Sage.

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, adsorption and monomolecular layers, membrane transport, facilitated transport, active transport, convective diffusion, concentration boundary layers, current flow through electrolytic solutions, interfacial turbulence. Not offered in 1968-69. Instructor: Friedlander.

ChE 204 ab. Advanced Thermodynamics. *9 units (2-0-7); second, third terms. Prerequisite: ChE 105 abc, AM 113 abc.* A discussion from the quantitative standpoint of the volumetric and phase behavior of pure substances and of binary, ternary, and multicomponent fluid systems at physical and at physiochemical equilibrium is presented. Development of the background necessary for a working knowledge of multicomponent open systems of particular interest to the engineer follows. The solution of problems relating to the application of multicomponent thermodynamics to industrial practice is an important part of this course. Texts: *Volumetric and Phase Behavior of Hydrocarbons*, Sage and Lacy; *Thermodynamics of Multicomponent Systems*, Sage. Not offered in 1968-69. Instructor: Sage.

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 1968-69. 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. Offered in alternate years, beginning 1968-69. Instructors: Tschoegl and 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.
Process control and optimization of chemical systems.
Liquid state physics.
Rheology and flow of suspensions and emulsions.
Mechanical behavior and ultimate properties of polymers.
Mechanics of dispersions.
Plasma chemistry and engineering.
Interfacial transport.
Statistical mechanics of gases, liquids, and ionic solutions.

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. Instructor: 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 problems. Texts: *Basic Chemical Thermodynamics*, Waser; *Quantitative Chemistry*, Waser. Instructors: Waser, Smith, Crawford, and other staff members and assistants.

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. Text: *Basic Principles of Chemistry*, Gray and Haight. Instructors: Gray, Richards, Beauchamp, Bergman.

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. Text: *Quantitative Chemistry*, Waser. Instructors: Waser, Smith, and other staff members and assistants.

Ch 14. Quantitative Analysis. *10 units (2-6-2); first term. Prerequisite: Ch 1 abc or equivalent.* A lecture and laboratory course. The lectures offer a systematic discussion of ionic equilibria including solubility effects, complex ion formation, oxidation-reduction and acid base reactions in aqueous and non-aqueous solutions. The laboratory work provides opportunity to apply the principles discussed in the lectures to selected problems in inorganic chemical analysis. Instructor: Schaefer.

Ch 16. Chemical Instrumentation. *8 units (0-6-2); first term. Prerequisite: Ch 1 abc and consent of the instructor.* Laboratory practice designed to familiarize the student with selected instruments, principally those that are useful in measurements of the interaction of electromagnetic radiation with chemical systems. Instructor: Sturdivant. Offered in 1968-69.

Ch 21 abc. Physical Chemistry. *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. Instructors: Dickerson, Robinson.

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. *8 units (0-6-2); second, third terms. Prerequisites: Ch 1 abc; Ch 21 a; two terms of EE 90, or EE 9, or equivalent (e.g., suitable physics laboratory courses).* 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.* Structural chemistry of covalent compounds, including experimental methods and theory. Texts: *Elements of Organic Chemistry*, Richards, Cram, and Hammond; *Molecular Orbital Theory*, Ballhausen and Gray; *Symmetry in Chemistry,* Jaffé and Orchin. Instructors: Gray, Hammond.

Ch 46 abc. Experimental Methods of Covalent Chemistry. *7 units (1-6-0); first, second, third terms. Prerequisite: Ch 1 abc.* Laboratory accompaniment 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: Raftery and assistants.

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, and 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 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: Waser.

ADVANCED SUBJECTS

Ch 113 ab. Advanced Inorganic Chemistry. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 abc or concurrent registration.* A discussion of modern inorganic chemistry and chemical dynamics. The first term includes discussion of experimental and theoretical aspects of structural coordination chemistry. In the second term the electronic, structural, and thermodynamic aspects of inorganic chemistry will be discussed with particular emphasis on the factors influencing chemical reactivity. Among the reactions whose mechanisms will be considered are: substitution reactions of metal complexes, oxidation-reduction and acid-base reactions, and reactions of organometallic compounds. Instructors: Halpern, Gray, Smith.

Ch 114. Quantitative Analysis. *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: Schaefer.

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 small 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. A non-mathematical and semi-empirical treatment is given to the various types of interatomic forces and their relationship to the chemical and physical properties of substances. Text: *Nature of the Chemical Bond*, Pauling. Instructors: Marsh, Waser.

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: Chan, Goddard, McKoy.

Ch 127 ab. Nuclear Chemistry. *12 units (3-3-6); first, second terms. Prerequisite: Ch 21 abc or equivalent.* An introductory lecture and laboratory course designed to acquaint the student with basic nuclear processes and techniques. The topics covered in the lectures and illustrated in the laboratory work include the nuclear masses and energetics, rates of production and decay of radioactive nuclei, the interaction of radiation with matter, alpha and beta decay, gamma ray emission, fission, nuclear reactions, radiochemistry, and other chemical applications of radioactivity. 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 1968-69. Instructor: Sturdivant.

Ch 130. Photochemistry. *6 units (2-0-4); third term. Prerequisites: Ch 41 abc, Ch 21 ab.* Mechanisms of photochemical reactions including discussion of radiative and non-radiative decay processes that compete with chemical change in the degradation of electronic excitation of molecules. Not offered in 1968-69. Instructor: Hammond.

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 1968-69. Instructors: Davidson, Dickerson, Hodge, 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. 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. Text: *Kinetics and Mechanism,* Frost and Pearson. Not offered in 1968-69. Instructors: Kuppermann, Davidson, Hammond.

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. Instructors: faculty members, research fellows.

Ch 144 abc. Advanced Organic Chemistry. *9 units (3-0-6); first, second, third terms.* During the first two terms an intensive study of synthetic organic chemistry that embodies the stereochemical, theoretical, and practical aspects of the synthesis of organic molecules. Examples will be drawn from naturally occurring substances as well as theoretically challenging structures. The third term will be devoted to problems in physical organic chemistry. Instructor: Ireland.

Ch 145. Advanced Organic Chemistry Laboratory. *7 units (1-5-1); first term. Prerequisites: Ch 41 abc, Ch 46 abc.* Advanced laboratory practice, synthetic experiments, use of kinetics in mechanistic studies, and selected optional work. Not offered in 1968-69. Instructors: Hammond, and assistants.

Ch 148. Separation and Identification of Organic Compounds. *6 units (3-0-3); second term. Prerequisites: Ch 41 abc, Ch 46 abc.* Lectures and recitations concerning the isolation, purification, and identification of organic compounds. Heavy emphasis devoted to the interpretation of infrared, ultraviolet, nuclear magnetic resonance, and mass spectrometric data. Not offered in 1968-69.

Ch 180. Chemical Research. *Offered to M.S. candidates in chemistry.*

Ch 190. Oral Presentation. *2 units (1-0-1); first term.* Training in the technique of oral presentation of chemical topics. Any graduate student in chemistry may be required to register for the course if, during his candidacy examination, or for any other reason, he gives evidence of needing instruction in oral presentation. Instructor: Waser.

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. Offered in 1968-69. Instructor: Pings.

Ch 224 abc. Special Topics in Magnetic Resonance. *4 units (2-0-2); first, second, third terms.* The principles of magnetic resonance will be discussed. Emphasis will be placed on nuclear interactions within molecules and their effects on magnetic resonance. Current developments in theoretical methods for *ab initio* calculations of magnetic properties will also receive attention. Texts: *The Principles of Magnetic Resonance*, Slichter, and *Introduction to Magnetic Resonance*, Carrington, McLachlan. Not offered in 1968-69. Instructor: Chan.

Ch 225 abc. Advanced Chemical Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or equivalent.* Basic concepts and the laws of thermodynamics are reviewed. The theories of heterogeneous and chemical equilibrium are developed according to the methods of J. Willard Gibbs. A systematic treatment is presented of the thermodynamic properties of pure systems, mixtures, chemical reactions, electrochemical systems, surface phases, and systems under the influence of external fields. The theory of heterogeneous equilibrium and phase diagrams is developed analytically. The third term is largely devoted to the thermodynamics of irreversible processes. Not offered in 1968-69.

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 228 abc. Special Topics in Physical Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Consent of instructor.* This course will be devoted to special current topics in areas of chemistry, such as molecular spectroscopy, group theory, electron scattering, molecular scattering, etc. The contents will vary from year to year and the course may be taken for credit more than once. Not offered in 1968-69.

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 1968-69. Instructors: Dickerson, Hughes, Marsh.

Ch 234. Introduction to the Spectra of Molecules. *6 units (2-0-4); first term.* The theory of the structure of the spectra of both the diatomic and simpler polyatomic molecules is presented, and the transition rules and their relation to the symmetry elements of molecules are discussed. Emphasis is laid on the methods of interpreting and analyzing molecular spectra, and it is shown how from an analysis one obtains information regarding the structure and other properties of a molecule of interest to the chemist. Problems are given in the interpretation of actual data. Not offered in 1968-69.

Ch 242 ab. Chemistry of Natural Products. *4 units (2-0-2); first, second terms. Prerequisite: Ch 41 abc.* The chemistry of antibiotics, alkaloids, pigments, steroids, terpenes, etc. is used as a vehicle for a discussion of the general principles of structural elucidation, total synthesis, and biogenesis of natural products. Not offered in 1968-69. Instructors: Ireland, Richards.

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. Instructors: Richards, 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. Texts. *Spin-Spin Splitting and Molecular Orbital Calculations,* Roberts. Given in alternate years. Not offered in 1968-69. Instructor: Roberts.

Ch 247 ab. Organic Reaction Mechanisms. *6 units (2-0-4); first, second terms. Prerequisite: Ch 144 abc or equivalent.* Various tools for the study of organic reaction mechanisms will be discussed with major emphasis on kinetic methods. Not offered in 1968-69. (Somewhat similar material will be introduced in Ch 144 c.) Instructor: Hammond.

Ch 253 ab. Chemistry of the Enzymes. *6 units (2-0-4); first, second terms.* Consideration of the nature and mechanism of enzyme action. Not offered in 1968-69.

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 1968-69. Instructor: Schroeder.

Ch 255 abc. Chemistry of Bio-organic Substances. *3 units (1-0-2); first, second, third terms.* Lectures on selected subjects of organic chemistry such as alkaloids, essential oils, and other major groups of natural products. Not offered in 1968-69. Instructor: Haagen-Smit.

Ch 258. Immunochemistry. *8 units (2-3-3); second term. Prerequisite: Consent of instructor.* Two formal lectures and two conferences and demonstrations of laboratory experiments each week, review of literature, and either a special research project or a review paper dealing with some aspect of immunochemistry. Emphasis is on the isolation and characterization of antigens and types of antibody molecules and the manifestations of their physical and biological interactions. Texts: *Methods of Immunology*, Campbell, Garvey, Cremer, and Sussdorf; *Principles of Immunology*, Cushing and Campbell; *Fundamentals of Immunology*, Boyd; *Experimental Immunochemistry*, Kabat and Mayer; and *The Proteins*, Neurath and Bailey. Given in alternate years. Offered in 1968-69. 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.
Molecular beam spectroscopy.
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.
Microwaves and nuclear 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.

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 fields of application of chemistry to biological and medical problems—

Mechanism of antigen-antibody reactions and the structure of antibodies.

Functional significance of antibodies.

Chemical and physical properties of blood.

Isolation and characterization of cellular antigens.

Mechanisms of enzyme action.

Chemical analysis of proteins and determination of the order of amino-acid residues in polypeptide chains.

Physical chemical studies of nucleic acids and viruses.

Crystal structures of amino acids, peptides, and proteins.

Plant hormones and related substances of physiological importance.

Investigation of mammalian and bacterial polysaccharides including the blood-group specific substances.

Behavior of biological macromolecules in the ultracentrifuge.

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. Every graduate student in chemistry is expected to attend these conferences. Seminars in 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 of 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 141. Applied Aqueous Solution Chemistry. *9 units (3-3-3); first term. Prerequisites: Ch 1 abc or equivalent; Ch 114 or concurrent registration in Ch 114.* 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 to the analysis of natural waters. Instructor: Morgan.

CE 142 ab. Applied Chemistry of Natural Water Systems. *9 units (2-3-4); second and third terms. Prerequisite: CE 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.

CE 145 ab. Environmental Health 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.

CE 146 abc. Analysis and Design of Environmental Systems. *9 units (3-0-6); each term. Prerequisites: ME 17 ab, ME 19 ab, AM 113 ab, CE 145 ab, or equivalents. (The graduate prerequisites may be taken concurrently.)* 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 design of works; and economic aspects of projects. Instructor: McKee.

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 152 ab. Environmental Radiation. *9 units (2-3-4); second and third terms. Prerequisites: Ch 1 abc, Ph 2 abc, Ma 2 abc, ME 17 ab, ME 19 ab.* Engineering analysis of the problems associated with ionizing radiations in the human environment, especially in water, waste water, and air; evaluation of radiation sources; interactions of radiation with matter; methods of detection and measurement; use of radioactive tracers; acute and chronic effects on health; radioactive waste disposal; and engineering principles of control. Instructor: McKee.

CE 153. Seminar in Environmental Health Engineering. *3 units (2-0-1); third term.* Special seminars and field trips to cover several aspects of engineering in environmental health not normally included in formal courses; e.g., engineering aspects in problems of epidemiology; sanitation of swimming pools, hospitals, and housing; engineering control of insects, rodents, and vermin; waste disposal in the marine environment; occupational hazards, and environmental control in space. Instructors: Staff and visiting lecturers.

CE 156. Industrial Wastes. *9 units (3-0-6); third term. Prerequisite: CE 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.

CE 160. Advanced Hydrology. *6 or more units as arranged; any term. Prerequisite: Hy 112 ab or permission of instructor.* Advanced studies of various phases of hydrology. The course content will vary depending on needs and interests of students enrolling in the course. Instructor: Brooks.

CE 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.

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 203. Advanced Work in Environmental Health Engineering. A purpose of this course is to explore new approaches which bear on environmental health problems. Hence the topics covered change from year to year.

CE 204. Advanced Work in Water Resources.

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.

Hy 200. Advanced Work in Hydrodynamics or Hydraulic Engineering.

CE 300. Civil Engineering Research.

For courses in Hydraulics see separate section.

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, especially industry. It is intended for two groups of technically trained students: 1) those who wish, sooner or later, to take advantage of opportunities in industry beyond their strict technical fields, and 2) those who will be engaged in teaching and in scientific research, but who wish to get an understanding of industry in both its technical and philosophical aspects. 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) industrial organization and finance, 2) factory management with emphasis on automation, 3) industrial sales, 4) personal investments, and 5) business economic topics, especially the business cycle. 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. The case method of instruction is used extensively in the course. Instructor: Gilbert.

*Advanced students in Economics should be aware that IS 181 ab, Linear Programming, 9 units (3-0-6) second and third terms, is valuable for its economic applications. Credit in this course may be counted toward the fulfilment of requirements for a Ph.D. minor in Economics.

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 instructors. Instructors: Gilbert, Gray.

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 1968-69.

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. Instructor: Sweezy.

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.

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.

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).* 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: Noll.

Ec 122 b. Econometric 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. Instructor: Noll.

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. Instructor: Dohan.

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. Instructor: Oliver.

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: Ec 126 or its equivalent.* Consideration of selected topics in economic theory. Instructors: Members of the staff and guest lecturers. Not offered in 1968-69.

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.

IS 181 ab. Linear Programming. *9 units (3-0-6).* See page 352.

Electrical Engineering

UNDERGRADUATE SUBJECTS

EE 3. Introduction to Solid State Electronics. *4 units (2-0-2); first term.* An introduction to the significant concepts of modern electronic devices such as diodes, junction and field effect transistors, controlled rectifiers, etc. Topics will include: conductors, energy barriers, junctions, and rectification. The operating principles of transistors and transistor-like devices. Instructor: Mead.

EE 5. Introductory Electronics. *9 units (3-0-6); third term.* This is an introductory course to provide a background in electronics for students both in engineering and in other fields. The subjects covered will be simple a.c. circuit theory, properties of vacuum tubes and transistors, simple rectifiers and switching circuits. Instructor: Langmuir.

EE 9. Solid State Electronics Laboratory. *6 units (1-3-2); second term. Prerequisite: EE 3.* 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. Instructors: Mead, Humphrey.

EE 13 abc. Linear System Theory. *9 units (3-0-6); three terms. Prerequisites: Ma 2 abc and Ph 2 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, Laplace and "Z" transforms, convolutions, autocorrelation, feedback systems, flow graphs, noise and distributed linear systems. Instructor: Harp.

EE 14 abc. Electronic Circuits. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 abc, Ph 2 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-O-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. Not offered in 1968-69.

EE 90 abc. Laboratory in Electronics. *3 units (0-3-0); 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 274). Instructor: Martel.

EE 91 abc. Experimental Projects in Electrical Engineering and Applied Physics. *5 units (0-4-1); each term. Prerequisite: EE 90 abc or equivalent.* A general laboratory program designed to give the student an opportunity to do original experiments in the fields of electrical engineering and applied physics. Emphasis is placed not only upon modern laboratory techniques but also upon the selection of significant projects, the formulation of the experimental approach and the interpretation of the data. Facilities are available for experiments involving electronic circuits, electronic circuit elements, cryogenics, lasers, magnetism, optics, microwaves, thermionics and electronic properties of semiconductor materials. Text: *Literature References.* Instructor: Humphrey.

ADVANCED SUBJECTS

EE 112 abc. Network Synthesis. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 13 abc.* The analysis and synthesis of lumped and distributed parameter circuits. Energy theorems and mathematical properties of the matrices of the general n-port. Lumped elements: Classical synthesis methods for active and passive two-ports, including ladders, lattices, and amplifiers. Approximation problems, applications of Laplace and Hilbert transforms, and computer-aided synthesis. Microwave filters: rigorous guided mode theory, scattering matrix, realization theory, equivalent circuits of matching elements, synthesis of distributed circuits. Texts: *Synthesis of Passive Networks*, Guillemin; *Generalized Networks*, P.I.B. Symposium, Vol. 16. Not offered in 1968-69.

EE 113 abc. Modern Optics. *9 units (3-0-6); first, second, third terms.* 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. Electronic Circuit Design. *9 units (3-0-6); third term. Prerequisite: EE 14 abc or equivalent.* Applications of solid-state electronic devices, with emphasis on methods of engineering analysis and design. Practical design of feedback and d-c amplifiers and regulators. Circuit noise problems. 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, mechanical and electrical filters, band theory of crystals, electrons, holes, semiconductors, theory of p-n junctions and of semiconductor devices. Instructors: Mayer and McCaldin.

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, nonlinear 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. 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: Langmuir.

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 application 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 162 ab. Stochastic Processes in Communication and Controls. *9 units (3-0-6); first and second terms. Prerequisite: AM 95 abc or Ma 108.* An introduction to probability theory and stochastic processes. Topics covered include continuous and discrete random variables, characteristic functions and moments. Methods of characterizing stochastic processes. Real and complex representation of random processes, processes with independent increments, stationary and ergodic processes, correlation functions and power spectra, Markov processes. Response of linear and nonlinear systems with random inputs. Optimum filtering and prediction. Not offered in 1968-69.

EE 163 abc. Statistical Communication Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 162 a.* Mathematical methods in Modern Communication Theory. The representation of deterministic and random signals, sampling theorems. Linear filtering of stochastic processes, the Wiener Filter, the matched filter, prediction theory. Decision theoretic models for the analysis and synthesis of optimum data processing systems. Detection of signals and estimation of signals parameters. Signal selection and criteria for system comparisons. Instructor: Grettenberg.

EE 164. Information Theory. *9 units (3-0-6); first term. Prerequisite: AM 95 or Ma 108.* The information rate of a source. Coding for reliable transmission of source information over continuous and discrete channels with noise. Channel capacity and Shannon's first and second coding theorems. Instructor: Grettenberg. Not offered in 1968-69.

EE 165. Pattern Recognition and Learning. *9 units (3-0-6); third term. Prerequisite: EE 162 a.* Evaluation of the various approaches to automatic pattern recognition and machine learning. A discussion of heuristic approaches and their limitations. Decision theoretic models and sequential rules. Convergence and performance limits. Instructors: Staff. Not offered in 1968-69.

EE 166. Special Topics in Stochastic Processes. *9 units (3-0-6); third term. Prerequisite: EE 162 ab.* Topics of current research interest to be selected from Communication Theory, Information Theory, Noise Theory and Control Theory. Not offered in 1968-69.

EE 172 abc. Feedback Control Systems. (Same as ChE 172 abc.) *9 units (3-0-6); first, second, third terms. Prerequisite: AM 95 abc or equivalent.* Block diagram representation of Control Systems. Linear control systems. Frequency and time domain analysis. Stability. Synthesis using Bode diagrams, Nyquist plots and Root Locus Methods. Linear sampled data systems. Z-transform analysis. Analysis and Synthesis of Multivariable systems. Statistical design. Applications of Wiener filtering. Nonlinear control systems. Phase plane and describing function techniques. Identification by cross-correlation techniques. Parameter optimization. Hill climbing methods. Applications of these methods in the analysis and synthesis of chemical, electrical, and mechanical systems will be discussed. Instructors: Gavalas, Seinfeld, and Sridhar.

EE 174. Control Systems. *9 units (3-0-6); first term. Prerequisite: AM 95 abc or equivalent.* System representation: continuous systems and discrete systems. Linear systems: controllability and observability. Stability: second method of Liapunov, Method of Popov. Instructor: Sridhar.

EE 175. Optimization in Control. *9 units (3-0-6); second term. Prerequisite: EE 174 or equivalent.* The Deterministic optimal control problem: classical variational methods; Pontriagin's maximum principle; Bellman's dynamic programming; optimization via linear and nonlinear programming. Computational methods: the quasilinearization method; gradient methods. Instructor: Sridhar.

EE 176. Stochastic Problems in Control. *9 units (3-0-6); third term. Prerequisite: EE 175 and EE 162 or equivalent.* Linear Filtering and Estimation; Nonlinear filtering; Stochastic optimal control; Adaptive Control Systems: Identification and decision problems. Stochastic approximation. Instructor: Sridhar.

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 advisors 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: Gould.

EE 221 abc. Topics in Physical Electronics. *4 units (1-0-3); first, second, third terms. Prerequisite: EE 124 abc.* 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 1968-69.

EE 225 abc. Solid State Device Theory. *9 units (3-0-6); first, second, third terms.* An integrated treatment of the theory and application of solid-state electronic devices, with emphasis on methods of engineering analysis and design. Physics of insulators, semiconductors, and conductors. Basic equations of current flow in various media. Principle of charge-controlled devices. Junctions between media, and application to vacuum and solid-state diodes. Detailed treatment of p-n junctions. Ideal and real junction and field-effect transistors, and their static and incremental models. Instructor: Middlebrook.

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. For the year 1968-69 the subject will be a basic review of magnetism in metals. Instructor: Wilts.

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. Instructors: George, 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 advisors before registering for this course.

ENGINEERING

E 10 ab. Technical Presentations. *2 units (1-0-1); first and second terms.* A course concerned with oral presentations of technical material. Instructors: Staff.

E 11 ab. Technical Presentations. *2 units (1-0-1); first and second terms.* A course concerned with oral presentations of technical material coordinated with EE 91 ab. EE 91 ab must be taken concurrently with E 11 ab. Instructors: Staff.

E 150 abc. Engineering Seminar. *1 unit (1-0-0); each term.* All candidates for the M.S. degree in Applied Mechanics, Electrical Engineering, Materials Science, and Mechanical Engineering are required to attend any graduate seminar in any division each week of each term.

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. Instructors: Welch, Auksmann.

Gr 5. Descriptive Geometry. *6 units (0-6-0); third term. Prerequisite: Gr 1.* The course is primarily for geology students and is designed to supplement the study of shape description as given in Gr 1 and to present a graphical means of solving the more difficult three-dimensional problems. The student reviews geometrical relationships of straight lines and planes, then advances to curved lines, single and double curved surfaces, warped surfaces and intersections. Methods of combining the analytical solution of the simpler problems with the graphical solution are discussed and applied. Emphasis is placed throughout the course on practical problems in mining and earth structures and on the development of an ability to visualize in three dimensions. Instructors: Staff.

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. Instructor: Lurie.

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. Instructor: Corngold.

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. Instructor: Shapiro.

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: Wu.

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). Instructor: Plesset.

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: Cohen, Corngold.

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. Given in alternate years. Offered in 1968-69. 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.

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: Diestel. *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 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, philosophy, 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. *(3-0-6).* The vocabularies of analysis for the study of painting, sculpture and architecture. Approaches to the study of art history, and case studies of selected art forms. Instructor: Wark.

En 50. Shakespeare. *9 units (3-0-6); first and third terms. 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 51 ab. Development of the Modern Drama. *9 units (3-0-6); second, third terms. Prerequisite: En 1 or En 7. En 51 a* will trace the development of English and Continental drama from its medieval and Renaissance origin to the late nineteenth century. Major texts will be used to illustrate the great epochs in European drama. *En 51 b* will deal with the leading British, Continental, and American dramatists from Ibsen to the present. Special attention will be given to dramatic technique and to philosophical content. The two terms may be taken as a sequence, or independently of each other. *(En 51 b replaces En 10. Credit for both is not allowed.)* Instructor: Mandel.

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 Conrad, Joyce, and Lawrence. Instructors: D. R. Smith, Mayhew.

En 102. Linguistics. *9 units (3-0-6).* An introductory, one-term course in the scientific study of natural language (with primary emphasis on English). Historical background and the development of major linguistic concepts and methods. (1) Phonology, (2) morphology, and (3) syntax, as the descriptive theoretical levels for the study, respectively, of (1) sound systems, (2) internal structure of words, and (3) structure of word combinations (sentence and sentence relations). Selected topics in current syntactic and semantic analysis. Fields of application (automated language processing; psycholinguistics; sociolinguistics; pedagogical linguistics). Instructor: Dostert.

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. Instructor: Zeigel.

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 124 b. Credit for both is not allowed.) Instructor: Cozart.

En 122 abc. Senior Seminar. *9 units (2-0-7); first, second, third terms. For majors only.* 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 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. Instructor: Zeigel.

En 132. Hemingway and Faulkner. *9 units (3-0-6); third term. 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.

French

(See under Languages)

Geological Sciences

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: Smith.

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: Schon, 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. Instructors: Wasserburg, Taylor.

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 112. Paleontology Laboratory. *6 units (0-6-0); by arrangement with instructor.* Training in preparation, organization, and evaluation of fossil assemblages as a tool in stratigraphic, paleontological, and paleogeographic research. Not offered in 1968-69.

Ge 114. Mineralogy II—Optical Mineralogy. *10 units (3-6-1); second term. Prerequisite: Ge 104 a.* Systematic study of the physical properties of important rock-forming minerals and mineral groups as a function of their crystal structure and chemical composition. The elements of optical crystallography and their application in microscopic mineralogy will be studied. The laboratory work will emphasize the development of basic competence in mineral identification using hand specimens and the petrographic microscope. 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 a or 124 a or Ch 21 a.* The mineralogical and chemical composition, origin, occurrence, and classification of igneous rocks considered mainly in the light of chemical equilibrium and of experimental studies. Detailed consideration of the structure, 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. *10 units (4-0-6); second term.* Primarily a consideration of dynamic processes acting on the surface of the earth, and the genesis of landforms. Instructor: Sharp. Offered in alternate years (1969-70).

Ge 130 ab. Introduction to Geochemistry. *6 units (2-0-4); first and second terms. 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 and radioactive isotopic geochemistry. Instructor: Epstein.

Ge 131. Geochronology. *6 units (2-0-4); third term. Prerequisite: Ge 130 ab.* A lecture and problem course covering topics in radioactive isotopes, and geochronology. Instructor: Patterson. Not offered in 1968-69.

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 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 151. Laboratory Techniques in the Earth Sciences. *5 units (0-5-0); second term.* Introductory training in the use of tools and techniques used in earth sciences research. Experiments of geological interest are done using the electron microprobe, emission spectrograph, spectrophotometer, X-ray diffractometer and spectrometer, alpha and beta counters, mass spectrometers, wet chemical techniques and other available tools and techniques. The course carries a minimum of 5 units but additional units may be elected. Instructor: Epstein.

Ge 152. Radar Astronomy. *9 units (3-0-6); first 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: R. 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 155. Introductory Planetary Science. *6 units (3-0-3); first term.* An introduction to aspects of planetary science for advanced undergraduates and for graduate students from other disciplines. Topics will be selected from such fields as planetary dynamics, atmospheric physics, planetary surfaces and interiors, and planetary geochemistry. Instructor: Ingersoll, other staff participating.

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.

Ge 171. Applied Geophysics. *10 units (3-4-3); first term.* Offered in accordance with student interest. The use of gravity, magnetic, electrical, and seismic methods applied to geological field problems. Instructor: Dix.

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: Richter.

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 (1968-69).

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, non-ideality 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, Pitzer, and Brewer. Instructor: Taylor. Offered in alternate years (1968-69).

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. The application of modern optical, powder diffraction, and single-crystal X-ray methods to the study of the feldspars, pyroxenes, micas, and other important mineral groups. Instructor: Kamb.

Ge 215 abc. Topics in Advanced Petrology. *Prerequisites: Ge 115, Ch 124, Ge 151.* (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 1968-69.

215 b. Advanced Igneous Petrology. *12 units (3-6-3); third term.* Instructor: Silver. Offered in alternate years (1969-70).

215 c. Advanced Metamorphic Petrology. *12 units (3-6-3); second term.* Instructor: Albee. Offered in alternate years (1969-70).

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 radioactivities 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: Burnett.

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. Instructor: Murray. Offered in alternate years (1969-70).

Ge 221. Astrogeology. *10 units (3-1-6); second term. Prerequisite: Ge 115 abc desirable. Consult with instructor.* A review of the distribution of solid objects in the solar system and the probabilities of their collision; physics and phenomenology of shock propagation and cratering in rocks; shock metamorphism; fine-grained particles in space near the earth; distribution and characteristics of impact structures on the earth and applications to the interpretation of the stratigraphy, structure and history of the Moon. Instructor: Shoemaker.

Ge 222. The Chemistry of the Solar System. *6 units (3-0-3); third term. Permission of instructor.* A discussion of the chemical composition in relation to other properties, of the Sun, planets (including Earth), satellites, comets, interplanetary gas and dust, and asteroids. Planetary atmospheres will be discussed in some detail. Special emphasis will be placed upon meteorites and their properties, including their motion and fall, morphology, chemistry, mineralogy and petrography as well as nuclear and chemical transformations induced by cosmic rays. Instructor: Brown.

Ge 223 a. Atmospheric Radiation. *6 units (3-0-3); first term. Permission of instructor.* The role of electromagnetic radiation in the energy balance of planetary atmospheres. This course will cover scattering, thermal emission, gaseous absorption, line shape and band models, with applications to theory and observations of the structure of planetary atmospheres. Instructor: Ingersoll. Offered in alternate years (1968-69).

Ge 223 b. Atmospheric Dynamics. *6 units (3-0-3); second term.* The fluid mechanics of planetary atmospheres. Topics to be covered include thermodynamics of moist air, thermal convection, rotating stratified flow, stability of rotating fluids. Principal applications will be circulation regimes in the earth's atmosphere. Instructor: Ingersoll. Offered in alternate years (1968-69).

Ge 225. Selected Topics in Planetary Science (Seminar). *5 units; second term.* Review of current research in a selected area of the chemistry, physics, or geology of the Moon, planets, or meteorites. In charge: Staff.

Ge 229. Glacial Geology. *10 units (3-0-7); second term. Prerequisite: Ge 126.* Origin of glaciers, existing glaciers, glaciology and glacial mechanics, erosional and depositional features of mountain and continental glaciers, chronology of the Pleistocene. Text: *Glacial and Pleistocene Geology*, Flint. Instructor: Sharp. Offered in alternate years (1968-69).

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 1968-69.

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 (1968-69).

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 nonlinear 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 (1969-70).

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: Brune.

Ge 264 ab. Theoretical Geophysics. *9 units (3-0-6); second and third terms. Prerequisite: Ph 129 abc.* A detailed analytical treatment of theoretical seismology including inversion methods for estimation of elastic and anelastic properties of the media and a presentation of models of elasto dynamic sources. Theoretical considerations of the earth's magnetic field, thermal properties and history, and various dynamical processes described by fluid flow or creep. Instructor: Archambeau. Offered in alternate years (1968-69).

Ge 265 ab. Advanced General Geophysics. *9 units (3-0-6); second and third terms. Prerequisite: Ph 106 abc; Ph 129 also desirable.* Topics from among the following areas will be selected: thermal regime of the earth, submarine geophysics; geomagnetism; planetary geophysics; gravity field; large-scale motions in the earth. Instructors: Staff.

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.

H3. 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.*

ADVANCED SUBJECTS

H 101. Tutorial. Open to students majoring in history. Reading, preparation of a research paper, and preparation for a general examination, under the supervision of members of the staff.

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 123. Islamic Society. *9 units (3-0-6).* An introduction to a society in constant flux. The course will explore Islam from several different points of view over an extended period of time. Its purpose is to illuminate the transformations which have occurred in the past and the influence these have had in shaping the present reactions of Muslims in a geographical area which extends from Morocco to Indonesia. Instructors: Munger, Schaar.

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. Industrial Change and an Age of Reform in America, 1865-1917. *9 units (3-0-6).* An examination of major political responses in the United States to the dislocations of an emergent industrial and urban society.

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.

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 ab. Science in America, 1865-present. *9 units (3-0-6). H 157 a is a prerequisite for H 157 b.* The first term a study of the social and political history of American science, emphasizing the role of science in government, industry, and university. The second term 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 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, turbulent shear flow; introduction to problems in heterogeneous flow, chemically reacting flow, sediment transport, flow through porous media. Instructor: Marble.

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. *9 units (3-0-6); second and third terms. Prerequisites: AM 95 abc or AM 113 ab (concurrently); basic fluid mechanics; and some knowledge of elements of hydrology (may be satisfied by special reading assignments).* The hydrologic cycle and its interrelations with man; statistical analysis and simulation of hydrologic data; floods; overall mass balance; transport and dispersion of solutes, sediments, and contaminants in rivers, lakes, estuaries; river morphology; physics of flow through porous media, including dispersion of solutes, flow toward wells, ground-water recharge, drainage; sea water intrusion in aquifers and estuaries; heat exchange and density stratification in natural waters; thermal pollution control. Instructor: Brooks.

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. Instructor: 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. Hydraulic Machinery. *6 units (2-0-4); first, second, third terms. Prerequisite: Hy 101 or equivalent.* A study of rotating flow machines such as turbines, pumps, propellers, and blowers and their design to meet specific operating conditions. 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. Instructor: Staff.

Hy 210 ab. Hydrodynamics of Sediment Transportation. *9 units (3-0-6). Prerequisites: AM 95 abc, Hy 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. *9 units (3-0-6); first term. Prerequisites: AM 95 abc or AM 113 abc; Hy 101 abc and Hy 112 ab.* The hydrodynamics of turbulent diffusion in jets and plumes in uniform and density-stratified environments; large-scale turbulent diffusion in the ocean; dispersion in shear flows, including natural streams; mixing in tidal estuaries; selective withdrawal from density-stratified reservoirs. Applications to engineering problems of pollution control in hydrologic and coastal environments. Instructor: Brooks.

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); second term.* 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. Instructors: Franklin, Keller.

100 series courses open to juniors and seniors or by special permission of instructors.

IS 103 a. Combinatorial Algorithms. *9 units (3-0-6); third term.* Basic techniques for manipulation of information within computers; processing of trees and multiply-linked lists, sorting, table searching, symbol table subroutines, backtrack programming, generating permutations and combinations, scanning algebraic languages.

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. Instructors: Fender and staff.

IS 129 abc. Formal Languages and Programming Systems. *9 units (3-0-6).* Introduction to concepts of computer programming and computer languages, assembly languages, comparison of algebraic languages including FORTRAN, ALGOL, and PL/I. Formal language theory; Turing machines, introduction to automata theory; parsing, syntax directed compilation, algebraic linguistics. Programming systems, monitors, I/O supervision, real time operation, time share, content addressable memory allocation. Instructor: Caine.

IS 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: Franklin.

IS 203 ab. Computer Analysis of Data. *9 units (3-0-6); second and third terms. Prerequisite: EE 162 or Ma 112.* A treatment of selected statistical models and the relation of these models to the methods of graphical display for the analysis of data. Techniques of fitting data, analysis of variance, spectral theory of stationary process, graphic methods for composing multi-response data are included. The integration of these models into heuristic strategies employing a data analysis language will be stressed.

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 System Synthesis. *9 units (3-0-6); taught alternate years. Prerequisites: IS 103 and IS 129.* This course presents a systematic consideration of the concepts and practices involved in the design of large-scale operating systems for information processing. The course starts with a treatment of the basic system design tools such as scanning, text encoding, list processing and storage allocation. Translation and communication processors are covered next. Design criterion and techniques for compilation, translation and buffering are discussed. The processing components are developed now into complete operating systems. The remainder of the course consists of a study of such concepts as shared-file processors, real-time computing and data collection, and multi-tasking processors. Text: Class notes. Instructor: Caine.

IS 250 abc. Mathematical Linguistics. *9 units (3-0-6); taught alternate years. Not offered 1968-69. 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.

IS 260 abc. Artificial Intelligence. *9 units (1-2-6); taught alternate years. Prerequisite: Consent of instructor.* Investigation of principal strategies and problems in achieving intelligent behavior on a computer; discreteness of the space of alternatives, search strategies and heuristics, hill climbing, pattern recognition and articulation of patterns; learning systems. Review of recent developments in selected areas of research; problem solving programs, computer understanding of natural and graphic languages and question answering. Simulation of cognitive processes. The student will be expected to develop and successfully run a computer program demonstrating understanding of advanced application of computers. Instructor: Thompson.

IS 280. Research in Information Science. *Units in accordance with work accomplished. Approval of student's research advisor and his department advisor 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 337.

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, turbulent flames. Instructor: Rannie.

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: Zukoski.

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. Offered 1968-69. 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 1968-69. 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 (1-0-0); each term.* Seminar on current research problems in propulsion and related fields. Instructors: Staff.

LANGUAGES*

UNDERGRADUATE SUBJECTS

L 1 abc. Elementary French. *10 units (3-1-6); first, second, third terms.* A course in grammar, pronunciation, and reading that will provide the student with a vocabulary and with a knowledge of grammatical structure sufficient to enable him to read at sight French scientific prose of average difficulty. Accuracy and facility will be insisted upon in the final tests of proficiency in this subject. One session in the language laboratory will be scheduled each week. Students who have had French in the secondary school should not register for this subject without consulting with the department of languages. Instructor: Rosenstone. *Not available for credit toward humanities-social science requirement.*

L 5 abc. French Literature. *9 units (3-0-6). Courses need not be taken in sequence. Prerequisite: Ability to read French with some ease.* Reading of a limited number of major literary works, accompanied by discussion of the literary and language problems they present. Instructor: Greenlee.

L 32 abc. Introductory 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. Instructors: Bowerman, Jobst. *Not available for credit toward humanities-social science requirement.*

L 33 abc. Introductory Literary German. *10 units (3-1-6); first, second, third terms.* A study of the fundamentals of grammar and pronunciation, culminating in the reading of several short literary works by modern German writers. Although primary emphasis is upon the reading goal, some stress is also placed upon the oral use of the language by both instructor and students. Classroom work is supplemented by an hour of language laboratory drill weekly. Students who have had German in the secondary school or junior college should not register for this course without consulting the staff in languages. Instructor: Wayne. *Not available for credit toward humanities-social science requirement.*

L 35. Scientific German. *10 units (0-0-10); first term. Prerequisite: L 32 abc, or equivalent.* This is a continuation of L 32 abc, with special emphasis on the translation of scientific material in the student's field. Instructor: Bowerman. *Not available for credit toward humanities-social science requirement.*

L 37 abc. Intermediate Readings in German Literature. *9 units (2-0-7). Prerequisite: L 32 or L 33 with grade of B or better, or equivalent.* The reading of selected short works of intermediate difficulty with some classroom drill in listening comprehension and controlled conversation. Students who wish to offer German study elsewhere as basis for admittance to the course should consult the appropriate staff member in languages. Instructor: Wayne.

L 39 abc. Reading in French or German. *Units to be determined for the individual by the department.* Reading in scientific or literary French or German under the direction of the department. *Not available for credit toward humanities-social science requirement.*

L 50 abc. Elementary Russian. *10 units (4-0-6); 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. Students are expected to become familiar with a basic scientific vocabulary. Articles from current Russian scientific periodicals are used in the second and third terms. Instructors: Kosloff, Novins. *Not available for credit toward humanities-social science requirement.*

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. Instructor: Kosloff.

ADVANCED SUBJECTS

L 102 abc. French for Graduate Students. *10 units (3-1-6); first, second, third terms.* The first year of a two-year course, designed to give the student a superior reading knowledge of the language, and the ability to understand the contents of a lecture in his general field and to discuss the subject matter in the language, as well as some competence in general conversation. Open to a limited number of graduate students. *Prerequisite: none.* Instructor: Greenlee.

L 103 abc. *10 units (3-1-6); first, second, third terms.* The continuation of L 102 abc. *Prerequisite: L 102 abc or equivalent.* Instructor: Greenlee.

L 105. Same as L 5. For graduate students.

L 130 abc. German for Graduate Students. *10 units (3-1-6); first, second, third terms. Prerequisites: none. Open to a limited number of graduate students.* The first year of a two-year course, designed to give the student a superior reading knowledge of the language and the ability to understand the contents of a lecture in his general field and to discuss the subject matter in the language, as well as some competence in general conversation. Instructor Jobst.

L 131 abc. German for Graduate Students. *10 units (3-1-6); first, second, third terms. Prerequisite: L 130 abc or equivalent.* The continuation of L 130 abc. Instructor: Jobst.

L 140. German Literature. *9 units (2-0-7); third term. Prerequisite: Ability to read and to speak German with some ease.* Reading of selected modern German literary works, accompanied by discussion of the literary problems they present. Conducted in German. Open to undergraduate and graduate students. Instructors: Staff.

L 152 abc. Russian for Graduate Students. *10 units (3-1-6); first, second, third terms. Prerequisite: none.* Open to a limited number of graduate students. The first year of a two-year course, designed to give the student a superior reading knowledge of the language and the ability to understand the contents of a lecture in his general field and to discuss the subject matter in the language, as well as some competence in general conversation.

L 153 abc. Russian for Graduate Students. *10 units (3-1-6); first, second, third terms. Prerequisite: L 152 abc or equivalent.* The continuation of L 152 abc. Offered 1969-70.

*For linguistics, see En 102 in this catalog, page 337.

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. Instructors: Clark, Buffington.

ADVANCED SUBJECTS

MS 100. Advanced Work in Physical Metallurgy. The staff in physical metallurgy will arrange special courses or problems to meet the needs of students working toward the M.S. degree or 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 will deal with the crystal structure of solids and X-ray diffraction. The first term will also include a discussion of crystal imperfections, including dislocations associated with basic concepts of the mechanical behavior of metallic materials. The second term will consist 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 will be devoted to a discussion of nucleation and growth and phase transformations in one and two component systems. Instructors: Buffington, Duwez, Vreeland, Wood.

MS 102. Pyrometry. *9 units (1-6-2); third term. Prerequisite: Ph 2 abc.* Study of the principles of thermometry and the theory underlying instruments that are used to measure temperatures. Experiments will be conducted with a variety of such instruments to illustrate their applications and limitations. Instructors: Staff.

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 will be concerned with the techniques of optical metallography and photomicrography, temperature measurements, and cooling curves. The second term will be concerned with the instrumentation and techniques used in the study of the mechanical behavior of solids involving the measurement of stress and strain. The third term will be 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: Clark, Duwez, Vreeland, Wood.

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 antistropic 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: MS 115 a.* Essential features of the electron microscope. Geometrical aspects of electron diffraction: Kikuchi lines; double diffraction. Kinematical theory of electron diffraction and its limitations. Dynamical theory of electron diffraction including anomalous absorption. Application of theory to the study of stacking-faults, dislocations, second-phase particles, anti-phase boundaries in ordered crystals. Study of periodic and ordered structures by direct lattice resolution and Moire fringes. Lorentz microscopy of ferromagnetic materials.

MS 126. Transmission Electron Microscopy Laboratory. *9 units (0-3-6); second term. Prerequisite: MS 125.* Principles of operation of the electron microscope, emphasizing the techniques necessary for work in diffraction contrast; e.g., dark-field microscopy, selected area diffraction; preparation of thin foils from bulk metal samples; experiments on contrast effects from commonly encountered crystalline imperfections such as dislocations, stacking faults, coherent precipitates; experiments on ferromagnetic films using the techniques of Lorentz microscopy.

MS 135. Radioisotopes Laboratory. *9 units (0-9-0); third term. Prerequisites: AM 103 a, MS 112 a.* Experiments illustrating the use of radioisotopes in the field of physical metallurgy. Typical examples are studies of solid state diffusion and the determination of chemical inhomogeneities in metals and alloys. Instructor: Buffington.

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: *Dislocations*, Friedel. 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 II. *9 units (0-6-3); any term. Prerequisite: MS 116.* 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 will be assigned, depending on the student's field of interest. Instructor: Duwez.

MS 225. Industrial Physical Metallurgy. *9 units (0-6-3); any term. Prerequisites: MS 103, MS 116.* Application of the principles of physical metallurgy and the techniques of metallographic laboratory practice to the solution of problems concerning the causes of failure of commercial parts. Typical cases are used as problems to be solved by the student and presented and discussed before the class and staff in the form of reports. Instructor: Clark.

MS 250 abc. Advanced Topics in Physical Metallurgy. *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 207abc	Mechanical Behavior and Ultimate Properties of Polymers (See Chemical Engineering Section)

Ch 21 abc	Physical Chemistry (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. *6 units (2-0-4) for the lecture part of the course and 4 units (2-0-2) for the recitation part of the course; 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 lecture part of the course stresses primarily the mathematical notions of the calculus and the other topics listed above. Credit for this lecture course is obtained on a term-by-term basis.

The recitation part of the course consists of two recitations per week. It provides active practice by the students in the applications of the corresponding mathematical techniques. Credit for this recitation course is obtained by passing appropriate examinations which will be given at regular intervals. Instructor in charge: Dean.

Ma 1 bc, 2 a. Advanced Placement Freshman Mathematics. *6 units (2-0-4) for the lecture part of the course and 4 units (2-0-2) for the recitation part of the course; first and second terms; 12 units (4-0-8); third term.* This course is restricted to entering freshmen who have been given credit for Ma 1 a. Topics covered are those of the second and third terms of Ma 1 abc as described above and those of the first term of Ma 2 abc as described below. Instructor in charge: DePrima.

Ma 2 abc. Sophomore Mathematics. *12 units (4-0-8); 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. Also topics selected from: probability; numerical anaylsis; partial differential equations. Instructor in charge: Apostol.

Ma 2 bc. Advanced Placement Mathematics. *12 units (4-0-8); first and second terms.* This course is restricted to sophomores who have completed Ma 2 a. Topics covered are those of the second and third terms of Ma 2 abc as described above. Instructors: Schultz, Glasner, Whitham.

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: Crawley, Kisilevsky, Wales.

Ma 31. Introduction to the Constructive Theory of Functions. *9 units (3-0-6); first 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 1968-69.

Ma 91. Special Course. *9 units (3-0-6); third term.* Normally, during the third term, a course will be given in one of the following topics:

(a) Some field of number theory. (Given in 1966-67.)
(b) Some field of algebra or logic. (Given in 1965-66.)
(c) Some field of analysis. (Given in 1964-65.)
(d) Game Theory. (Given in 1960-61.)

Ma 92 abc. Senior Thesis. *9 units (0-0-9); three terms. Prerequisite: Approval of advisor.* 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); first term.* Selected topics in metrical differential geometry. Not offered in 1968-69.

Ma 103. Algebraic Geometry. *9 units (3-0-6); second term. Prerequisite: Ma 5 abc.* A study of the relations between geometric objects (varieties) and the algebraic structures attached to them. Not offered in 1968-69.

Ma 104. Projective Geometry. *9 units (3-0-6); second term. Prerequisite: Ma 5 abc.* Foundation of projective geometry. Theorems of Desargues and Pappus. Introduction of coordinates. Selected topics on properties of incidence and order, and various systems of coordinates. Given in 1968-69 and alternate years. Instructor: Ryser.

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 Lebesgue integral of function of one or more variables is considered. Other topics include: functions defined by integrals; Fourier series and integrals; Poisson summation formula. Instructors: Luxemburg, Boyd, J. Todd.

Ma 109. Delta Functions and Generalized Functions. *9 units (3-0-6); first term.* Introduction to operational calculus and to delta functions. Applications to ordinary and partial differential equations. Given in 1969-70 and alternate years.

Ma 112. Elementary Statistics. *9 units (3-0-6); first and repeated in third term. Prerequisites: Ma 1, Ma 2.* This course is intended for anyone interested in the application of statistics to science and engineering. The topics treated will include the preparation and systematization of experimental data, the fundamental statistical concepts; population, sample, mean and dispersion, curve fitting and least squares, significance tests and problems of statistical estimation. Instructor: 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. Given in 1967-68. 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: Bohnenblust.

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

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 experiment, linear programming, and finite geometrics. Instructor: Ryser.

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. Topics include solution of recurrence relations, use of generating functions, random number generation, properties of tree structures, algorithms for sorting and searching, optimal evaluation of polynomials, multiple precision arithmetic, backtrack algorithms, recursive subroutines and co-routines, syntax and semantics of languages, parsing algorithms. Not offered in 1968-69.

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. Instructor: Lau.

Ma 143 abc. Introduction to Functional Analysis and Integral Equations. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* This course provides an introduction to methods of functional analysis. L^p spaces and their conjugates. Stieltjes integrals. The Riesz representation theorem. Daniell integrals. The Radon-Nikodym theorem. Linear operators on Banach spaces. Spectral theory of compact operators. Integral equations with applications to potential theory and to the Sturm-Liouville problem. Instructor: Zaanen.

Ma 144 ab. Probability. *9 units (3-0-6); first and second terms. Prerequisite: Ma 108 or equivalent.* Basic concepts of probability, limit theorems, random walks, Markov chains, stochastic processes with applications. Instructor: Lorden.

Ma 150 abc. Combinatorial Topology. *9 units (3-0-6); three terms.* Introduction to combinatorial topology. The course covers homology and co-homology theory with applications to fixed point theorems and homotopy theory. Selected topics from the theory of fibre 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. Given in 1969-70 and alternate years.

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. Given in 1969-70 and alternate years.

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: Hall, Wales.

[B] The following courses are open primarily to graduate students. Notice that some courses are given on an alternating basis.

Ma 205 abc. 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 value 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, Schultz.

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 1968-69.

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. Given in 1969-70 and alternate years.

Ma 223 ab. Matrix Theory. *9 units (3-0-6); second and third terms. Prerequisite: Ma 120 or equivalent.* Algebraic, arithmetic and analytic aspects of matrix theory. Not offered in 1968-69.

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. Given in 1968-69 and alternate years. Instructors: Crawley, 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. Not offered in 1968-69.

Ma 237 abc. Real Variable Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 143 or equivalent.* The axiom of choice and its relation to the other axioms of set theory. Measure theory; the theory of integration; and related topics such as differentiation of set functions, Banach function spaces, and ergodic theory. Topological linear spaces, introduction to Banach algebras, the Stone-Weierstrass theorem. Instructor: Ellis.

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. Instructor: Glasner.

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 1968-69.

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 1968-69.

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. Second and third terms.*

Ma 324 abc. Seminar in Matrix Theory. *Units to be arranged. Three terms.* Instructor: O. Todd.

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.* Kinematic and dynamic analysis of basic and commonly encountered useful machine elements and mechanisms. Development of approximate graphical and analytical techniques for rapid engineering evaluation and as tools for design and synthesis. Study of machine elements and mechanisms in terms of their design criteria involving materials, manufacturing, economic, and other factors. Emphasis will be on rational approaches to engineering design problems. Instructors: Auksmann, 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, Auksmann, 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 nonequilibrium 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. Flow and wave phenomena in open conduits. Theory and practice of some turbomachines such as fans, pumps, compressors, and turbines. Convective transfer of heat. Availability of mechanical, chemical, nuclear, and solar energy sources. Brief discussion and comparison of some types of systems for power. 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 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, Auksmann, 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, 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 302.
Hydraulics, page 349.
Jet Propulsion, page 354.
Materials Science, page 358.

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: MacGowan. *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.

PALEONTOLOGY

(See under Geological Sciences)

PHILOSOPHY AND PSYCHOLOGY

UNDERGRADUATE SUBJECTS

Pl 1. Introduction to Philosophy. *9 units (3-0-6).* 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: Hertz.

Pl 2. Symbolic Logic. *9 units (3-0-6).* A study of the logic of elementary propositions, the logic of general propositions, the logic of relations and the logic of classes as a basis for the philosophical analysis of knowledge. Instructor: Bures.

Pl 3. Contemporary European Philosophy. *9 units (3-0-6).* A critical analysis of the main trends in contemporary European philosophy, especially in France, Germany, Italy, and Spain. The course will include neo-Kantianism, neo-Hegelianism, Bergsonism, Logical-Positivism, Phenomenology, neo-Thomism, and Existentialism, in their influence on the whole of modern culture.

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 Behavioral 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: Shenfield.

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. Instructor: Ferguson. *Not available for credit toward humanities-social science requirement.*

Pl 9. Epistemology. *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, and the past and the future; the verifiability theory of factual meaning; the nature and justification of logical truth. Instructor: Hertz.

Pl 10. Philosophy of Language. *9 units (3-0-6).* A systematic study of philosophy problems pertaining to the structure of language and the relation of language to thought, perception and action. The work of linguists and philosophers will be considered. Instructor: Hertz.

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.*

ADVANCED SUBJECTS

Pl 100 abc. Philosophy 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 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 353.)

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 two general lectures each week, in which the main topics of the course are presented, and two 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: Neugebauer, Sherwood, 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 the same lines as 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: Barish, Cowan, Vogt, 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.

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.

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.

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.

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 γ-rays, ratios of abundances of isotopes and the Stern-Gerlach experiment.

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. Instructor: Leighton.

Ph 77 ab. Advanced Physics Laboratory. *6 units; second and 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: Kavanagh, Whaling.

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 1968-69 the topics will be (a) an introduction to nuclear physics, (b) nuclear astrophysics, (c) elementary particle physics. Instructors: Lauritsen, Fowler, Frautschi.

Ph 102 abc. Atomic Physics. *9 units (3-0-6); first, second and third terms. Prerequisites: Ph 2 abc, Ma 2 abc, or equivalents; Ph 106 abc concurrently.* A lecture and problem course on the experimental and theoretical foundations of the physics of atoms, nuclei, and elementary particles. The course will include a study of atomic and molecular structure, spectroscopy, radiative transitions and selection rules, with emphasis upon the interpretation of atomic properties on the basis of quantum mechanics. Selected topics in experimental and theoretical nuclear and particle physics will also be studied. In addition, there will be a discussion of classical and quantum statistical mechanics. Instructors: Barnes, Peck, Pine.

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: Christy, Frautschi, Persson, Tombrello.

Ph 113 abc. Introduction to 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. Instructor: Goodstein.

Ph 125 abc. Quantum Mechanics. *9 units (4-0-5); first, second, and third terms. Prerequisite: Ph 2 abc. Recommended: Ph 102 abc, and either AM 95 abc or Ma 108 abc.* A fundamental course in non-relativistic quantum mechanics aimed at understanding physical phenomena at the atomic level and introducing the mathematical techniques of calculation. The subject matter will include the Schrödinger equation, stationary states, the theory of angular momentum and spin, stationary and time-dependent perturbation theory, variational method, classical approximation, Zeeman effect, atomic structure, scattering, and quantum statistics. Instructors: Bahcall, Boehm, Walker.

Ph 129 abc. Methods of Mathematical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 106 abc or the equivalent (may be taken concurrently), and some knowledge of complex variables.* 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 non-commutative algebra. The emphasis is toward applications, with special attention to approximate methods of solution. Instructor: 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 Advisor 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 Advisor 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 Advisor or Registration Representative must be obtained before registering.

ADVANCED SUBJECTS

Ph 203 ab. Nuclear Physics. *9 units (3-0-6); second and third term. 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: Lauritsen.

Ph 204. Low Temperature Physics. *9 units (3-0-6); second 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 1968-69.

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: Mathews.

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. Instructor: Zachariasen.

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. Not offered in 1968-69.

Ph 214 ab. Solid State Physics. *9 units (3-0-6); first and second 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: Gregory.

Ph 216 abc. Introduction to 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 1968-69.

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 1968-69.

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. In 1968-69 the course will deal with resonance spectroscopy of gamma-radiation and its application to problems of solid state physics. Topics presented will include basic aspects of recoilless nuclear resonance absorption of gamma-radiation, isomer shifts, electric quadrupole and magnetic dipole hyperfine interactions in solids, origin of internal fields in matter, electronic relaxation phenomena in solids. The presentation includes many examples from current research developments. Instructor: Mössbauer.

Ph 227 abc. Thermodynamics, Statistical Mechanics, and Kinetic Theory. *9 units (3-0-6); first, second and third terms. Prerequisites: Ph 106 abc, Ph 125 abc, or the equivalent.* The fundamental concepts and laws of thermodynamics. Entropy and other characteristic functions. Nernst's theorem. Kinetic theory of gases. Classical and quantum statistical mechanics. The relation between statistical mechanics and thermodynamics. Illustrative applications of thermodynamics and statistical mechanics. Instructor: Plesset.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 205 abc.* 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: Feynman.

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: Heusch.

Ph 234 abc. Topics in Theoretical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 205 or equivalent.* The content of this course will vary from year to year. Topics presented will include: General methods in quantum mechanics such as operator calculus, group theory and its application; theory of meson and electromagnetic fields; atomic and molecular structure; theory of solids; theoretical nuclear physics. Instructor: Zweig.

Ph 236 abc. Relativity. *9 units (3-0-6); first, second and third terms.* A systemic exposition of Einstein's special and general theories of relativity with particular emphasis on modern developments and applications. First term: the fundamentals of special relativity; relativistic kinematics; the Lorentz group; electromagnetism analyzed in the language of differential forms. Second and third terms: the fundamentals of general relativity; experimental tests; the general-relativistic theory of stellar structure and dynamics; gravitational collapse to zero volume; cosmology; gravitational radiation; failure of the concept of energy; Hamiltonian formulation of general relativity; attempts at canonical quantization of the gravitational field. Tensor analysis and differential geometry will be developed as required, but a prior familiarity with tensors will be most helpful in the second and third terms. 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 1968-69.

Ph 238 abc. Seminar on Theoretical Physics. *4 units; first, second, and third terms.* Recent developments in theoretical physics for specialists in mathematical physics. In charge: Frautschi, Christy, Feynman, Gell-Mann, Mathews, Zachariasen, 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 Advisor or Registration Representative must be obtained before registering.

POLITICAL SCIENCE

ADVANCED SUBJECTS

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)

Section VII

DEGREES CONFERRED JUNE 7, 1968

DOCTOR OF PHILOSOPHY

Nawal Abd El-Hay Ahmed *(Neurophysiology)*. B.Sc. (Hons.), Ain Shams University (Egypt), 1959; B.Sc. (Hons.), 1961. *Thesis:* The Iodide Space in Rabbit Brain.

Christopher Marlowe Anderson *(Astronomy)*. B.S., University of Arizona, 1963. *Thesis:* The Interstellar Extinction of Stars in H II Regions.

Johann Arbocz *(Aeronautics)*. B.S., Northrop Institute of Technology, 1963; M.S., California Institute of Technology, 1964. *Thesis:* The Effect of General Imperfections on the Buckling of Cylindrical Shells.

Luc-Olivier Edouard Bauer *(Engineering Science)*. Dipl., Ecole Polytechnique Lausanne, 1962; M.S., California Institute of Technology, 1964. *Thesis:* Experimental Study of Upper Hybrid Echo in Plasmas.

William Robert Bauer *(Chemistry)*. B.S., California Institute of Technology, 1961; B.A., Oxford University, 1963. *Thesis:* I. The Structure and Properties of Closed Circular Duplex DNA. II. Chemically Interacting Systems at Equilibrium in a Buoyant Density Gradient.

Eric Edward Becklin *(Physics)*. B.S., University of Minnesota, 1963. *Thesis:* Infrared Observations of the Galactic Center.

Lon Edward Bell *(Mechanical Engineering)*. B.S., California Institute of Technology, 1962; M.S., 1963. *Thesis:* Energy Transport by Combined Radiation and Conduction.

David Bernard Benson *(Engineering Science and Mathematics)*. B.S., California Institute of Technology, 1962; M.S., 1963. *Thesis:* Formal Languages, Part Theory and Change.

Elliot R. Bernstein *(Chemistry and Physics)*. A.B., Princeton University, 1963. *Thesis:* I. Site Effects and Exciton Structure in Molecular Crystals-Benzene. II. The First and Second Triplet States of Solid Benzene.

Fred Andrew Blum, Jr. *(Physics)*. B.S., University of Texas, 1962; M.S., California Institute of Technology, 1964. *Thesis:* Echoes and Scattering From Plasma in a Magnetic Field.

George Wallace Bluman *(Applied Mathematics)*. B.Sc., University of British Columbia, 1964. *Thesis:* Construction of Solutions to Partial Differential Equations by the Use of Transformation Groups.

Kenneth Paul Bogart *(Mathematics)*. B.S., Marietta College, 1965. *Thesis:* Structure Theorems for Local Noether Lattices.

Charles LaMonte Borders, Jr. *(Chemistry)*. B.A., Bellarmine College, 1964. *Thesis:* I. Purification and Partial Characterization of Testicular Hyaluronidase. II. Mechanistic Studies of Human Lysozyme.

James David Bowman *(Physics and Mathematics)*. B.S., California Institute of Technology, 1961. *Thesis:* The Measurement of Nuclear Gyromagnetic Ratios of Short Lived States Using Internal Fields.

Richard Runyon Brock *(Civil Engineering).* B.S., University of California (Berkeley), 1961; M.S., 1962. *Thesis:* Development of Roll Waves in Open Channels.

Robert Jay Buck *(Mathematics).* B.A., University of Buffalo, 1963. *Thesis:* A Generalized Hausdorff Dimension for Functions and Sets.

David Chapman Cartwright *(Chemical Physics and Physics).* B.S., Hamline University, 1962; M.S., California Institute of Technology, 1963. *Thesis:* The Exchange Excitation of Helium and the Hydrogen Molecule by Low Energy Electrons.

Ronald Sinclair Cole *(Chemistry).* A.B., University of California (Riverside), 1962. *Thesis:* I. Photodimerzations of Coumarin. II. Asymmetric Induction During Energy Transfer.

Steven Douglas Colson *(Chemistry).* B.S., Utah State University, 1963. *Thesis:* Excitons in Crystalline Benzene.

Robert William Conn *(Engineering Science).* B.Ch.E., Pratt Institute, 1964; M.S., California Institute of Technology, 1965. *Thesis:* The Theory of Pulsed Neutron Experiments in Polycrystalline Moderators.

Antonio Crespo-Martínez *(Aeronautics).* Ing., Escuela Técnica Superior de Ingenieros Aeronáuticos (Madrid), 1964; M.S., California Institute of Technology, 1965. *Thesis:* I. Theoretical Investigation of the Reflection of Ionizing Shocks. II. Theoretical Study of Sound and Shock Waves in a Two-Phase Flow.

Michael Edward Dahmus *(Biochemistry and Chemistry).* B.S., Iowa State University, 1963. *Thesis:* I. Studies on Chromosomal RNA. II. Effect of Hydrocortisone on the Template Activity of Liver Chromatin.

Charles Newbold David *(Biophysics and Chemistry).* A.B., Harvard College, 1962. *Thesis:* Ferritin in the Fungus *Phycomyces.*

Guy DeBalbine *(Engineering Science).* Dipl. Ing., Ecole Centrale des Arts et Manufactures (Paris), 1963; M.S., California Institute of Technology, 1964. *Thesis:* Computational Analysis of the Random Components Induced by a Binary Equivalence Relation.

Raymond Kay DeLong *(Mechanical Engineering).* B.S., Kansas State University, 1962; M.S., California Institute of Technology, 1965. *Thesis:* The Unsteady Forces on Slender Delta Wing Hydrofoils Oscillating in Heave.

Andrea DeMari *(Electrical Engineering and Physics).* Ing., Politécnico di Torino, 1962; M.S., California Institute of Technology, 1964. *Thesis:* Accurate Numerical Steady-State and Transient One-Dimensional Solutions of Semiconductor Devices.

Dennis Jon Diestler *(Chemistry).* B.S., Harvey Mudd College, 1964. *Thesis:* I. Quantum Mechanics of One-Dimensional Two-Particle Models. II. A Quantum Mechanical Treatment of Inelastic Collisions.

James Johnson Duderstadt *(Engineering Science and Physics).* B.E., Yale University, 1964; M.S., California Insittute of Technology, 1965. *Thesis:* The Theory of Neutron Wave Propaganda.

Richard Timothy Eakin *(Biochemistry and Chemistry).* B.S., University of Texas, 1963. *Thesis:* Mitochondrial Oxidase Systems in *Neurospora.*

David Albert Evans *(Chemistry).* A.B., Oberlin College, 1963. *Thesis:* A Stereoselective Approach Toward the Synthesis of Some Pentacyclic Triterpenes.

Douglas McIntosh Fambrough, Jr. *(Biochemistry and Chemistry).* B.A., University of North Carolina, 1963. *Thesis:* Studies on Plant and Animal Histones.

Steven Mark Farber *(Electrical Engineering and Mathematics).* B.S., California Institute of Technology, 1964; M.S., Stanford University, 1965. *Thesis:* On the Signal Selection Problem for Phase Coherent and Incoherent Communication Channels.

Rena Scher Fersht *(Aeronautics).* B.Sc., Israel Institute of Technology (Haifa), 1962; M.Sc., 1964. *Thesis:* Buckling of Cylindrical Shells with Random Imperfections.

Douglas Gun Fong *(Physics).* A.B., Princeton University, 1961. *Thesis:* Experimental Study of Antiproton-Proton Annihilation into a Pair of Charged Pi-Mesons or K-Mesons for Incident Antiproton Momenta in the Range from 0.72 GeV/c to 2.62 GeV/c.

David Scott Gilbert *(Neurophysiology).* A.B., Harvard College, 1963. *Thesis:* Visual Acuity and Eye Movements.

Robert Ridgeway Gilpin *(Engineering Science and Physics).* B.Sc., University of Alberta, 1964; M.S., California Institute of Technology, 1965. *Thesis:* An Electrothermal Instability in a Nonequilibrium Plasma.

Stuart Frederick Goldstein *(Cell Biology).* B.A., University of Minnesota, 1962. *Thesis:* Local Activation and Inactivation Experiments on Flagella.

Jeffrey Archibald Gorman *(Engineering Science).* B.C.E., Cornell University, 1958; M.S., California Institute of Technology, 1966. *Thesis:* The Mobility of Dislocations in High Purity Aluminum.

David Henry Griffel *(Physics).* B.Sc. (Hons.), Birmingham University (England), 1961. *Thesis:* Kinetic Theory of the Solar Wind and its Interaction with the Moon.

William Paul Gruber *(Mechanical Engineering).* B.S., University of Washington, 1962; M.S., California Institute of Technology, 1963. *Thesis:* Formation of Jets by Impulsive Acceleration of a Curved Free Surface.

Thomas Arthur Halgren *(Chemistry).* A.B., Wabash College, 1963. *Thesis:* Nature of the Radical Intermediates in a Cyclopropylcarbinyl-Allylcarbinyl System.

Roy Woodrow Harding, Jr. *(Biochemistry and Chemistry).* B.S., George Washington University, 1962. *Thesis:* Carotenoid Biosynthesis in *Neurospora Crassa.*

Robert Jack Hemstead *(Mathematics and Philosophy).* B.S., Stanford University, 1964. *Thesis:* Stationary Absolute Distributions for Chains of Infinite Order.

Thomas Louis Henyey *(Geophysics).* A.B., University of California (Berkeley), 1962. *Thesis:* Heat Flow Near Major Strike-slip Faults in Central and Southern California.

Chee Leung Ho *(Applied Mechanics).* B.Sc., Queen's University (Canada), 1963; M.S., California Institute of Technology, 1964. *Thesis:* Energy Inequalities and Error Estimates for Axisymmetric Torsion of Thin Elastic Shells of Revolution.

Leroy Edward Hood *(Biochemistry).* B.S., California Institute of Technology, 1960; M.D., Johns Hopkins University, 1964. *Thesis:* Antibodies: Structure, Genetics and Evolution.

Joel Anthony Huberman *(Biochemistry and Chemistry).* A.B., Harvard College, 1963. *Thesis:* Studies on the Structure and Function of Mammalian Chromosomes.

Robert John Huskey *(Genetics and Biophysics).* B.S., University of Oklahoma, 1960; M.S., 1962. *Thesis:* Isolation and Characterization of Deletion Mutants of Bacteriophage Lambda.

Harry Lester Hyndman *(Chemistry)*. B.S., University of Illinois, 1962. *Thesis:* The Excited State Geometry of Conjugated Dienes and Characterization of a Quantum Chain-Transfer Mechanism of Energy Transfer.

Lorella Margaret Jones *(Physics)*. B.A., Radcliffe College, 1964; M.S., California Institute, 1966. *Thesis:* Reggeization of Some Unequal Mass Processes Involving Higher Spins: The Reactions π N $\rightarrow$ VN, π N $\rightarrow$ V, and $\gamma_p \rightarrow \pi^+_n$.

John Joseph Kenny *(Electrical Engineering)*. B.S., University of Rhode Island, 1963; M.S., California Institute of Technology, 1964. *Thesis:* Electric Dipole Radiation in Isotropic and Uniaxial Plasmas.

Hugh Hartman Kieffer *(Planetary Science)*. B.S., California Institute of Technology, 1961. *Thesis:* Near Infrared Spectral Reflectance of Simulated Martian Frosts.

John Andrew Kiger, Jr. *(Biophysics and Chemistry)*. B.S., California Institute of Technology, 1963. *Thesis:* I. The Transcription of Simple and Complex DNAs by the RNA Polymerase of *Escherichia coli*. II. The Structure and Replication of Intracellular Bacteriophage Lambda DNA.

Jonathan Alan King *(Genetics and Chemistry)*. B.S., Yale University, 1962. *Thesis:* Steps in the Assembly of Bacteriophage T4.

Ronald Brian Kirk *(Mathematics)*. B.A., University of Colorado, 1963. *Thesis:* Measures in Topological Spaces.

John Michael Klineberg *(Aeronautics and Political Science)*. B.S.E., Princeton University, 1960; M.S., California Institute of Technology, 1962. *Thesis:* Theory of Laminar Viscous-Inviscid Interactions in Supersonic Flow.

Daniel Julius Krause *(Materials Science and Physics)*. B.Met.E., Ohio State University, 1958; M.S., California Institute of Technology, 1959. *Thesis:* Discontinuous Yielding and Fracture Initiation Near a Notch in Mild Steel.

Mitsuru Kurosaka *(Mechanical Engineering)*. B.S., University of Tokyo, 1959; M.S., 1961. *Thesis:* Approximate Theory for the Flow Through a Cascade of Cambered Airfoils.

Theodore Willis Laetsch *(Applied Mathematics)*. B.S., Washington University, 1961; S.M., Massachusetts Institute of Technology, 1962. *Thesis:* Eigenvalue Problems for Nonlinear Operators.

Frnest YeeYeung Lam *(Chemistry)*. B.Sc., University of Hong Kong, 1959; B.Sc. Sp. (Hons.), 1960. *Thesis:* I. Photodimerization of Cyclohexenone. II. Radiation Chemistry of Benzophenone in Cyclohexene Solution.

Richard Neil Lane *(Mathematics and English)*. B.S., California Institute of Technology, 1965. *Thesis:* Normal Structures and Automorphism Groups of t-Designs.

Richard Bondo Larson *(Astronomy and Physics)*. B.Sc., University of Toronto, 1962; M.A., 1963. *Thesis:* Dynamics of a Collapsing Protostar.

Raymond Walter Latham *(Electrical Engineering)*. B.Eng., *McGill University*, 1958; M.S., California Institute of Technology, 1959. *Thesis:* Electromagnetic Scattering From Cylindrically and Spherically Stratified Bodies.

Joseph Po-keung Lau *(Engineering Science and Applied Mathematics)*. B.Sc., Purdue University, 1962; M.S., California Institute of Technology, 1963. *Thesis:* Steady Surface Wave Pattern in Shear Flow.

Stephen Stuart Lavenberg *(Electrical Engineering)*. B.E.E., Rensselaer Polytechnic Institute, 1963; M.S., California Institute of Technology, 1964. *Thesis:* Feedback Communication Using Orthogonal Signals.

Leroy Chi-tsun Lin *(Chemistry and Physics).* B.S., Tunghai University (China), 1960; M.S., Texas Christian University, 1963. *Thesis:* I. The Crystal Structure of Potassium Bis-(Tricyanovinyl) Amine. II. NMR Studies of Alkali Halide Solutions. III. Elucidation of the Intramolecular Hydrogen Bond in Acetylacetone by the Deuterium Isotope Effect on the Chemical Shift of the Bridge Hydrogen.

Stephen Chung-Hsiung Lin *(Materials Science).* B.S., National Taiwan University, 1963; M.S., California Institute of Technology, 1965. *Thesis:* Structure and Properties of an Amorphous Ferromagnetic Alloy.

Kau-un Lu *(Mathematics).* B.S., National Taiwan University, 1961. *Thesis:* Some Properties of the Coefficients of Cyclotomic Polynomials.

Thomas William MacDowell *(Applied Mathematics).* B.S., California Institute of Technology, 1964. *Thesis:* Boundary Value Problems for Stochastic Differential Equations.

James Andrew Magnuson *(Chemistry).* B.S., Stanford University, 1964. *Thesis:* I. The Effect of N,N,N^1,N^1-Tetramethylethylenediamine on the Schlenk Equilibrium. II. The Nature of the Di-Grignard Reagent.

Thomas Bard McCord *(Planteary Science and Astronomy).* B.S., Pennsylvania State University, 1964; M.S., California Institute of Technology, 1966. *Thesis:* Color Differences on the Lunar Surface.

Thomas Richard McGetchin *(Geology and Planetary Science).* A.B., Occidental College, 1959; Sc.M., Brown University, 1961. *Thesis:* The Moses Rock Dike: Geology, Petrology and Mode of Emplacement of a Kimberlite-Bearing Breccia Dike, San Juan County, Utah.

William Walter Miller *(Chemistry).* B.S., University of California (Berkeley), 1963. *Thesis:* The Role of Coenzyme B_{12} in the Isomerization of Methylmalonyl Coenzyme A.

Michael Philip Mortell *(Applied Mathematics).* B.S., University College (Cork), 1961; M.S., 1963; M.S., California Institute of Technology, 1964. *Thesis:* Some Approximate Solutions of Dynamic Problems in the Linear Theory of Thin Elastic Shells.

Calvin Elroy Moss *(Physics).* B.S., University of Virginia, 1961; M.S., California Institute of Technology, 1963. *Thesis:* Nuclear Energy Levels of ^{31}s and ^{33}C1.

Adolph Vincent Mrstik, Jr. *(Electrical Engineering).* B.S., University of Illinois, 1964; M.S., 1965. *Thesis:* The Resolution of the Thermodynamic Paradox and the Theory of Guided Wave Propagation in Anisotropic Media.

Hans-Karl Christian Alfred Mueller *(Aeronautics).* Dipl., Technische Hochschule Aachen, 1963; M.S., California Institute of Technology, 1964. *Thesis:* Stable Crack Propagation in a Viscoelastic Strip.

Michael John O'Sullivan *(Applied Mechanics and Mathematics).* B.E., University of Auckland, 1962; B.Sc., 1963. *Thesis:* On the Dynamic Behavior of Thin Elastic Plates.

Martin Lawrence Pall *(Biochemistry and Genetics).* B.A., Johns Hopkins University, 1962. *Thesis:* I. Tyrosinase Induction by Antimetabolites in Neurospora. II. Amino Acid Transport in Neurospora.

Albert Bernard Pincince *(Civil Engineering).* B.S., Northeastern University, 1963; M.S., California Institute of Technology, 1965. *Thesis:* Oxygen Relationships in Intermittent Sand Filtration of Wastewaters.

Hugo de Oliveira Piva *(Aeronautics and Applied Mathematics)*. Ae.E., Instituto Tecnológico de Aeronáutica (Brazil), 1958; M.S., California Institute of Technology, 1965. *Thesis:* Electron Beam Measurements of Density in Shock Waves Reflecting From a Cold Wall.

Roger James Radloff *(Biophysics and Chemistry)*. B.S., Iowa State University, 1962. *Thesis:* Structure and Properties of Closed Circular DNA.

Merle Eugene Riley *(Chemistry)*. B.S., Marietta College, 1963. *Thesis:* Energy Transfer in Molecular Collisions.

Leon S. Rochester *(Physics)*. A.B., University of Chicago, 1962. *Thesis:* Photoproduction of ETA Mesons from Hydrogen at Photon Energies Betewen 0.8 and 1.45 GeV.

Anil Sadgopal *(Biochemistry and Chemistry)*. B.Sc. (Hons.), University of Delhi, 1960; M.Sc., Indian Agricultural Research Institute, 1962. *Thesis:* I. Sychronization of the Cell Division Cycle of HeLa Cells in Suspension Cultures. II. Studies on Chromosomal Proteins of HeLa Cells During the Cell Division Cycle.

Jeffrey Drexel Scargle *(Astronomy)*. B.A., Pomona College, 1963. *Thesis:* Activity in the Crab Nebula.

Charles Albert Schaffner *(Electrical Engineering)*. B.S., Drexel Institute of Technology, 1961; M.S., University of Southern California, 1963. *Thesis:* The Global Optimization of Phase-incoherent Signals.

Robert Jay Schmulian *(Applied Mathematics)*. B.S., California Institute of Technology, 1963. *Thesis:* Nearly Free Molecular Heat Transfer from a Sphere.

William Addison Scott *(Biochemistry and Chemistry)*. B.S., University of Illinois, 1962. *Thesis:* Cytochrome c Synthesis in *Neurospora Crassa.*

Robert L. Seliger *(Applied Mathematics)*. B.S., Polytechnic Institute of Brooklyn, 1963. *Thesis:* I. On the Breaking of Nonlinear Dispersive Waves. II. Variational Principles in Continuum Mechanics.

Pattamadai Narasimhan Shankar *(Engineering Science and Physics)*. B.Sc., Imperial College of Science and Technology (London), 1964; M.S., California Institute of Technology, 1967. *Thesis:* I. The Effect of Droplet Solidification Upon Two-Phase Flow in a Rocket Nozzle. II. A Kinetic Theory Investigation of Some Condensation-Evaporation Phenomena by a Moment Method.

Wesley Loren Shanks *(Physics)*. B.S., California Institute of Technology, 1960; M.S., 1964. *Thesis:* The Photoproduction of Charged Pions from Hydrogen at Photon Energies Between 800 and 1500 MeV.

Cheng-chung Shen *(Engineering Science)*. B.S., National Taiwan University, 1959; M.S., Massachusetts Institute of Technology, 1964. *Thesis:* I. Stokes Flow Past a Thin Screen. II. Viscous Flows Past Porous Bodies of Finite Size.

Arnold Louis Shugarman *(Chemistry)*. B.Sc., California State College at Los Angeles, 1964. *Thesis:* I. Autoxidation of Manganese (II) β-Diketonates. II. Synthesis of Dipivaloylmethane Chelates of Manganese (II).

Leonard Merriman Stephenson, Jr. *(Chemistry)*. B.S., University of North Carolina, 1964. *Thesis:* The Mechanism and Effect of the Quenching of Aromatic Hydrocarbon Singlet Excited States by Conjugated Dienes.

Richard Forsythe Taylor *(Mathematics)*. A.B., University of Kansas, 1964. *Thesis:* Invariant Subspaces in Hilbert and Normed Spaces.

Richard King Teague *(Chemical Engineering and Chemistry)*. B.S., Washington University, 1963; M.S., California Institute of Technology, 1965. *Thesis:* The Refractive Index and the Lorentz-Lorenz Function of Fluid Argon.

Ansel Frederick Thompson, Jr. *(Civil Engineering).* B.S., Pennsylvania State University, 1963; M.S., California Institute of Technology, 1965. *Thesis:* The Ultrafiltration of Salt-Polyelectrolyte Solutions.

Dino Sabatino Tinti *(Chemistry).* B.A., University of California (Riverside), 1962. *Thesis:* I. Spectroscopic Evidence for Slow Vibrational Relaxation in Excited Electronic States of Diatomics in Rare Gas Solids. II. Static Crystal Field Effects in the Electronic Spectra of Isotopically Mixed Benzene Crystals.

Virginia Louise Trimble *(Astronomy).* B.A., University of California (Los Angeles), 1964; M.S., California Institute of Technology, 1965. *Thesis:* Motions and Structure of the Filamentary Envelope of the Crab Nebula.

Matias Jose Turteltaub *(Applied Mechanics).* Ing., University of Chile, 1961; M.S., California Institute of Technology, 1965. *Thesis:* On Concentrated Loads and Green's Functions in Elastostatics.

Athanassios Demetrius Varvatsis *(Electrical Engineering and Physics).* Dipl., National Technical University (Greece), 1960; M.S., California Institute of Technology, 1965. *Thesis:* A Multiple Scattering Problem.

George Francis Vesley, Jr. *(Chemistry).* A.B., Ripon College, 1962; M.A., Wesleyan University, 1964. *Thesis:* Complications in the Systematic Study of Photochemical Mechanisms.

Pax Samuel Pin Wei *(Chemistry).* B.S., National Taiwan University, 1960; M.S., University of Illinois, 1963. *Thesis:* Determination of Electronic Energy Levels of Molecules by 90° Low Energy Electron Scattering.

Frank Julian Weigert *(Chemistry).* S.B., Massachusetts Institute of Technology, 1965. *Thesis:* Carbon-13 Magnetic Resonance Spectroscopy.

Martin Eric Weiner *(Materials Science and Applied Mathematics).* B.S., California Institute of Technology, 1964; M.S., 1965. *Thesis:* Magnetic Moments In Amorphous Palladium-Cobalt-Silicon Alloys.

Larry Gale Williams *(Biochemistry and Chemistry).* B.S., University of Nebraska, 1961; M.S., 1963. *Thesis:* Thymidine Metabolism in *Neurospora crassa.*

Franklin Bruce Wolverton *(Physics).* B.S., University of Michigan, 1961. *Thesis:* Pi Zero Photoproduction from Hydrogen Between 574 and 1211 MeV.

Tyan Yeh *(Applied Mathematics).* B.S., National Taiwan University, 1959; M.S., Cornell University, 1963. *Thesis:* I. Nonexistence of Looping Trajectories in Hydromagnetic Waves of Finite Amplitude. II. Breaking of Waves in a Cold Collision-free Plasma in a Magnetic Field. III. On Stability of Periodic Waves in a Cold Collision-free Plasma in a Magnetic Field.

Peter John Andrew Zoutendyk *(Engineering Science).* B.S., University of Washington, 1959; M.S., University of California (Los Angeles), 1961. *Thesis:* Spontaneous and Stimulated Light Emission Due to Radiative Recombination in Forward Biased Lead Telluride P-N Junctions.

Engineer's Degree

Chia-Chun Chao *(Aeronautical Engineer).* B.Sc., Taiwan Provincial Cheng Kung University, 1962; M.S., California Institute of Technology, 1964.

Raymond Benedict Dirling, Jr. *(Aeronautical Engineer).* B.S., Virginia Polytechnic Institute, 1964; M.S., 1965.

Saurindranath Majumdar *(Aeronautical Engineer).* B.E., University of Calcutta, 1963; M.E., McGill University, 1965.

Michael Herbert McLaughlin *(Mechanical Engineer).* B.M.E., Cornell University, 1965.

Patrick Dan Weidman *(Aeronautical Engineer).* B.S., California State Polytechnic College, 1963; M.S., California Institute of Technology, 1964.

Master of Science

Bernard Ikecukwu Afoeju *(Mechanical Engineering).* B.S., Yale University, 1967.

Ponmalai Vijayan Anandamohan *(Aeronautics).* B.E., Coimbatore Institute of Technology, 1967.

Vijay Hanumappa Arakeri *(Mechanical Engineering).* B.S., Utah State University, 1967.

Alain Adrien Artaud *(Electrical Engineering).* Ing., Ecole Polytechnique (Paris), 1964; Ing., Ecole Nationale Supérieure de l'Aeronautique (Paris), 1967.

Jerome Martin Auerbach *(Mechanical Engineering).* Sc.B., Brown University, 1967.

Christopher Henry Bajorek *(Electrical Engineering).* A.A., Pasadena City College, 1964; B.S., California Institute of Technology, 1967.

George Nick Balanis *(Electrical Engineering).* B.S., California Institute of Technology, 1967.

Stephen Joseph Barker *(Engineering Science).* B.S., Harvey Mudd College, 1967.

Ricardo Pablo Belloni *(Aeronautics).* B.S., Northrop Institute of Technology, 1967.

Edward Francis Bernard *(Physics).* B.S., Oregon State University, 1966.

Roland Charles Binst *(Mechanical Engineering).* Ing. Civ., Ing. Mech., Université de Louvain, 1965; Dipl. Nuclear Sc., 1967.

Donald Campbell Brabston, Jr. *(Applied Mathematics).* B.S., Georgia Institute of Technology, 1967.

Leonard William Brownlow, Jr. *(Electrical Engineering).* B.A., Pomona College, 1966; M.S., University of Arizona, 1967.

Jeffrey Allen Burke *(Electrical Engineering).* B.S.E.E., University of Michigan, 1967.

Tim Jay Burns *(Mechanical Engineering).* B.S., University of Redlands, 1967.

Michael Akylas Caloyannides *(Electrical Engineering).* B.S., California Institute of Technology, 1967.

Frank Udo Canis *(Mechanical Engineering).* B.Eng., McGill University, 1967.

Douglas Arthur Carne *(Applied Mechanics).* A.B., Occidental College, 1965; B.S., California Institute of Technology, 1967.

Lucian Carlton Carter III *(Physics).* B.A., University of Texas, 1960; B.S. (Chem.), 1960; B.S. (Ph.), 1961.

Sung Jen Chen *(Chemical Engineering).* B.S., National Taiwan University, 1962; M.S., Kansas State University, 1965.

John Pierce Classen *(Aeronautics).* B.S.E., Princeton University, 1966.

Barry Michael Cohen *(Mechanical Engineering).* B.S., Northeastern University, 1967.

Russel Elliot Cole *(Electrical Engineering).* B.S., University of California (Berkeley), 1967.

Nolan Gerald Core *(Engineering Science).* A.B., Harvard University, 1967.

Gerald Michael Cotreau *(Electrical Engineering).* A.A., Pensacola Junior College, 1964; B.S., University of Florida, 1967.

Luc Philippe Marie Cyrot *(Electrical Engineering).* Ing., Ecole Nationale Supérieure de l'Aeronautique, 1967.

John Charles Dean *(Electrical Engineering).* B.S., University of California (Santa Barbara), 1967.

Paul Maurice Debrule *(Engineering Science).* Ing. Physicien, Université de Liège, 1967.

Terry Joseph Delph *(Aeronautics).* B.A.E., Georgia Institute of Technology, 1967.

William Michael Denny *(Physics).* B.S., St. Louis University, 1964.

Samuel Digirolamo *(Aeronautics).* B.S., St. Louis University, 1967.

Charles Joseph Dixon *(Electrical Engineering).* B.S., University of Washington, 1967.

Robert Joseph D'Orazio *(Electrical Engineering).* B.S., Drexel Institute of Technology, 1967.

William Jack Driskell *(Biology).* B.S., University of Georgia, 1967.

Robert George Dunlap *(Aeronautics).* S.B., Massachusetts Institute of Technology, 1967.

Joseph Daniel Dupcak *(Aeronautics).* B.S.E., Princeton University, 1967.

Paul Marie Dupont *(Aeronautics).* Ing., Université de Louvain, 1967.

Edward Norton Evans *(Electrical Engineering).* B.S., University of California (Berkeley), 1967.

James Edward Fisher *(Geology).* B.S., Villanova University, 1966.

Jacques Pierre Fleuret *(Electrical Engineering).* Ing., Ecole Nationale Supérieure des Télecommunications, 1967.

Michael Glen Foley *(Aeronautics).* B.S., California Institute of Technology, 1967.

Blair Allen Folsom *(Mechanical Engineering).* B.S., California State College at Long Beach, 1967.

Kirby William Fong *(Applied Mathematics).* B.S., University of California (Berkeley), 1967.

Dennis Masato Furuike *(Applied Mechanics).* A.B., Occidental College, 1967; B.S., California Institute of Technology, 1967.

Detlef Hain Garbrecht *(Civil Engineering).* Diplom-Ingenieur, Technische Hochschule Karlsruhe, 1967.

Philip Wayne Garrison *(Aeronautics).* B.S.Ae.E., Auburn University, 1965.

Norton Robert Greenfeld *(Engineering Science).* B.S., California Institute of Technology, 1967.

Ryusuke Hasegawa *(Electrical Engineering).* B.E., Nagoya University, 1962; M.E., 1964.

Jimmy Lee Held *(Mechanical Engineering).* B.S., California Institute of Technology, 1967.

John Anthony Hoef, Jr. *(Aeronautics).* B.S., St. Louis University, 1967.

Bruce Lynn Hopper *(Mechanical Engineering).* B.S., Texas A & M University, 1967.

Duane Thomas Hove *(Aeronautics).* B.S., University of Minnesota, 1967.

Myung Kyu Hwang *(Chemical Engineering).* B.S., Seoul National University, 1965.

Michael Stephen Hyland *(Civil Engineering).* B.C.E., Manhattan College, 1967.

James Gregory Jerrell *(Electrical Engineering).* S.B., Massachusetts Institute of Technology, 1967.

Ender Mustafa Kaya *(Civil Engineering).* B.S., C. W. Post College, 1967.

Ronald Harrison Knapp *(Mechanical Engineering).* B.S., University of Hawaii, 1967.

Gary Don Knott *(Engineering Science).* B.A., American University (Washington, D.C.), 1964.

Toby Martin Kolstad, Jr. *(Applied Mechanccs).* B.S., Tulane University, 1967.

James Anthony Komarek *(Electrical Engineering).* B.S., Iowa State University, 1967.

Jacques Jean Lerau *(Civil Engineering).* Dipl., Institut National Des Sciences Appliquées (Toulouse), 1967.

Lucien Benjamin Levy *(Mathematics).* B.A., University of California (Los Angeles), 1967.

Michael Jay Lineberry *(Mechanical Engineering).* B.S., University of California (Los Angeles), 1967.

Richard Elmer Lowe *(Civil Engineering).* B.E., University of Southern California, 1951.

Michael Majteles *(Engineering Science).* B.S., University of California (Berkeley), 1967.

Dean Anthony Malencik *(Biology).* B.S., University of Notre Dame, 1965.

Ernesto R. Martin *(Mechanical Engineering).* B.S., University of Florida, 1967.

Wallace William Martin *(Mechanical Engineering).* B.A.Sc., University of Toronto, 1967.

Mario Martínez-García *(Physics).* Lic. Ciencias Físicas, Instituto Tecnológico y de Estudios Superiores de Monterrey, 1965.

Warren Louis McBride *(Chemical Engineering).* B.S., Purdue University, 1967.

William Keith McClary *(Physics).* B.Sc., University of Alberta, 1966.

Robert Leonard McDonald *(Electrical Engineering).* B.S., Iowa State University, 1967.

Harold Finley McFarlane *(Engineering Science).* B.S., University of Texas, 1967.

Michael Herbert McLaughlin *(Mechanical Engineering).* B.M.E., Cornell University, 1965.

Alan Noel Meier *(Aeronautics).* B.S., Northrop Institute of Technology, 1966.

Dale Loy Miller *(Engineering Science).* B.S., Arlington State College, 1965.

Ralph Edward Miller *(Chemistry).* B.S., Washington State University, 1964.

Robert Sanford Mitcham *(Mechanical Engineering).* B.S., United States Air Force Academy, 1967.

Charles Loyd Moore *(Mechanical Engineering).* B.S., United States Military Academy, 1966.

John Daryl Moore *(Mechanical Engineering).* B.S., University of California (Berkeley), 1967.

Wayne Meredith Moore *(Engineering Science).* B.S., University of California (Los Angeles), 1967.

Ronald Carl Moran *(Aeronautics).* B.S., University of Notre Dame, 1967.

Francois Marie Michel Morel *(Civil Engineering).* Dipl., Institut Polytechnique de Grenoble, 1967.

Jean-Pierre Georges Morel *(Aeronautics).* Ing., Ecole Centrale des Arts et Manufactures, 1965; Dr.Ing., Université de Paris, 1967.

Martin Yasuyuki Oiye *(Aeronautics).* B.S., California Institute of Technology, 1967.

John Edwin O'Pray *(Aeronautics).* B.S., California Institute of Technology, 1967.

Alan Harold Osterheim *(Mechanical Engineering).* B.S., University of Hawaii, 1967.

Adelbert Owyoung *(Electrical Engineering).* B.S., University of California (Berkeley), 1967.

Paul David Patent *(Mathematics).* B.A., Oakland University, 1965; M.A., 1966.

James Edward Pearson *(Electrical Engineering).* B.S., California Institute of Technology, 1967.

Philip Reed Perry *(Geology).* B.S., Cornell University, 1967.

Jay Cee Pigg, Jr. *(Astronomy).* B.S., Loyola University (New Orleans), 1966.

Jaime Podolsky *(Electrical Engineering).* B.S., National University of Mexico, 1966.

George Harber Purcell, Jr. *(Astronomy).* S.B., Massachusetts Institute of Technology, 1966.

Carl Frithjof Rasmussen *(Electrical Engineering).* A.A., Los Angeles City College, 1941; B.S., California Institute of Technology, 1947.

Gary Herbert Ratekin *(Aeronautics).* A.A., Bakersfield College, 1965; B.S., University of California (Berkeley), 1967.

Arakali Lakshminarayan Ravimohan *(Chemical Engineering).* B. Tech., Indian Institute of Technology (Bombay), 1967.

Edward Albert Rinderle, Jr. *(Applied Mathematics).* B.S., Louisiana State University, 1966.

Richard Stephen Rose *(Mechanical Engineering).* B.M.E., Rensselaer Polytechnic Institute, 1967.

James Edward Rumbaugh *(Astronomy).* S.B., Massachusetts Institute of Technology, 1967.

Charles George Sammis *(Geology).* Sc.B., Brown University, 1965.

Thomas Peter Santoro *(Electrical Engineering).* B.S., University of Rhode Island, 1967.

Jeffrey Lee Saperstein *(Aeronautics).* B.S., Columbia University, 1967.

Brian Morris Schaefer *(Engineering Science).* B.A.Sc., University of Waterloo, 1967.

Melvin Herbert Scott, Jr. *(Mechanical Engineering).* B.S., Purdue University, 1966.

Allen Curtis Shallbetter *(Electrical Engineering).* B.S., Washington State University, 1967.

Carl Alvin Shollenberger *(Aeronautics).* B.S., Pennsylvania State University, 1967.

James Dow Smith *(Aeronautics).* B.A.E., University of Minnesota, 1967.

Martin Leo Smith *(Geology).* B.S., California Institute of Technology, 1967.

Ira Robert Snyder *(Aeronautics).* B.S., Cornell University, 1967.

William Arthur Stinger *(Aeronautics).* B.S.E., Princeton University, 1967.

Erik Storm *(Aeronautics).* B.S., California Institute of Technology, 1967.

Arthur Dewey Struble III *(Aeronautics).* B.S., United States Naval Academy, 1967.

Frank Thomas Surber *(Aeronautics).* B.S., University of Nebraska, 1967.

Conrad Melton Swartz *(Chemical Engineering).* B.Ch.E., The Cooper Union, 1966.

Brian Hyman Tabak *(Electrical Engineering).* B.Eng. (Hons.), McGill University, 1967.

Robert Wofford Tate *(Electrical Engineering).* B.E., Yale University, 1963; M.E., 1963.

Bernard Tiegerman *(Aeronautics).* B.S., Polytechnic Institute of Brooklyn, 1967.

Ralph Christopher Tisdale *(Electrical Engineering).* B.S., Stanford University, 1967.

Clark John Tomita *(Electrical Engineering).* B.S., Illinois Institute of Technology, 1967.

Richard Martin Traci *(Aeronautics).* B.S., Carnegie Institute of Technology, 1967.

Eugene Ward Wester *(Electrical Engineering).* B.S., University of Kansas, 1967.

James Edward Westmoreland III *(Physics).* B.S., Georgia Institute of Technology, 1966.

Richard Jay Williams *(Electrical Engineering).* B.S., California Institute of Technology, 1967.

Eran Zaidel *(Engineering Science).* A.B., Columbia University, 1966.

Kenneth Allan Zuckerman *(Civil Engineering).* B.S.E., Princeton University, 1967.

Craig ZumBrunnen *(Geology).* B.A., University of Minnesota, 1966.

Bachelor of Science

Students whose names appear in boldface type are being graduated with honor in accordance with a vote of the Faculty.

Bruce W. Baillie, *Canton, Ohio*. English.
Robert Lee Bell, *Glendale, California*. Physics.
Peter Bernard Bendix, *Portland, Oregon*. Physics.
Richard Wayne Bild, *Placitas, New Mexico*. Chemistry.
William George Bloom, *Prairie Village, Kansas*. Chemical Engineering.
Peter Samuel Bloomfield, *Winthrop, Massachusetts*. Economics.
Kellogg Speed Booth, *Portuguese Bend, California*. Mathematics.
Jacques Gregori Bourque, *Babylon, New York*. Astronomy.
Paul S. Brandon, *Kent, Washington*. Economics.
Gregory John Brewer, *Malibu, California*. Biology.
Johan Michael Brinch, *Oslo, Norway*. Engineering.
Larry Robert Brown, *Portville, New York*. Chemistry.
Charles Joseph Bruce, *Savannah, Georgia*. Mathematics.
Terry Ronald Bruns, *La Puente, California*. Geophysics.
Douglas Lee Brutlag, *Albuquerque, New Mexico*. Biology.
James Edward Burns, *Atlanta, Georgia*. Mathematics.
Robert Duncan Campbell, *Downey, California*. Chemistry.
Bruce Alan Carter, *Hydesville, California*. Geology.
Michael Alan Casteel, *Auburn, Washington*. Physics.
Robert Nai-Young Chan, *Hong Kong*. Physics.
Daniel Pan Yih Chang, *Los Angeles, California*. Engineering.
David Chang, *Silver Springs, Maryland*. Physics.
Edward Jay Chapyak, *Montrose, New York*. Engineering.
Randall Bramston Cook, *Long Beach, California*. Chemistry.
Peter Stanley Cross, *North Hollywood, California*. Engineering.
Thomas Mills Dailey III, *Panama City, Florida*. Physics.
John Stanley Dancz, *Clifton, New Jersey*. Chemistry.
Erno Scipiades Daniel, *Santa Barbara, California*. Chemistry.
Roger Alvernaz Davidheiser, *Lodi, California*. Physics.
Charles Edward Dean, Jr., *Olympia, Washington*. Mathematics.
Henry Koch Dewitt, *Oakland, California*. Mathematics.
Paul Emmanuel Dimotakis, *Athens, Greece*. Physics.
Philip Doberne, *North Hollywood, California*. Mathematics.
James Eugene Downum, *Denver, Colorado*. Physics.
Richard Edwin Drews, *Brielle, New Jersey*. English.
Ronald Phillip Drucker, *Roseville, California*. Chemistry.
Denis Anthony Elliott, *San Gabriel, California*. Astronomy.
Leonard Ardel Erickson, Jr., *Tacoma, Washington*. Biology.
David Charles Erlich, *Los Angeles, California*. Physics.
Aaron Louis Felder, *Jeannette, Pennsylvania*. Mathematics.
Frederic Arthur Ferdman, *Studio City, California*. Mathematics.

Lester Alan Fettig, *Glendale, Brooklyn, New York.* Engineering.
Robert Steven Firestone, *Sepulveda, California.* Biology.
Leslie Gary Fishbone, *Elizabeth, New Jersey.* Physics.
Richard Alan Flammang, *Encino, California.* Physics & Economics.
Martin Richard Flannery, *Granby, Connecticut.* Physics.
William G. Fowler, *Suffern, New York.* Mathematics.
Curtis L. Frank, Jr., *Evansville, Indiana.* Engineering.
John Allen Frazzini, *Denver, Colorado.* Physics.
Jay Reynolds Freeman, *Burlington, Vermont.* Physics.
Carl A. Friedlander, *North Bellmore, New York.* English.
Kenneth Douglas Garbade, *New Hyde Park, New York.* Physics & History.
Eric Robert Garen, *Rancho Cordova, California.* Engineering.
Walter Christian Gish, *Colton, California.* Physics.
Gary Lunt Godfrey, *San Francisco, California.* Physics.
Stuart Robert Goodgold, *Torrance, California.* Mathematics.
Donald Robert Goral, *Los Angeles, California.* Mathematics.
Barton Joel Gordon, *Malden, Massachusetts.* Engineering.
Edward John Groth III, *Scottsdale, Arizona.* Physics.
Gregory Scott Harkness, *Tampa, Florida.* Physics.
Ulli Georg Hartmann, *Mountain View, California.* Engineering.
Jon Robert Haviland, *Radnor, Pennsylvania.* Engineering.
Brad Lee Holian, *Worland, Wyoming.* Chemistry.
Frederick John Hollander, *Pacific Palisades, California.* Chemistry.
James William Howell, *Sheridan, Wyoming.* Biology.
James Charles Hunter, *Los Angeles, California.* Chemistry.
David Lee Isaman, *San Jose, California.* Engineering.
Nathan Gerald Isgur, *South Houston, Texas.* Physics.
Clayton William Jacobsen, *Littleton, Colorado.* Chemistry.
Walter Joseph Jaffe, *Granada Hills, California.* Astronomy.
Vincent Robinson Johns, *Pottstown, Pennsylvania.* Mathematics.
Delmar Lee Johnson, *Brownsburg, Indiana.* Engineering.
Herbert Jubin, *Hayward, California.* Economics.
Lawrence Joseph Karr, *Torrance, California.* Economics & Engineering.
Raymond Robert Kawal, *Sepulveda, California.* Engineering.
Ralph Frederick Kimbrell, *Montgomery, Alabama.* Engineering.
Jules Michael Kline, *Chicago, Illinois.* Chemistry.
David Allen Kolb, *St. Joseph, Illinois.* Chemistry.
Gregory Nicolas Kourilsky, *Los Angeles, California.* Mathematics.
Kermit Rudolph Kubitz, *Janesville, Wisconsin.* Economics.
Steven Barry Landy, *Los Angeles, California.* Physics.
Allen Donald Lee, *Norwalk, California.* Engineering.
John Marquardt Lehman, *Portland, Oregon.* Engineering.
Jeffrey Samuel Leon, *Sacramento, California.* Mathematics.
Simon Rock Levinson, *New City, New York.* Biology.
Barry Richard Lieberman, *Gardena, California.* Physics.

Richard Glenn Ligon, *Almont, Michigan.* Mathematics & Economics.
Wayne Anthony Lobb, *Bedford, New Hampshire.* English.
Robert Shelley Logan, *Clinton, Iowa.* Engineering.
Samuel Ernest Logan, *Woodland Hills, California.* Physics.
Sali Gee-Chung Ma, *Monterey Park, California.* Engineering.
David Michael MacKenzie, *La Crescenta, California.* Engineering.
David Frantz Macy, *Austin, Minnesota.* Engineering.
James Anthony Maiorana, *Boonsboro, Maryland.* Mathematics.
Willard Graham Manning, Jr. *Aurora, Colorado.* Economics.
Robert Marcel Mattheyses, *North Hollywood, California.* Engineering.
Walter William Matyskiela, Jr., *Farmington, Connecticut.* Chemistry.
Craig Darryl Maxwell, *Arcadia, California.* Physics.
Craig James McAllister, *Trumbull, Connecticut.* Chemistry.
David Bruce McKay, *Waterville, Washington.* Physics.
John W. McKenzie, *Duluth, Minnesota.* Physics.
James Cyrus McWilliams, *Tulsa, Oklahoma.* Engineering.
John Middleditch, *Tucson, Arizona.* Physics.
Stanley Craig Nelson, *El Paso, Texas.* Physics.
Gary Stephen Nix, *Palm Springs, California.* Physics.
Richard Alan Norman, *Los Altos, California.* Engineering.
Donald Paul Olshove, *Glenwood Springs, Colorado.* Engineering.
Peter Dorrington Orsburn, *Pasadena, California.* Mathematics.
William Franklin Pate, *Phoenix, Arizona.* Economics.
Spencer Gordon Pearson, *Wyckoff, New Jersey.* Engineering.
Luther B. Perry, *Watsonville, California.* Physics.
Dean Edwin Peterson, *Des Moines, Iowa.* Engineering.
Harold L. Petrie, *Arcadia, California.* Engineering.
Phillip Roy Pfaffman, *Savannah, Georgia.* Mathematics.
Gregory George Pihos, *Sacramento, California.* Physics.
Sanford Mark Pokras, *Encino, California.* Chemistry.
Steven Edward Poltrock, *Seattle, Washington,* Engineering.
Wally Ewald Rippel, *Hollywood, California.* Physics.
Peter Alan Rumsey, *Berkeley, California.* Mathematics.
Walter Lawrence Ruzzo, *Marion, Ohio.* Mathematics.
Craig L. San Pietro, *Forest Hills, New York.* Engineering.
Norman Jensen Schofield, Jr., *Morris Plains, New Jersey.* Physics.
Marshall I. Schor, *Visalia, California.* Engineering.
Allen John Schwenk, *Milwaukee, Wisconsin.* Mathematics.
Edward Stephen Seguine, *Montebello, California.* Chemical Engineering.
David John Shirley, *Mobile, Alabama.* Mathematics.
Baruch Thomas Soifer, *Los Angeles, California.* Physics.
Craig Spencer, *Albany, Oregon.* Physics.
James Hammons Stanley, *Northridge, California.* Physics.
Robert Ernest Starrett, *Atlanta, Georgia.* Engineering.
Bruce Allen Stern, *Los Angeles, California.* Chemistry.

John Charles Stevens, *Pasadena, California.* Physics.
William Van Dover Stoecker, *St. Louis, Missouri.* Mathematics.
Robert Bruce Stokes, *San Jose, California.* Engineering.
Harry Brown Thacker, Jr., *Tucson, Arizona.* Physics.
Edward Floyd Thompson, *Sacramento, California.* Engineering.
Gregory Allan Thompson, *Los Angeles, California.* Chemistry.
Joseph David Titlow, *Tacoma, Washington.* Engineering.
George Kenton Tucker, *Grand Junction, Colorado.* Engineering.
Raymond Lloyd Wakefield, *Turlock, California.* Engineering.
John Franklin Walters, *Riverside, California.* Biology.
Dennis Miles Weaver, *Sacramento, California.* Astronomy.
Earl Glen Whitehead, Jr., *Rancho Santa Fe, California.* Mathematics.
Norman McKee Whiteley, *Portland, Oregon.* Chemistry.
Eric Wickstrom, *Evanston, Illinois.* Biology.
John Richard Wilschke, *Horsham, Pennsylvania.* Engineering.
Charles Allan Wolfe, *North Hollywood, California.* Engineering.
William Stephen Woodward, *Los Angeles, California.* Engineering.
Rufus Woody III, *Clovis, New Mexico.* Physics.
Neil Richard Wright, *Cincinnati, Ohio.* Economics.
Richard Weston Wright, *Midland, Texas.* Engineering.
William Allen Wright, *Phoenix, Arizona.* Geology.
Kenneth Teiji Yano, *Hilo, Hawaii.* Engineering.
Charles Peretz Zeller, *San Antonio, Texas.* Engineering.

HONORS AND AWARDS

HONOR STANDING

The undergraduate students listed below have been awarded honor standing for the current year, on the basis of excellence of their academic records for the year 1967-68.

No honor standing has been granted for the class of 1971. Under present Institute policy, grades in all freshman courses are only "P," indicating passed, or "F," indicating failed.

CLASS OF 1969

Clough, Gene Alan
Cummings, John Chester
Dede, Christopher James
DeVore, John Gerald
Evans, Gregory Walter
Farber, Michael Bruce
Fredman, Michael Lawrence
Grove, Gerald Franklin, Jr.
Hadler, Stephen Craig
Haralambis, Nicos Miltos
Hockert, John William
Hunt, Lawrence Allen
Inwood, William Buell
Jennings, Scott William
Jones, Stanley Eldon
Kalisvaart, Maarten
Kamm, Kenneth Salem
Leininger, James Edward
Loh, Edwin Din
Mitze, Robert Wayne
Molodowitch, Dennis Ray
Mosher, James Marshall
Nelson, Leroy Ernest
Nicolaides, Pericles Leonidas
Radomski, Mark Stephen
Reece, Douglas Kent
Sacks, Richard Arthur
Tarjan, Robert Endre
Villani, Daniel Dexter
Webster, Grant Daniel Lee
Wilson, Robert Dennis
Wright, Gregg Fleetwood
Young, Kenneth
Yuen, David Alexander

CLASS OF 1970

Atwood, William Bradford
Broido, Michael David
Carrie, Charles Dennis
Chevalier, Roger Alan
Cormier, Vernon Francis
Davis, Thomas Rowlands
Duesdieker, Giles Anthony
Epstein, Reuben
Feinberg, Jerry Mark
Fong, Kenneth Toy
Garrels, James Irwin
Gray, Robert James
Holmes, Neil Conrad
Horning, Tex Lawrence
Jain, Atul
Jensen, Eric Bruce
Kanamori, Akihiro
Kuan, Pui
Markert, Thomas Henry
Marshall, Howard Dennis
McCarthy, John Joseph
Messmer, John Patrick
Moore, Terrence Neil
Moreira, Armando Fernandes Da Silva
Murata, Gary Toshi
Ogawa, Arthur
Patterson, Steven Robert
Pearson, Peter Kelley
Piccard, Richard Dickson
Powers, Dana Auburn
Reul, Douglas Eric
Rewoldt, Gregory Maynard
Richardson, Jeffrey Howard
Rossum, David Philip
Samuelson, Bruce Victor
Szolovits, Peter
Thuan, Trinh Xuan
Tye, Sze-Hoi Henry
Wierenga, Steven Warren

American Institute of Aeronautics and Astronautics Award

Awarded to the student member of the AIAA attaining the best scholastic record in engineering or the physical sciences.

John Pierce Classen

Don Baxter, Inc. Prizes

Awarded to the undergraduate students who during the year have carried out the best original researches in chemistry.

First prize: Brad Lee Holian
Second prize: Richard Wayne Bild
Clayton William Jacobsen

E. T. Bell Mathematics Prize

Awarded annually to one or more juniors or seniors for outstanding original research in mathematics.

Michael Lawrence Fredman

Donald S. Clark Alumni Awards

Awarded annually to two sophomores and two juniors in recognition of demonstrated potential leadership and good academic performance. Preference is given to students in the Division of Engineering and Applied Science and to those in Chemical Engineering.

Claude Alan Beagle
Thomas Dee Burton
William David Nichols
Richard Rubinstein

Conger Peace Prizes

Established in 1912 by the late Everett D. Conger, D.D., for the promotion of interest in the movement toward universal peace, and for the furtherance of public speaking.

Not Given This Year

Eastman Kodak Scientific Awards in Chemistry

Awarded to doctoral students on the basis of outstanding contributions and progress either in graduate studies and research or in teaching.

James Kinsey Rice
Frank Julian Weigert

Haren Lee Fisher Memorial Award

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.

Kenneth Young

George W. Green Memorial Award

Awarded to the undergraduate students who, in the opinion of the Division Chairmen, have shown outstanding ability and achievement in the field of creative scholarship.

Douglas Lee Brutlag
Paul Emmanuel Dimotakis
Brad Lee Holian
Akihiro Kanamori

Honeywell Award

Established by Honeywell, Inc. for presentation to a senior student for outstanding individual performance in undergraduate engineering and science.

Gerald Franklin Grove, Jr.

Frederic W. Hinrichs, Jr., Memorial Award

Awarded to the senior who, in the opinion of the Undergraduate Deans, has throughout his years at the Institute made the greatest contributions to the welfare of the student body and whose qualities of leadership, character and responsibility have been outstanding.

John Allen Frazzini

David Joseph Macpherson Prize

Awarded annually to the graduating senior in engineering who best exemplifies excellence in scholarship.

Peter Stanley Cross

Mary A. Earle McKinney Prizes

This prize, donated by Samuel P. McKinney in 1946, is designed to promote proficiency in English.

Not Given This Year

Don Shepard Awards

Awarded annually to one or more outstanding residents of the Student Houses in order to pursue cultural opportunities which they might otherwise not be able to enjoy.

Gary Norbert Billerbeck
Jack Lawrence Falk

The Morgan Ward Award

Awarded for the best problems and solutions in mathematics submitted by a freshman or sophomore.

Jerry Mark Feinberg

GENERAL INDEX