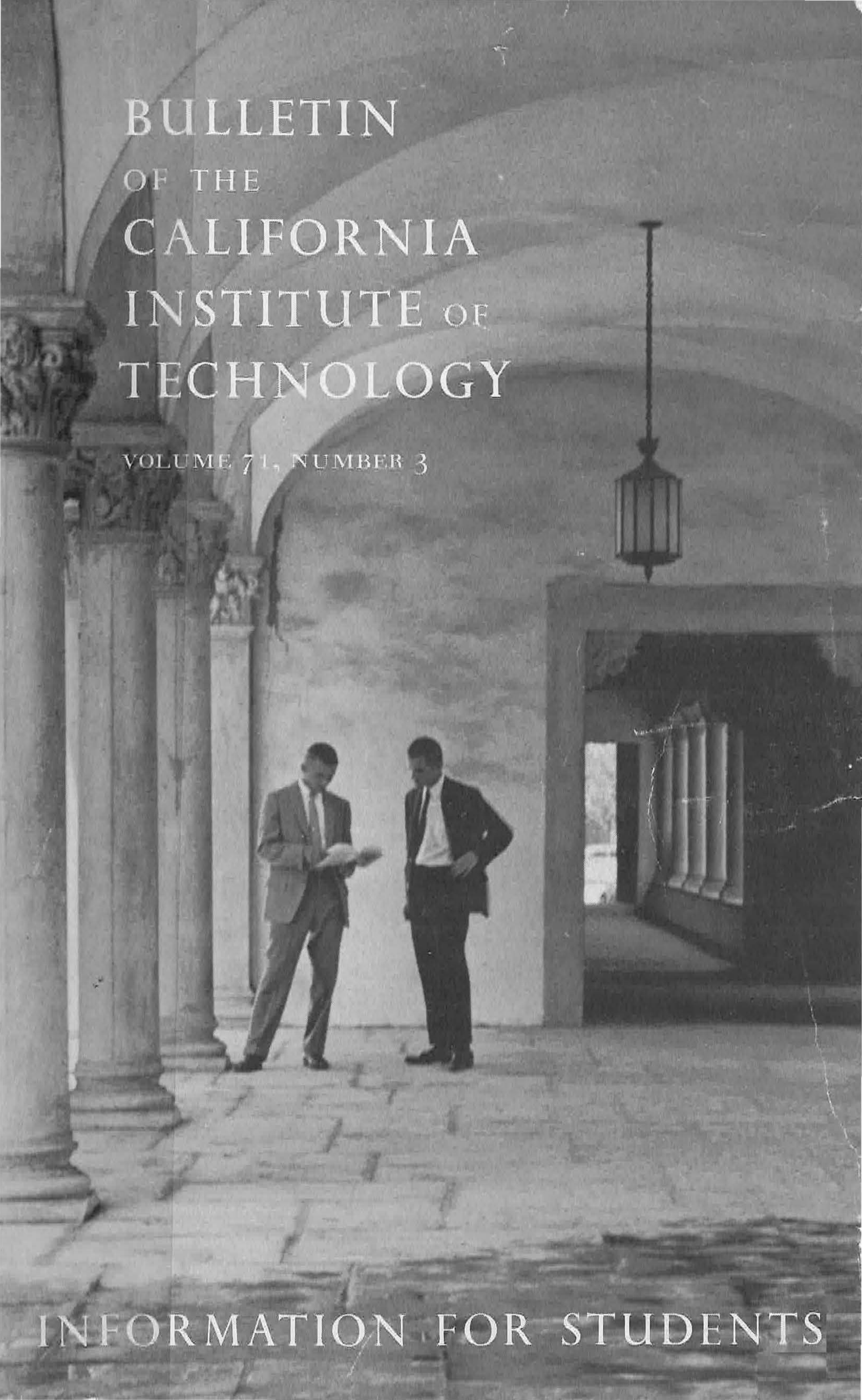

BULLETIN OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

VOLUME 71, NUMBER 3

INFORMATION FOR STUDENTS

1962

SEPTEMBER

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1963

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DECEMBER

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BULLETIN OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

Volume 71 Number 3

The California Institute of Technology Bulletin is published quarterly

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Second class postage paid at the Post Office at Pasadena, California under the Act of August 24, 1912

INFORMATION FOR STUDENTS 1962-1963

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA · CALIFORNIA
SEPTEMBER 1962

CONTENTS

ACADEMIC CALENDAR

1962-1963

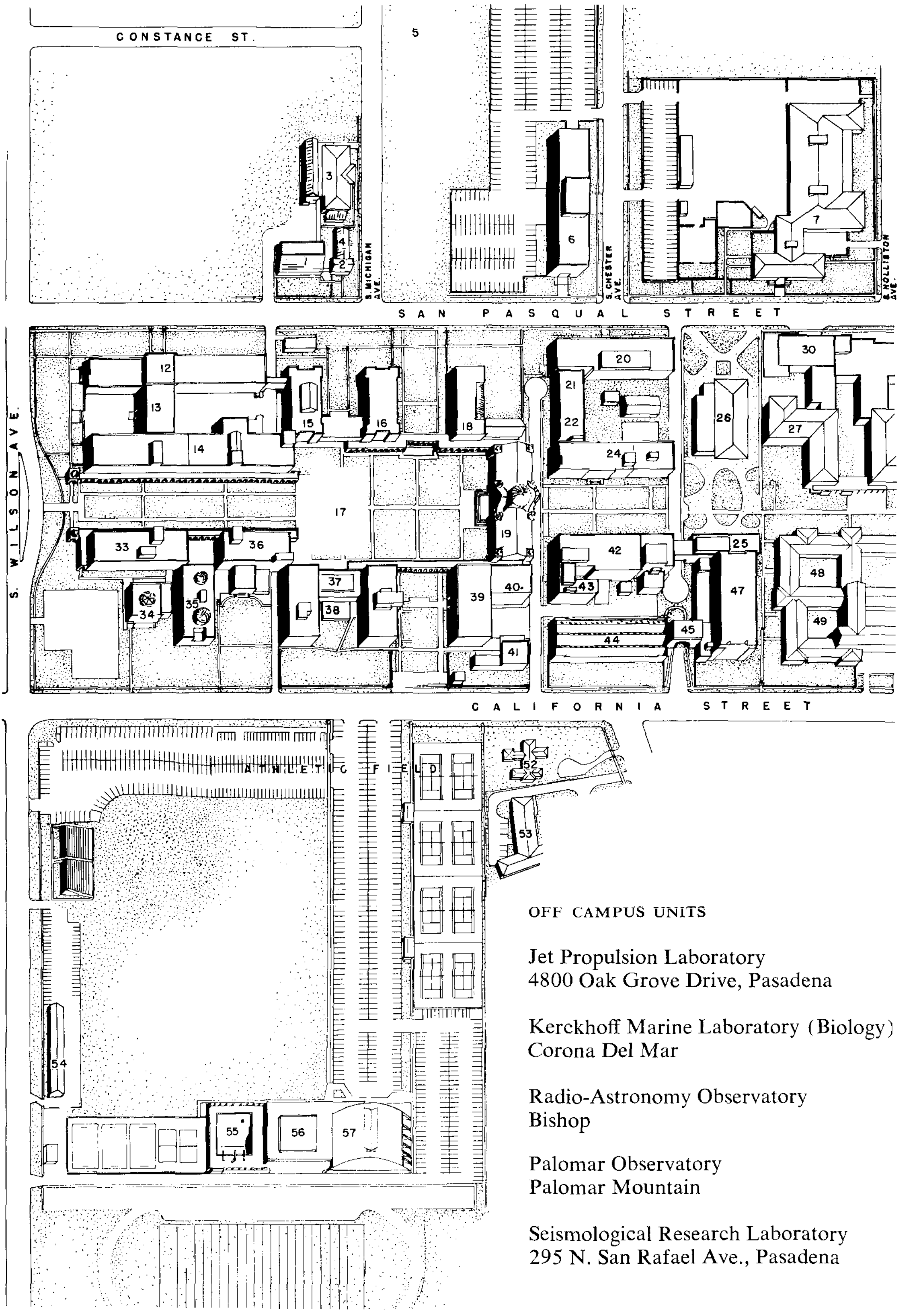
1962	FIRST TERM
September 20	Registration of entering freshmen—8:00 a.m. to 12 noon.
September 20	Registration of students transferring from other colleges—8:00 a.m. to 12 noon.
September 20-22	Student Camp.
September 24	General Registration—8:30 a.m. to 3:30 p.m.
September 24	Undergraduate Academic Standards and Honors Committee—3:00 p.m.
September 25	Beginning of instruction—8:00 a.m.
October 12	Last day for adding courses.
October 13	Examinations for the removal of conditions and incompletes.
October 27	Parents' Day.
Oct. 29-Nov. 3	Mid-Term Week.
November 3	MID-TERM.
November 5	Mid-Term deficiency notices due—9:00 a.m.
November 9	Last day for dropping courses.
November 9	French examination for admission to candidacy for degree of Doctor of Philosophy.
November 13	Freshman-Sophomore MUDEO—3:00 p.m.
November 16	German examination for admission to candidacy for degree of Doctor of Philosophy.
November 19-23	Pre-registration for second term, 1962-63.
November 22-25	Thanksgiving recess.
November 22-23	Thanksgiving holidays for employees.
December 1	Students' Day.
December 8-14	Final examinations—first term, 1962-63.
December 15	End of first term, 1962-63.
Dec. 16-Jan. 1	Christmas vacation.
December 24-25	Christmas holidays for employees.
December 28	Undergraduate Academic Standards and Honors Committee—9:00 a.m.

1963	SECOND TERM
January 1	New Year's holiday for employees.
January 2	General Registration—8:30 a.m. to 3:30 p.m.
January 3	Beginning of instruction—8:00 a.m.
January 18	Last day for adding courses.
January 19	Examinations for the removal of conditions and incompletes.
Jan. 28-Feb. 2	Mid-Term Week.
February 2	MID-TERM.
February 4	Mid-Term deficiency notices due—9:00 a.m.
February 8	Last day for dropping courses.
February 8	French examination for admission to candidacy for the degree of Doctor of Philosophy.
February 15	German examination for admission to candidacy for the degree of Doctor of Philosophy.
February 18-22	Pre-registration for third term, 1962-63.
March 9-15	Final examinations—second term, 1962-63.
March 16	End of second term, 1962-63.
March 17-24	Spring Recess.
March 22	Undergraduate Academic Standards and Honors Committee—9:00 a.m.

1963	THIRD TERM
March 25	General Registration—8:30 a.m. to 3:30 p.m.
March 26	Beginning of instruction—8:00 a.m.
April 12	Last day for adding courses.
April 13	Examinations for the removal of conditions and incompletes.
April 22-27	Mid-Term Week.
April 27	Last day for obtaining admission to candidacy for Engineers' degrees.
April 27	MID-TERM.
April 29	Mid-Term deficiency notices due—9:00 a.m.
May 3	Last day for dropping courses.
May 3	French examination for admission to candidacy for the degree of Doctor of Philosophy.
May 10	German examination for admission to candidacy for the degree of Doctor of Philosophy.
May 10-11	Examinations for admission to upper classes, September 1963.
May 13-17	Pre-registration for first term, 1963-64.
May 24	Last day for final oral examinations and presenting of theses for the degree of Doctor of Philosophy.
May 24	Last day for presenting theses for Engineers' degrees.
May 25-31	Final examinations for senior and graduate students, third-term, 1962-63.
May 30	Memorial Day holiday.
May 30	Memorial Day holiday for employees.
June 1-7	Final examinations for undergraduate students, third term, 1962-63
June 3-14	Summer Registration.
June 5	Curriculum Committee—10:00 a.m.
June 5	Faculty Meeting—2:00 p.m.
June 6	Class Day.
June 7	Commencement.
June 8	End of third term, 1962-63.
June 14	Undergraduate Academic Standards and Honors Committee—9:00 a.m.
July 4	Independence Day holiday for employees.

1963	FIRST TERM, 1963-64
September 2	Labor Day holiday for employees.
September 26	Registration of entering freshmen—8:00 a.m. to 12 noon.
September 26	Registration of students transferring from other colleges—8:00 to 12 noon.
September 26-28	Student Camp.
September 30	General Registration—8:30 a.m. to 3:30 p.m.
October 1	Beginning of instruction—8:00 a.m.

CAMPUS · CALIFORNIA



OFF CAMPUS UNITS

Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena

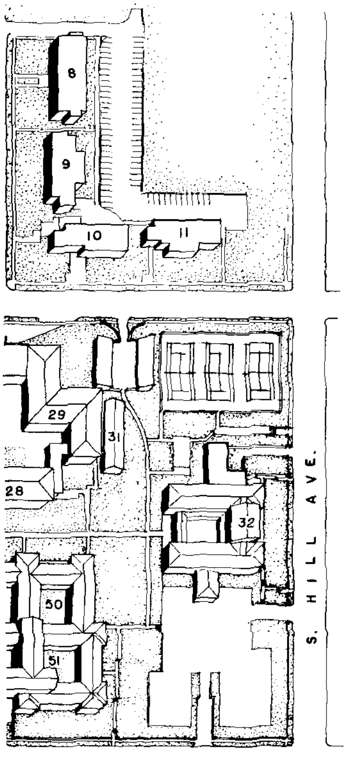
Kerckhoff Marine Laboratory (Biology)
Corona Del Mar

Radio-Astronomy Observatory
Bishop

Palomar Observatory
Palomar Mountain

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

INSTITUTE OF TECHNOLOGY



1. Campbell Laboratory (Plant Research)
2. Dolk Laboratory (Plant Research)
3. Earhart Laboratory (Plant Research)
4. Clark Laboratory (Plant Research)
5. Site of Future Beckman Auditorium
6. Keck Laboratories (Engineering)
7. Physical Plant (Administration and Shops)
8. Keck House
9. Mosher-Jorgensen House

.0. Braun House

1. Marks House
2. Church Laboratory (Chemical Biology)
3. Alles Laboratory (Molecular Biology)
4. Kerckhoff Laboratory (Biological Sciences)
5. Crellin Laboratory (Chemistry)
6. Gates Laboratory (Chemistry)
7. Site of Future Millikan Memorial Library

18. Dabney Hall (Humanities)
19. Throop Hall (Administration)
20. Spalding Laboratory (Chemical and Electrical Engineering)
21. Chemical Engineering Laboratory
22. Heating Plant
24. Thomas Engineering Laboratory
25. Firestone Aeronautical Research Center
26. Winnett Student Center
27. Page House
28. Lloyd House
29. Ruddock House
30. Chandler Dining Hall
31. Building T-4
32. Athenaeum
33. Mudd Laboratory (Geological Sciences)
34. Culbertson Hall (Industrial Relations Auditorium)
35. Robinson Laboratory (Astrophysics)
36. Arms Laboratory (Geological Sciences)
37. Bridge Laboratory (Physics)
38. Cosmic Ray Laboratory
39. Sloan Laboratory (Mathematics & Physics)
40. Kellogg Laboratory (Electrical Engineering and Physics)
41. Central Warehouse
42. Guggenheim Aeronautical Laboratory
43. Karman Laboratory
44. Central Engineering Machine Shop
45. Merrill Wind Tunnel
47. Synchrotron Laboratory
48. Fleming House
49. Dabney House
50. Ricketts House
51. Blacker House
52. Arden House
53. Archibald Young Health Center
54. Building T-1 (Air Force ROTC)
55. Alumni Swimming Pool
56. Locker Rooms
57. Scott Brown Gymnasium

Section I

CALIFORNIA INSTITUTE OF TECHNOLOGY
OFFICERS AND FACULTY

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(Arranged in order of seniority of service with dates of first election)

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(Arranged in order of seniority of service on the Board, with date of election as Honorary Trustee)

*Died July 22, 1962

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1962-63

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L. Davis, Jr.	D. C. Elliot	W. H. Corcoran
R. V. Langmuir	R. W. Gould	M. Hall, Jr.
T. Lauritsen	M. S. Plesset	D. E. Hudson
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Term expires June 30, 1963	*Term expires June 30, 1964*
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N. R. Davidson*	J. L. Greenstein*
C. Niemann*	R. D. Owen*

*Automatic nominee for election to 2nd two-year term

**Serving 2nd two-year term, not eligible for re-election

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PATENTS—*R. V. Langmuir,* C. D. Anderson, R. W. Kavanagh, D. E. Coles, P. A. Longwell, T. Vreeland, Jr.

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[THESE FOOTNOTES PERTAIN TO PAGES 17 AND 18]

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Dipl., New South Wales University of Technology, 1946. Research Engineer, California Institute, 1955-58; Senior Research Fellow, 1958-62; Research Associate, 1962-. (102 Robinson) 1654 East Loma Alta Drive, Altadena.

Roger Fellows Stanton, Ph.D., *Professor of English; Director of Institute Libraries*
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-. (5 Dabney) 790 East Woodbury Road.

Herbert Steinberg, Ph.D., *Visiting Associate in Chemistry*
Ph.D., University of Amsterdam, 1961. California Institute, 1963-64.

Thomas Eugene Stelson, D.Sc., *Visiting Associate in Civil Engineering*
B.S., Carnegie Institute of Technology, 1949; M.S., 1950; D.Sc., 1952. ALCOA Professor; Head, Department of Civil Engineering, Carnegie Institute of Technology, 1959-. California Institute, 1962-63.

Captain Cary D. Stephenson, B.S., *Assistant Professor of Air Science*
B.S., Oklahoma State University, 1952. California Institute, 1959-. (Bldg. T-1). 1449 Daveric Drive.

Alfred Stern, Ph.D., *Professor of Languages and Philosophy*
Ph.D., University of Vienna, 1923. Instructor, California Institute, 1947-48; Lecturer, 1948-50; Assistant Professor, 1950-53; Associate Professor, 1953-1960; Professor, 1960-. (302 Dabney).

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-. (219 Firestone) 2393 Tanoble Drive.

**Part-time.

William Sheldon Stewart, *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-. 1666 Oakwood Avenue, Arcadia.

Werner Stöber, Ph.D., *Research Fellow in Engineering*
Ph.D., Max-Planck-Institute for Medical Research, Gottingen, 1955. Scientific Assistant, Max-Planck-Institute, 1955-. Research Fellow in Physics, California Institute, 1961-62; Research Fellow in Engineering, 1962-63. (Keck) 216 South Chester Avenue.

Charles Allison Stout, Ph.D., *Research Fellow in Chemistry*
B.A., The Rice Institute, 1952; M.A., 1953; Ph.D., Ohio State University, 1961. California Institute, 1962-63. (251-C Crellin) 1030 North Raymond, Apt. 9-A.

Thomas Foster Strong, M.S., *Assistant Professor of Physics; Dean of Freshmen*
B.S., University of Wisconsin, 1922; M.S., California Institute, 1937. Assistant Professor, 1944-; Dean of Freshmen, 1946-. (115 Throop) 1791 East Mendocino Street, Altadena.

Sewall Cushing Strout, Jr.,* Ph.D., *Professor of History*
B.A., Williams College, 1947; M.A., Harvard University, 1949; Ph.D., 1952. Associate Professor, California Institute, 1959-62; Professor, 1962-.

Otto Struve, Ph.D., *Addison White Greenway Visiting Professor of Astronomy; Staff Member, Mount Wilson and Palomar Observatories*
Ph.D., University of Chicago, 1923. California Institute, 1962-65. (217 Robinson)

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 Fellow in Research, 1935-38; Assistant Professor, 1938-45; Associate Professor, 1945-47; Professor, 1947-. (68 Crellin) 270 South Berkeley Avenue.

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-. (305 Kerckhoff) 1244 Arden Road.

Bradford Sturtevant, Ph.D., *Assistant Professor of Aeronautics*
B.E., Yale University, 1955; M.S., California Institute, 1956; Ph.D., 1960. Research Fellow, 1960-62; Assistant Professor, 1962-. (307 Karman) 3516 North Marengo Avenue, Altadena.

Norman Stuart Sutherland, Ph.D., *Research Fellow in Biology*
B.A., Oxford University, 1949; M.A., 1952; Ph.D., 1957. University Lecturer in Experimental Psychology, Oxford University. California Institute, 1962.

Richard Manliffe Sutton, Ph.D., *Professor of Physics; Director of Relations with Secondary Schools*
B.S., Haverford College, 1922; Ph.D., California Institute, 1929. Professor, 1958-. (54 West Bridge) 2226 Crescent Drive, Altadena.

Alan R. Sweezy, Ph.D., *Professor of Economics*
B.A., Harvard University, 1929; Ph.D., 1934. Visiting Professor, California Institute, 1949-50; Professor, 1950-. (311 Dabney) 433 South Greenwood Avenue.

Ernest Haywood Swift, Ph.D., LL.D., *Professor of Analytical Chemistry; Chairman of the Division of Chemistry and Chemical Engineering*
B.S., University of Virginia, 1918; M.S., California Institute, 1920; Ph.D., 1924; LLD., Randolph-Macon College, 1960. Instructor, 1920-28; Assistant Professor, 1928-39; Associate Professor, 1939-43; Professor, 1943-; Chairman of Division, 1958-. (162 Crellin) 572 La Paz Drive, San Marino.

Henrietta Hill Swope, A.M., *Research Fellow in Astronomy*
A.B., Columbia University, 1925; A.M., Radcliffe College, 1928. Research Assistant, Mount Wilson and Palomar Observatories, 1952-62; Research Fellow, 1962-. (Mount Wilson Office) 135 South Holliston Avenue.

Richard Michael Talman, M.A., *Research Fellow in Physics*
B.A., University of Western Ontario, 1956; M.A., 1957. California Institute, 1962-63. (Synchrotron) 645 South Mentor Avenue.

Hugh Pettengill Taylor, Jr., Ph.D., *Assistant 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-.

Herman Teitelbaum, Ph.D., *Research Fellow in Biology*
A.B., Johns Hopkins University, 1957; M.S., University of Washington, 1959; Ph.D., McGill University, 1962. California Institute, 1961-. (386 Alles) 42 Marion.

*Leave of absence, 1962-63.

John Todd, B.Sc., *Professor of Mathematics*
B.Sc., Queen's University, Ireland, 1931. California Institute, 1957-. (262 Sloan). 1625 Sierra Bonita Lane.

Olga Taussky Todd, Ph.D., *Research Associate in Mathematics*
Ph.D., University of Vienna, 1930; M.A., University of Cambridge, 1937. California Institute, 1957-. (264 Sloan) 1625 Sierra Bonita Lane.

Seikichi Tokuda, Ph.D., *Research Fellow in Biology*
Ph.D., University of Washington, 1959. California Institute, 1960-. (84 Alles) 2093 Alta Pasa Drive, Altadena.

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-. (172 Sloan) 461 Mariposa Drive, Altadena.

Kenneth M. Towe, Ph.D., *Research Fellow in Geology*
A.B., Duke University, 1956; M.Sc., Brown University, 1959; Ph.D., University of Illinois, 1962. California Institute, 1962-63.

Colwyn Boyd Trevarthen, Ph.D., *Research Fellow in Biology*
B.Sc., Auckland University College, 1952; M.Sc., 1954; Ph.D., California Institute, 1962. Research Fellow, 1961-62. (387 Alles) 800 South San Rafael Avenue.

Paul On Pong Ts'o, Ph.D., *Senior Research Fellow in Biology*
B.S., Lingnan University, Canton, China, 1949; M.S., Michigan State University, 1951; Ph.D., California Institute, 1956. Research Fellow, 1955-61; Senior Research Fellow, 1961-. (125 Kerckhoff) 93 South Oak Avenue.

Albert Tyler, Ph.D., *Professor of Embryology*
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-. (312 Kerckhoff) 530 Bonita Avenue, San Marino.

Ray Edward Untereiner, Ph.D., *Professor of Economics*
A.B., University of Redlands, 1920; M.A., Harvard University, 1921; J. D., Mayo College of Law, 1925; Ph.D., Northwestern University, 1932. California Institute, 1925-. (10 Dabney) 1089 San Pasqual Street.

Sitaram Rao Valluri, Ph.D., *Senior Research Fellow in Aeronautics*
B.S., Indian Institute of Science, Bangalore, 1949; M.S., California Institute, 1950; Ph.D., 1954. Research Fellow, 1954-57; Senior Research Fellow, 1957-. (209 Firestone) 109 North Catalina Avenue.

Cornelius H. Vanderwolf, Ph.D., *Research Fellow in Biology*
B.Sc., University of Alberta, 1958; M.Sc., McGill University, 1959; Ph.D., 1962. California Institute, 1962-63.

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-. (332 Kerckhoff) 764 South Oakland Avenue.

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-. (139 Keck) 3545 Lombardy Road.

Jerome Vinograd, Ph.D., *Research Associate in Chemistry*
M.A., University of California (Los Angeles), 1937; Ph.D., Stanford University, 1939. Senior Research Fellow, California Institute, 1951-56; Research Associate, 1956-. (05 Church) 343 South Parkwood Avenue.

Marguerite M. P. Vogt, M.D., *Senior Research Fellow in Biology*
M.D., Medical Faculty in Berlin, 1937. Research Fellow, California Institute, 1950-54; Senior Research Fellow, 1954-. (057 Church) 1067 San Pasqual Street.

Rochus Vogt, Ph.D., *Assistant Professor of Physics*
Ph.D., University of Chicago, 1961. California Institute, 1962-.

Thad Vreeland, Jr., Ph.D., *Associate Professor of Mechanical Engineering*
B.S., California Institute, 1949; M.S., 1950; Ph.D., 1952. Research Fellow, 1952-54; Assistant Professor, 1954-58; Associate Professor, 1958-. (209 Keck) 1209 Louise Avenue, Arcadia.

William Gerard Wagner, Ph.D., *Richard Chace Tolman Research Fellow in Theoretical Physics*
B.S., California Institute, 1958; Ph.D., 1962. Research Fellow, 1962-63. (East Bridge) 333 Raymondale, South Pasadena.

Sven B. F. Wahlborn, Lic., *Research Fellow in Theoretical Physics*
Lic., Royal Institute of Technology, Stockholm, 1960. Instructor, Royal Institute, 1961-. California Institute, 1962-63.

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-. (156 Sloan) 993 Dale Street.

Joan Wallace, Ph.D., *Research Fellow in Biology*
B.S., Cornell University, 1951; M.S., Rutgers University, 1954; Ph.D., 1957. Research Assistant, California Institute, 1958-59; Research Fellow, 1959-. (021 Kerckhoff) 1838-C Mill Road, South Pasadena.

Victor Gordon Walmsley, Ph.D., *Research Fellow in Paleontology*
B.Sc., University of Manchester, 1949; Ph.D., University of Wales, 1955. Lecturer, University of Wales, 1951-. California Institute, 1962-63.

Morgan Ward,*** Ph.D., *Professor of Mathematics*
A.B., University of California, 1924; Ph.D., California Institute, 1928. Research Fellow, 1928-29; Assistant Professor, 1929-35; Associate Professor, 1935-40; Professor, 1940-. (388 Sloan) 1550 San Pasqual Street.

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.

Arthur Howard Warner, Ph.D., *Executive Director, Office for Industrial Associates*
A.B., University of Colorado, 1917; B.S., 1920; Ph.D., California Institute, 1927. Executive Director, 1962-. (113 Throop) 3321 Grayburn Road.

Harold Hubbard Warren, Ph.D., *Visiting Associate in Chemistry*
B.S., University of New Hampshire, 1944; M.S., 1947; Ph.D., Princeton University, 1950. Associate Professor of Chemistry, Williams College, 1959-. California Institute, 1962-63.

Jurg Waser, Ph.D., *Professor of Chemistry*
B.S., University of Zurich, 1939; Ph.D., California Institute, 1944. Professor, 1958-. (119 Gates Laboratory) 1308 East California Street.

Gerald J. Wasserburg,*** Ph.D., *Professor of Geology*
S.B., University of Chicago, 1951; S.M., 1952; Ph.D., 1954. Assistant Professor, California Institute, 1955-59; Associate Professor, 1959-62; Professor 1962-. (268 Arms) 3100 Maiden Lane, Altadena.

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; Professor Emeritus 1962-; Dean of the Faculty, 1945-60. 930 Knollwood Drive, Santa Barbara.

Anthony McLean Watts, Ph.D., *Research Fellow in Aeronautics*
B.S., University of Sydney, Australia, 1955; B.E., 1957; Ph.D., 1961. California Institute, 1961-62. (317 Firestone) 99 North Holliston.

J. Harold Wayland, Ph.D., *Professor of Applied Mechanics*
B.S., University of Idaho, 1931; M.S., California Institute, 1935; Ph.D., 1937. Research Fellow, 1939-41; Associate Professor, 1949-57; Professor, 1957-. (327 Thomas) 361 South Greenwood Avenue.

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-. (304 Dabney) 853 Lyndon Street, South Pasadena.

Richard Fouke Webb, M.D., *Director of Health Services*
A.B., Stanford University, 1932; M.D., University of Pennsylvania, 1936. California Institute, 1953-. (Health Center) 1025 Highland Street, South Pasadena.

Jean J. Weigle, Ph.D., *Research Associate in Biophysics*
Ph.D., University of Geneva, 1923. California Institute, 1949-. (207 Kerckhoff) 551 South Hill Avenue.

Alfred Weil, M.D., *Research Fellow in Biology*
M.D., University of Berne, 1962. California Institute. 1962-63.

***Leave of absence, first term, 1962-63.

Roger Joseph Weil, M.D., *Research Fellow in Chemistry*
M.D., University of Berne, 1954. Research Fellow in Biology, California Institute, 1960-62; Research Fellow in Chemistry, 1962. (056 Church) 409 South Wilson Avenue.

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-. (152 Throop) 3193 Mesaloa Lane.

Henry I. Weitzel, Ph.D., *Registrar*
B.S., University of North Dakota, 1919; M.S., 1920; Ph.D., University of Southern California, 1933. California Institute, 1961-. (119 Throop) 2500 Queensberry Road.

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-. (307 Thomas) 2367 Lambert Drive.

Hugo Christel Helmut Werner, Dr.rer.nat., *Research Fellow in Chemistry*
Dipl., University of Jena, Germany, 1958; Dr.rer.nat., Technical Institute of Munich, 1961. Instructor, University of Munich, 1959-. California Institute, 1962-63.

Roderick Alan Westerman, Ph.D., *Research Fellow in Biology*
B.S., Adelaide University, 1953; M.B., 1954; Ph.D., Australian National University, 1961. Medical Officer, Department of Mental Hygiene, Victoria, Australia. California Institute, 1962-63. (387 Alles) 84 Grand Oaks.

Ward Whaling, Ph.D., *Professor of Physics*
B.A., Rice Institute, 1944; M.A., 1947; Ph.D., 1949. Research Fellow, California Institute, 1949-52; Assistant Professor, 1952-58; Associate Professor, 1958-62; Professor, 1962-. (1 Kellogg) 401 South Parkwood Avenue.

A. Bruce Whitehead, Ph.D., *Research Fellow in Physics*
B.Sc., University of New Brunswick, 1953; M.Sc., McGill University, 1955; Ph.D., 1957. California Institute, 1961-. (205 Kellogg) 114 South Craig Avenue.

John B. Whiteoak, Ph.D., *Research Fellow in Astronomy*
B.S., University of Melbourne, 1957; Ph.D., The Australian National University, 1962. California Institute, 1962-63. (Mt. Wilson Office).

Gerald Beresford Whitham, Ph.D., *Professor of Aeronautics and Mathematics*
B.Sc., Manchester University, England, 1948; M.Sc., 1949; Ph.D., 1953. Visiting Professor of Applied Mechanics, 1961-62; Professor, 1962-. (302 Karman) 1689 East Altadena Drive, Altadena.

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-. (321 Kerckhoff) 350 South Greenwood Avenue.

Robert Leroy Wildey, Ph.D., *Research Fellow in Space Science*
B.S. California Institute, 1957; M.S., 1958; Ph.D., 1962. Research Fellow, 1962-63. (Mudd) 9797½ Sunland Boulevard, Sunland.

Ronald Howard Willens, Ph.D., *Research Fellow in Engineering*
B.S., California Institute, 1953; M.S., 1954; Ph.D., 1961. Research Fellow, 1961-. (333 Keck) 1185 Daveric Drive.

Max L. Williams, Jr., Ph.D., *Professor of Aeronautics*
B.S., Carnegie Institute of Technology, 1942; M.S., California Institute, 1947; A.E., 1948; Ph.D, 1950. Lecturer, 1948-50; Research Fellow, 1950-51; Assistant Professor, 1951-55; Associate Professor, 1955-60; Professor, 1960-. (215 Firestone) 2036 San Pasqual Street.

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) 1754 Locust Street.

Robert Woodrow Wilson, Ph.D., *Research Fellow in Radio Astronomy*
B.A., The Rice Institute, 1957; Ph.D., California Institute, 1962. Research Fellow, 1962-63. (103 Robinson) 547 South Madison Avenue.

Charles Harold Wilts, Ph.D., *Professor of Electrical Engineering*
B.S., California Institute, 1940; M.S., 1941; Ph.D., 1948. Assistant Professor, 1947-52; Associate Professor, 1952-57; Professor, 1957-. (123 Spalding) 1431 Brixton Road.

Hubert Winkler, Ph.D., *Research Fellow in Physics*
Ph.D., University of Zurich, 1954. Lecturer in Physics, University of Zurich, 1961-. California Institute, 1962-63.

Ernest Winocour, Ph.D., *Research Fellow in Biology*
M.Sc., The Hebrew University, Jerusalem, 1955; Ph.D., Weizmann Institute of Science, 1961. California Institute, 1961-. (066 Church) 314½ South Wilson Avenue.

Aage Winther, Ph.D., *Senior Research Fellow in Physics*
M.S., University of Copenhagen, 1950; Ph.D., 1961. Lecturer, University of Copenhagen, 1955-. California Institute, 1956-57; 1962.

Hugo van Woerden, Ph.D., *Research Fellow in Astronomy*
B.Sc., University of Leiden, 1948; M.Sc., 1955; Ph.D., University of Groningen, 1961. Scientific Officer, Kapteyn Astronomical Laboratory, University of Groningen. California Institute, 1962-63. (Mt. Wilson Office).

David Shotwell Wood, Ph.D., *Professor of Mechanical Engineering*
B.S., California Institute, 1941; M.S., 1946; Ph.D., 1949. Lecturer, 1949-50; Assistant Professor, 1950-55; Associate Professor, 1955-61; Professor, 1961-. (205 Keck) 590 Elm Avenue, Sierra Madre.

Major Leo T. Woods, M.B.A., *Professor of Air Science*
B.S., St. Louis University, 1949; M.B.A., Columbia University, 1955. California Institute, 1962-. (Bldg. T).

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-. 319 Copa de Oro, Bel Air.

Kenneth Osborne Wright, Ph.D., *Research Associate in Astronomy*
B.A., Toronto University, 1933; M.A., 1934; Ph.D., University of Michigan, 1940. Assistant Director, Dominion Astrophysical Observatory, Victoria, B.C., 1961-. California Institute, 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-. (252 Crellin) 3300 Las Lunas Street.

Theodore Yao-Tsu Wu, Ph.D., *Professor of Applied Mechanics*
B.S., Chiao-Tung University, 1946; M.S., Iowa State University, 1948; Ph.D., California Institute, 1952. Research Fellow, 1952-55; Assistant Professor, 1955-57; Associate Professor, 1957-61; Professor, 1961-. (315 Thomas) 3300 Las Lunas Street.

Oliver Reynolds Wulf, Ph.D., *Research Associate in Physical Chemistry*
B.S., Worcester Polytechnic Institute, 1920; M.S., American University, 1922; Ph.D., California Institute, 1926. California Institute, 1945-. (56 Crellin) 557 Berkeley Avenue, San Marino.

Don M. Yost, Ph.D., *Professor of Inorganic Chemistry*
B.S., University of California, 1923; Ph.D., California Institute, 1926. Instructor, California Institute, 1927-29; Assistant Professor, 1929-35; Associate Professor, 1935-41; Professor, 1941-. (107 Gates) 1025 San Pasqual Street.

Arthur Howland Young, *Lecturer in Industrial Relations, Emeritus*
California Institute, 1939-52. 3 Rosemary Lane, Santa Barbara.

Fredrik Zachariasen, Ph.D., *Associate Professor of Theoretical Physics*
B.S., University of Chicago, 1951; Ph.D., California Institute, 1956. Assistant Professor, 1960-62; Associate Professor, 1962-. (160 Sloan) 399 Cherry Drive.

Adam Richard Zak, Ph.D., *Research Fellow in Aeronautics*
B.E., Auckland University, New Zealand, 1956; M.S., Purdue University, 1959; Ph.D., 1961. California Institute, 1961-. (217 Firestone) 615 South El Molino Avenue.

Egualdo Oscar Zangheri, M.D., *Research Fellow in Biology*
M.D., Faculty of Medicine, National University of Cuyo, Mendoza, Argentina, 1959. Instructor, Department of Physiology, National University of Cuyo. California Institute 1962-63. (222 Kerckhoff) 413 South Hudson Avenue.

Laszlo Zechmeister, Dr.Ing., *Professor of Organic Chemistry, Emeritus*
Diploma of Chemist, Eidgenossische Technische Hochschule, Zurich, Switzerland, 1911; Dr.Ing., 1913; Professor, California Institute, 1940-59; Professor Emeritus, 1959-. (254 Crellin) 1122 Constance Street.

Edward Edom Zukoski, Ph.D., *Associate 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-. (227 Thomas) 2386 Las Lunas Street.

Fritz Zwicky, Ph.D., *Professor of Astrophysics; Staff Member, Mount Wilson and Palomar Observatories*
B.S., Federal Institute of Technology, Zurich, Switzerland, 1920; Ph.D., 1922. Research Fellow International Education Board, California Institute, 1925-27; Assistant Professor of Theoretical Physics, 1927-29; Associate Professor, 1929-41; Professor of Astrophysics, 1941-. (201 Robinson) 2065 Oakdale Street.

California Institute of Technology

Graduate Fellows, Scholars and Assistants, 1961-62

Bruce Jerome Aborn, *Graduate Teaching Assistant, Laws Scholar, Mathematics*
B.S., Ohio State University, 1961; M.A., Middlebury College, 1961

Kenneth Hoyt Adams, *Ford Foundation Fellow, Graduate Teaching Assistant, Graduate Research Assistant, Institute Scholar, Materials Science*
B.S., California Institute, 1959; M.S., 1960

Eric George Adelberger, *National Science Foundation Fellow, Physics*
B.S., California Institute, 1960

David George Agresti, *Graduate Research Assistant, Institute Scholar, Physics*
B.S., Ohio State University, 1959

Harlow Garth Ahlstrom, *Institute Scholar, Aeronautics*
B.S., University of Washington, 1959; M.S., 1959

Roedar Ahmad, *U.S. Government Fellow, Drake Scholar, Physics*
F.Sc., Government Akar Memorial College (Mardan, Pakistan), 1955; B.Sc., 1958; M.Sc., University of Peshawar (Pakistan), 1961

Nazeer Ahmed, *Graduate Teaching Assistant, Institute Scholar, Aeronautics*
B.E., University of Mysore (India), 1961

Ezekiel Olabisi Akinrimisi, *Graduate Teaching Assistant, Institute Scholar, Biology*
B.Sc., Michigan State University, 1960

Frank Addison Albini, *Howard Hughes Fellow, Mechanical Engineering*
B.S., California Institute, 1958; M.S., 1959

Norman Webster Albright, *Graduate Teaching Assistant, Institute Scholar, Physics*
B.S., California Institute, 1956

Shelton Setzer Alexander, *Standard Oil of California Fellow, Graduate Research Assistant, Institute Scholar, Geology*
B.S., University of North Carolina, 1956; M.S., California Institute, 1959

Hector Alvarez-Pavez, *Anaconda Fellow, Geology*
Ing.Civ., University of Chile, 1958

Ethan Davidson Alyea, Jr., *Graduate Research Assistant, Institute Scholar, Physics*
A.B., Princeton University, 1953

John Philip Andelin, Jr., *Graduate Research Assistant, Institute Scholar, Physics*
B.S., California Institute, 1955; M.S., Stanford University, 1956

Don Lynn Anderson, *Standard Oil Company of California Fellow, Geology*
B.S., Rensselaer Polytechnic Institute, 1955; M.S., California Institute, 1959

William Judson Anderson, *Institute Scholar, Aeronautics*
B.S., Iowa State College, 1957; M.S., 1958

Stephen A. Andrea, *National Defense Education Act Fellow, Graduate Teaching Assistant, Mathematics*
B.A., Oberlin College, 1960

Vincent George Aquino, *Atomic Energy Commission Fellow, Mechanical Engineering*
B.S., University of Portland, 1957

Charles Bruce Archambeau, *Sinclair Fellow, Geology*
B.S., University of Minnesota, 1955; M.S., 1959

Robert James Arenz, (S.J.), *Institute Scholar, Aeronautics*
B.S., Oregon State College, 1945; M.S., Lic. in Phil., St. Louis University, 1957

George S. Argyropoulos, *Graduate Teaching Assistant, Institute Scholar, Mechanical Engineering*
Dipl. in M. and E.E., National Technical University of Athens, 1960; M.S., California Institute, 1961

Joseph Eliahu Arieh, *International Cooperation Administration Fellow, Geology*
M.Sc., Hebrew University (Jerusalem), 1961

Claude Arpigny, *Belgian-American Foundation Fellow, Institute Scholar, NATO Fellow, Astronomy*
Lic.Sci., University of Liége, 1958

Robert Carl Ashenfelter, *Graduate Research Assistant, Institute Scholar, Physics*
B.S., Harvey Mudd College, 1961

John Fredrich Asmus, *Tektronix Foundation Fellow, Electrical Engineering*
B.S., California Institute, 1958; M.S., 1959

Clement Audet, *Department of Health (Province of Quebec) Fellow, Civil Engineering*
B.Sc.A., Université Laval (Quebec), 1960

Boris Auksmann, *Graduate Teaching Assistant, Institute Scholar, Mechanical Engineering*
B.A.Sc., University of British Columbia, 1955; M.S., California Institute, 1958; M.E., 1959

Charles Dwight Babcock, Jr., *National Aeronautics and Space Administration Fellow, Aeronautics*
B.S., Purdue University, 1957; M.S., California Institute, 1958

Andrew Dow Bacher, *National Science Foundation Fellow, Physics*
B.A., Harvard University, 1960

Donald Baganoff, *National Aeronautics and Space Administration Fellow, Aeronautics*
B.S., Purdue University, 1957; M.S., Washington University, 1960

Peter Baine, *Graduate Teaching Assistant, Dobbins Scholar, Chemistry*
G.R.I.C., Royal Technical College (Salford, England), 1961

Donald Milford Baker, *Graduate Research Assistant, Institute Scholar, Physics*
B.S., University of Colorado, 1960

John Edwin Baldwin, *National Science Foundation Fellow, Chemistry*
A.B., Dartmouth College, 1959

Philip Oren Banks, *National Science Foundation Fellow, Geology*
S.B., Massachusetts Institute of Technology, 1958

James Maxwell Bardeen, *Francis J. Cole Fellow, Physics*
A.B., Harvard College, 1960

Clark Reid Barker, *Clinedinst Scholar, Applied Mechanics*
B.S.M.E., Bradley University, 1961

Dennis Barrett, *U.S. Public Health Service Fellow, Biology*
A.B., University of Pennsylvania, 1957

J. Frederick Bartlett, *Graduate Research Assistant, Inland Steel-Ryerson Scholar, Astronomy*
B.S., Yale University, 1958; M.S., California Institute, 1961

Leonard Daniel Baumert, *Drake Scholar, Mathematics*
B.A., University of California (Los Angeles), 1952; M.A., 1959

Douglas Stanley Beder, *Woodrow Wilson Foundation Fellow, Physics*
B.Sc., McGill University, 1961

Anthony Bedford, *ARCS Scholar, Aeronautics*
B.S., University of Texas, 1961

Wayne Metcalf Beebe, *Ford Foundation Fellow, Lockheed Leadership Fund Fellow, Aeronautics*
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The California Institute Associates are a group of public-spirited citizens, interested in the advancement of learning, who were incorporated in 1926 as a non-profit organization for the purpose of promoting the interests of the California Institute of Technology. Information concerning the terms and privileges of membership can be secured from the Secretary of the California Institute, Room 108 Throop Hall.

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The Industrial Associates was established in 1949 to provide a practical channel for communications and intellectual interchage between the scientists and engineers of industry and the faculty of the Institute. Companies with a strong research interest have been attracted by this plan. Features of the program are early distribution of research reports, special conferences, and an exchange of visits by faculty and company scienists. The membership fees make up a significant part of the unrestricted income available for the support of faculty salaries and research.

Inquiries should be directed to the Executive Director, Office for Industrial Associates.

The membership as of September 1, 1962, was as follows:

Aerojet–General Corporation

Beckman Instruments, Inc.

Bell & Howell Research Center

Bell Telephone Laboratories, Inc.

The Boeing Company

Burroughs Corporation

California Research Corporation

Campbell Soup Company

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Continental Oil Company

Douglas Aircraft Company, Inc.

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International Business Machines Corporation

International Minerals and Chemical Corporation

Litton Industries, Inc.

Lockheed Aircraft Corporation

Marathon Oil Company

North American Aviation, Inc.

Pan American Petroleum Corporation

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The Procter & Gamble Company

Richfield Oil Corporation

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Socony Mobil Oil Company, Inc.

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Texaco Inc.

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Union Carbide Corporation

Union Oil Company of California

United States Steel Corporation (Columbia-Geneva Steel Division and Consolidated Western Steel Division)

Westinghouse Electric 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.

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.

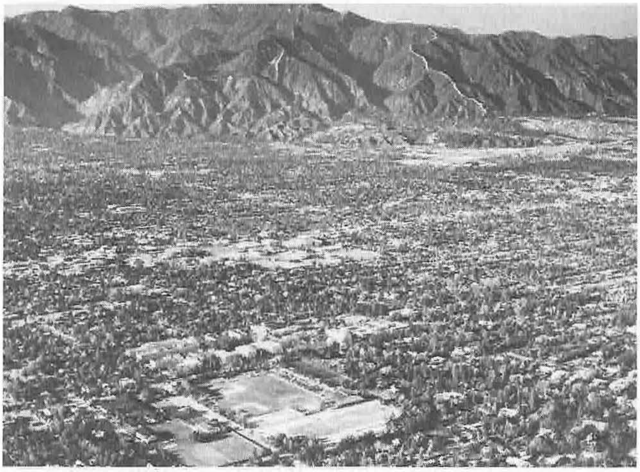
The Institute offers two four-year undergraduate courses, one in Engineering and the other in Science, both leading to the degree of Bachelor of Science and both planned so that interchange between them is not unduly difficult. For the first year, the work of all undergraduates is identical. Differentiation between these two courses begins with the second year. The Engineering course is of a general fundamental character, with a minimum of specialization in the separate branches of engineering. It includes an unusually thorough training in the basic sciences of physics, chemistry, and mathematics, as well as the professional subjects common to all branches of engineering. With minor exceptions, the student does not concentrate in his chosen field until the fourth year. The Engineering course also includes a large proportion of cultural studies, time for which is secured by eliminating the more narrowly particularized subjects. Such a curriculum, it is hoped, will provide a combination of the fundamental scientific training with a broad human outlook. This is, in fact, the type of collegiate education endorsed by leading engineers—a training which avoids technical narrowness on the one hand and broad superficiality on the other.

The course in Science affords, even more fully, an intensive training in physics, chemistry, and mathematics. In the third and fourth years optional studies are included which permit some measure of specialization in a chosen field of science. Instruction is also provided in French, German and Russian, with the object of giving the student a sufficient reading knowledge to follow the scientific and technical literature in those languages. The Science course includes the same proportion of cultural studies as the Engineering course, and for the same reason—to enlarge the student's mental horizon beyond the limits of his immediate professional interest and thus better qualify him to realize his opportunities and fulfill his responsibilities as a citizen and a member of his community.

The inclusion in the curriculum of a large proportion of non-scientific and non-technical subjects is one of the fundamental elements in the Institute's educational policy. The purpose which these studies is meant to achieve has already been indicated. Under the general designation of the Humanities, they include literature and composition, history and government, economics, philosophy, and psychology. To them the student devotes about one-fourth of his time during his undergraduate years (and, if he proceeds for the degree of Master of Science he continues with elective subjects in the Humanities throughout his fifth year). Formal instruction in the Humanities is supplemented by lectures by, and opportunities for contact with, distinguished scholars who are attracted to Pasadena by the opportunities for research at the Huntington Library and Art Gallery. In addition to these academic and semi-academic pursuits, the Institute encourages a reasonable participation in student activities of a social, literary, or artistic nature, such as student publications, debating, dramatics, and music; and all undergraduates are required to take regular exercise, preferably in the form of intercollegiate or intramural sports. In short, every effort is made in the undergraduate section of the Institute to carry on a well-rounded, well-integrated program which will not only give the student sound training in his professional field but 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 any of the 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 (about 46 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, 15 miles from Los Angeles. In the foreground, the Caltech campus.

HISTORICAL SKETCH

The California Institute of Technology, as it has been called since 1920, developed from a local school of arts and crafts, founded in Pasadena in 1891 by the Honorable Amos G. Throop and named, 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 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 1908 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 after 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."

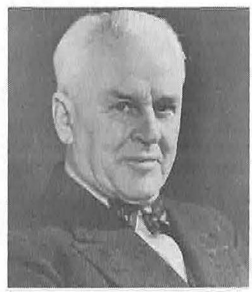
Perhaps some causes of this change were the rapid growth of southern California between 1911 and 1921, the springing up everywhere of high schools and vocational schools which relieved Throop of some of its responsibilities, and the increasing public interest in scientific research as the implications of 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, 600 graduate students, and a faculty of about 450.

HALE

NOYES



MILLIKAN

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, southern Californians, who could now feel pride in the Institute as well as hope. 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

CALTECH'S NOBEL LAUREATES

Top row: Robert A. Millikan, Thomas Hunt Morgan, Carl D. Anderson, Linus Pauling, Edwin M. McMillan. Bottom row: William B. Shockley, Donald A. Glaser, and Rudolph L. Moessbauer.

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 the laboratory finished in 1929, but courses in theoretical aerodynamics had been given at the Institute for many years by Professors Harry Bateman and P. S. Epstein. As early as 1917 Throop Institute had had a wind tunnel in which, the catalog proudly boasted, constant velocities of 4 to 40 miles an hour could be maintained, "the controls being very sensitive." The new program, under the leadership of Theodore von Kármán, 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 1942, 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 California Institute Associates were organized in 1925. These men and women, now numbering 240, 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 4000 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.

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 8746 alumni scatttered all over the world, many eminent in their fields of engineering and science. Five 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) and Donald A. Glaser (Ph.D. '50).

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 over $38,000,000 and those invested in endowment over $50,000,000.

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 and in 1950 a new engineering building. In 1951 a cosmic ray laboratory was built and in 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. 1957 saw the completion of the Eudora Hull Spalding Laboratory of Engineering, an important addition to the facilities available for instruction and research in chemical and electrical engineering, and a new student health center, the gift of Mrs. Archibald Young in memory of her husband who was long an Institute Associate. A new radio astronomy observatory—one of the finest in the world—was completed in the Owens Valley in 1959.

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. The first unit, a physical plant building, was completed in May 1959; and construction was completed by June 1961 of a new mathematics and physics building, the gift of the Alfred P. Sloan Foundation; of a new laboratory of molecular biology, the gift of Dr. Gordon A. Alles (B.S. '22, Ph.D. '26) and the U. S. Public Health Service; of the Campbell plant research laboratory, the gift of the Campbell Soup Company and the U.S. Public Health Service; the W. M. Keck Engineering Laboratories; three undergraduate student houses (the Page, Lloyd, and Ruddock Houses); and the Harry Chandler Dining Hall.

Olive Walk, which bisects the campus

During 1961-62, there were completed four graduate houses (the Keck, Mosher-Jorgensen, Marks and Braun Houses), the Firestone Flight Sciences Laboratory (gift of the Firestone Tire and Rubber Company) and the Karman Laboratory of Fluid Mechanics and Jet Propulsion (gift of the Aerojet-General Corporation). The P.G. Winnett Student Center was completed in the summer of 1962. Construction will begin soon on the Robert A. Millikan Library (gift of Dr. Seeley G. Mudd) and the Arnold O. Beckman Auditorium.

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 and is maintained by gifts from Donors and annual contributions from Sponsors. The Center concentrates on research and teaching in the field of employer-employee relationships; it is guided in this program 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) It conducts research on economic, psychological, social, and other related problems pertaining to employer-employee relationships. Special emphasis has been given to employee benefits through the work of the Benefits and Insurance Research Section. (2) The Center assists representatives of Sponsors, who participate in special conferences and workshops, to 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. (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. (5) The Center also 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. Many of these meetings are arranged by the Management Development Section.

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. In its work the Center adheres to its basic policy of not duplicating unnecessarily the work of other schools and organizations.

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 engineering and science students of the California Institute of Technology, emphasizing the fundamentals of supervision and working with people.

Detailed information about the specific services of the Center and the fees involved can be secured from the Director of the Industrial Relations Center, Culbertson Hall.

THE BENEFITS AND INSURANCE RESEARCH SECTION

In recognition of the growing importance of employee benefit and insurance programs in industrial relations, the Benefits and Insurance Research

Throop Hall

Gordon A. Alles Laboratory for Molecular Biology

Winnett Student Center

W. M. Keck Engineering Laboratories

Athenaeum

Karman Laboratory of Fluid Mechanics and Jet Propulsion

Section was established in 1955 as a part of the Industrial Relations Center. The Section is financed through special gifts from a large number of companies interested in supporting a program of objective research and instruction in this field. In its special area the work of the Section parallels closely the program of activities and services developed by the Industrial Relations Center.

Detailed information about the specific activities and services of the Section can be secured from the Director of the Industrial Relations Center or the Research Director of the Benefits and Insurance Research Section, Culbertson Hall.

THE MANAGEMENT DEVELOPMENT SECTION

The increasing complexity of business operations has emphasized the fact that a manager must not only know how to do the work being supervised but must also know how to supervise—a separate and distinct function. The expanding demand for training in the knowledge and skills required for supervision caused the establishment of the Management Development Section in 1957 as a part of the Industrial Relations Center.

This Section offers training in the field of management in general and in the specialized field of personnel administration. A wide range of courses is presented: on campus or off campus, full-time or part-time, for representatives of a variety of companies or specially designed for the management of a specific company. The courses do not carry academic credit.

Detailed information about the courses, conferences, and other services available through this Section can be secured from the Management Development Section, Culbertson Hall.

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 of the Institute, 1896-1917.

ALFRED P. SLOAN LABORATORY OF MATHEMATICS AND PHYSICS, 1923. Formerly the High-Voltage Research Laboratory erected with funds provided by the Southern California Edison Company. Rebuilt in 1960 with funds provided by the Alfred P. Sloan Foundation.

HEATING PLANT, 1926. Erected with funds provided in part by Dr. Norman Bridge and in part from other sources.

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 California Institute Associates and the staffs of the California Institute, the Huntington Library, and the Mount Wilson Observatory. The gift of Mr. and Mrs. Allan C. Balch of Los Angeles, 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 of the Institute, 1917-1933.

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

CENTRAL ENGINEERING MACHINE SHOP, 1931. Erected with funds provided by the International Education Board and the General Education Board. Formerly the Astrophysical Instrument Shop until the completion of the 200-inch Hale Telescope for Palomar Observatory.

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. Erected with funds provided by the International Education Board and the General Education Board. Following completion of the 200-inch Hale Telescope, this 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 to 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 by members of the Alumni Association 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 SHOP, 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; 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, Chairman of the Board of Trustees 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 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 Holmby Hills.

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 Earle M. Jorgensen of Los Angeles. Mr. Jorgensen is a member of the Board of Trustees.

KARMAN LABORATORY OF FLUID MECHANICS AND JET PROPULSION, 1961. The gift of The Aerojet-General Corporation and named in honor of Dr. Theodore von Karman, Professor of Aeronautics at the Institute, 1929-1949.

FIRESTONE FLIGHT SCIENCES LABORATORY, 1961. 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.

BECKMAN AUDITORIUM (under construction). 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 a member of the Board of Trustees.

LIBRARIES

The General Library, as the center of the Institute library system, houses the administrative office, which serves nine departmental libraries located in as many buildings on the campus. The departmental libraries house the collection of books, periodicals, and basic reference works in aeronautics, astronomy and astrophysics, biology, chemistry, chemical engineering, geology, humanities, industrial relations, and physics. The General Library houses the collections in mathematics and engineering, as well as the master catalog for the entire system. The bookstacks throughout the libraries are open to all readers. The collections constitute strictly a working library, including subscriptions to more than 3000 periodicals.

OFF-CAMPUS FACILITIES

KRESGE SEISMOLOGICAL LABORATORY, 1928, and DONNELLEY SEISMOLOGICAL LABORATORY, 1957 (of the Division of the Geological Sciences), North San Rafael Avenue, Pasadena.

The second laboratory was the gift of Mr. and Mrs. C. Pardee Erdman of Santa Barbara, The Kresge Foundation of Detroit, Michigan, and the James

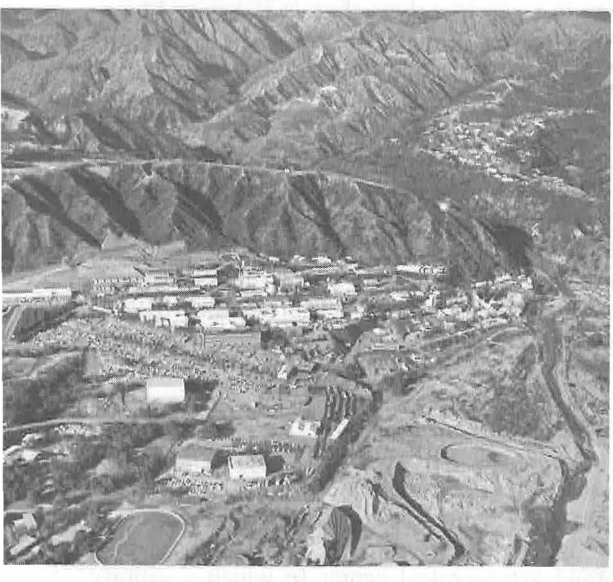
Irvine Foundation of San Francisco; and named in honor of Mrs. Erdman's father, Mr. Reuben H. Donnelley.

WILLIAM G. KERCKHOFF MARINE BIOLOGICAL LABORATORY, Corona del Mar, 1930.

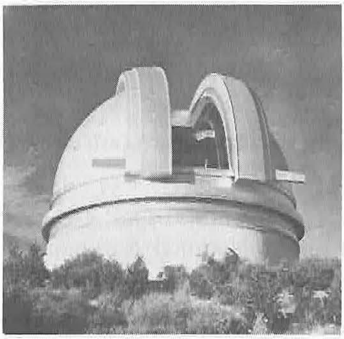
JET PROPULSION LABORATORY, 4800 Oak Grove Drive, Pasadena, 1944. Owned and sponsored by the National Aeronautics and Space Administration and operated by the Institute.

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.

RADIO ASTRONOMY OBSERVATORY, near Bishop, 1958.



The Jet Propulsion Laboratory, operated by Caltech for the National Aeronautics and Space Administration



The 200-inch telescope at the Palomar Observatory

STUDY AND RESEARCH

The Sciences

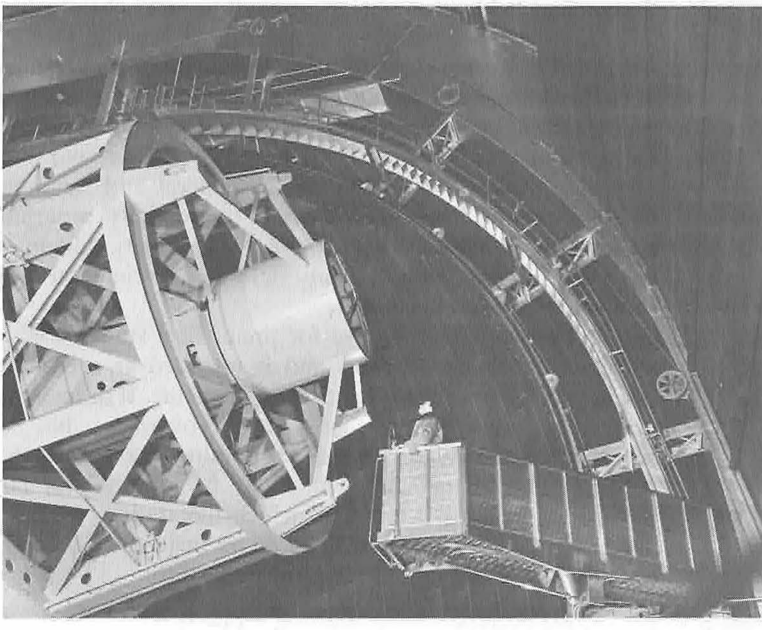
Astronomy

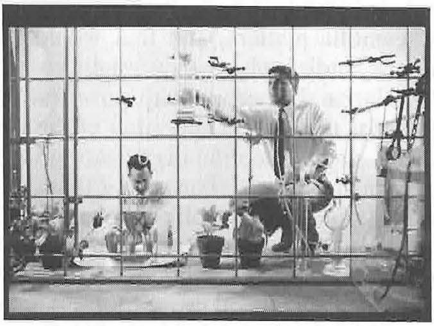
The Rockefeller Boards provided in 1928 for the construction by the Institute of an astronomical observatory on Palomar Mountain, equipped with a 200-inch reflecting telescope, 48-inch and 18-inch Schmidt wide-angle telescopes and other auxiliary instruments, together with an astrophysical laboratory on the Institute campus. The purpose of this observatory is to supplement, not to duplicate, 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. 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 nebulae; 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 nebulae, the luminosity function of nebulae and absolutely faint stellar systems, extended gaseous nebulae, and the stellar contents of the Milky Way. These two unique instruments 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 nebulae or a star cloud in our own galaxy.

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 neighboring fields of physics and mathematics. The California Institute of Technology and the Carnegie Institution of Washington have recognized the advantages implicit in the creation of a great astronomical center in which a unitary scientific program would be pursued under highly favorable circumstances that would attract distinguished investigators to collaborate with the staff of the observatories in scientific matters, and that would draw young men of great ability to graduate studies where they might enjoy the inspiration of leading minds and familiarize themselves with powerful tools of exploration. For this purpose a plan for the unified operation of the two observatories, in which they function as a single scientific organization under the direction of Dr. I. S. Bowen, was approved by the Trustees of the two institutions. Under this plan all the equipment and facilities of both observatories are made available for the astronomical investigations of the staff members of the combined observatories and the unified research program is paralleled by undergraduate and graduate training in astronomy and astrophysics in which members of the Staff of Mount Wilson Observatory join with the Institute Faculty.

In 1956 work started in radio astronomy and advanced study and research in this field are now under way. The first instrument was a 32-foot paraboloid for 21-cm research. Two precision, 90-foot diameter steerable paraboloids suitable for high frequencies are now in operation at a field station near Bishop. The two are used together as an interferometric radio telescope for exact position finding. This is one of the most advanced installations in this new and rapidly growing field. The radio astronomy group works in close cooperation with the optical astronomers in Pasadena; the program of study in the two fields is essentially the same, except for specialized advanced courses.

As a result of the cooperation possible over a broad range of astronomy, astrophysics, and radio astronomy, unusual 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 relevant subjects, as well as instruction in astronomy, radio astronomy, and astrophysics.





Biologists produce synthetic climatic conditions for studies of greenhouse plants

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 botany, zoology, microbiology and so on. The undergraduate option serves as a basis for graduate study in any field of experimental 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 adviser about this.

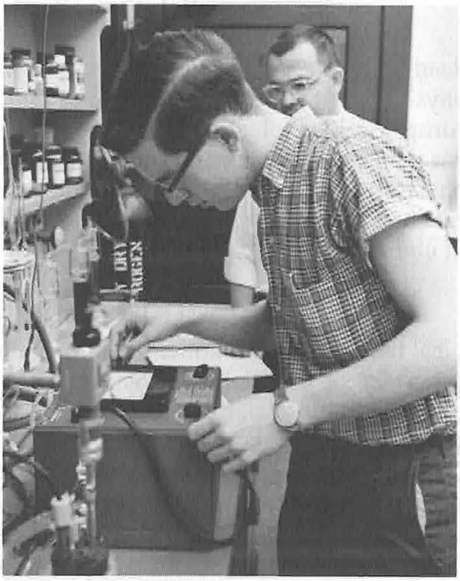
Graduate work leading to the Ph.D. degree is chiefly in the following fields: biochemistry, biophysics, cell biology, developmental biology, genetics, molecular biology, neurophysiology, plant physiology, psychobiology, and virology. These represent the fields in which active research is now going on in the Division. The emphasis in graduate work is placed on research. This is supplemented by courses and seminars in advanced subjects aimed at developing 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 of Chemical Biology. The Alles Laboratory links the Kerckhoff and Church Laboratories at all floor levels. The three laboratories contain classrooms and undergraduate laboratories, a biology library, 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 sea-water 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.



Selected freshmen are permitted to do honors research in chemistry

Chemistry and Chemical Engineering

The laboratories of chemistry consist of four adjacent 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 first three units include laboratories and other facilities for undergraduate and graduate instruction and research in inorganic, analytical, physical, and organic chemistry. Church Laboratory is used primarily for research on the applications of chemistry to biological and medical problems. These four laboratories provide space for about 150 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, and the structure of liquids.

Undergraduate Work

There are two undergraduate options in the Division, one in Chemistry and the other in Chemical Engineering, and the curricula 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 laboratory work in the first two terms is essentially quantitative analysis, but is designed to train the student to plan, execute, and critically interpret experiments involving quantitative measurements of various physical quantities. The third-term laboratory work involves a system of qualitative and semi-quantitative analysis and is used to extend and organize the student's knowledge of inorganic chemistry.

In the second year the two options are identical. There is a basic course covering the properties and reactions of organic compounds and a laboratory course in which fundamental manipulative techniques are acquired through the preparation of important types of pure organic compounds by useful general reactions. In addition there are elective courses which can be used by the student to enlarge his understanding of other fields of science and engineering.

Throughout the third year both the Chemistry and Chemical Engineering Options require a basic course in physical chemistry, as well as courses in analytical chemistry and physical chemistry laboratory. This is the year, however, where the requirements of the options begin to diverge. The Chemistry Option provides time for some of the elective courses described on page 227, whereas the Chemical Engineering Option requires professional courses which include chemical engineering thermodynamics, engineering mathematics, and introductory electronics.

In the fourth year the Chemistry Option has no required professional courses but permits specialization by electives of an advanced nature. The Chemical Engineering curriculum contains courses in industrial chemistry, applied mechanics, chemical engineering operations, 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 scientific contributions.

Chemical engineers discuss a problem in thermal transport

GRADUATE WORK

The degree of Master of Science is offered in both Chemistry and Chemical Engineering. All masters' programs at the Institute require at least 27 units of Humanities courses. In chemistry at least 40 units of research and an acceptable thesis are required; graduate courses in the student's field of interest complete the requirements. In chemical engineering there are advanced professional courses and an intensive laboratory course in engineering measurements and research methods; the remaining time is available for elective studies in either science or engineering.

Programs for study and research leading to the degree of Doctor of Philosophy are offered in the various fields of chemistry and chemical engineering and also in fields related to other scientific areas such as chemical biology, geochemistry, and chemical physics. Some of the fields of research in which members of the Divisional staff and their students are engaged are listed on pages 267 and 273-274.

GEOLOGY

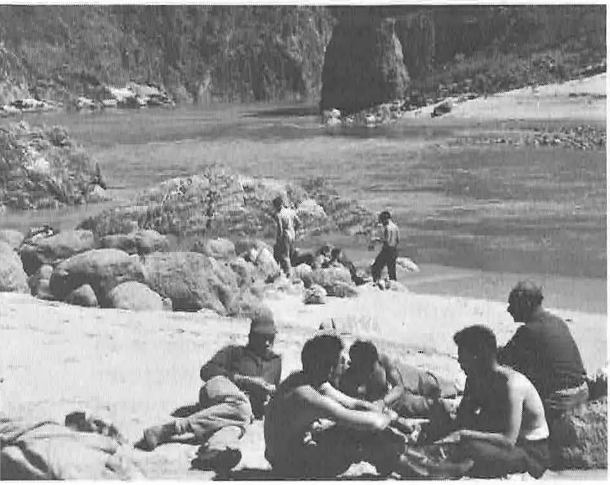
The Division of Geological Sciences is closely allied with the other active and creative fields of science and engineering at Caltech. Accordingly, a favorable intellectual atmosphere exists for education and research in geology, geobiology, geochemistry, geophysics and aspects of space science. The geographic 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 lunar and planetary studies; organic constituents laboratory; spectrographic, X-ray and X-ray fluorescent equipment; wet chemical laboratories; 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.

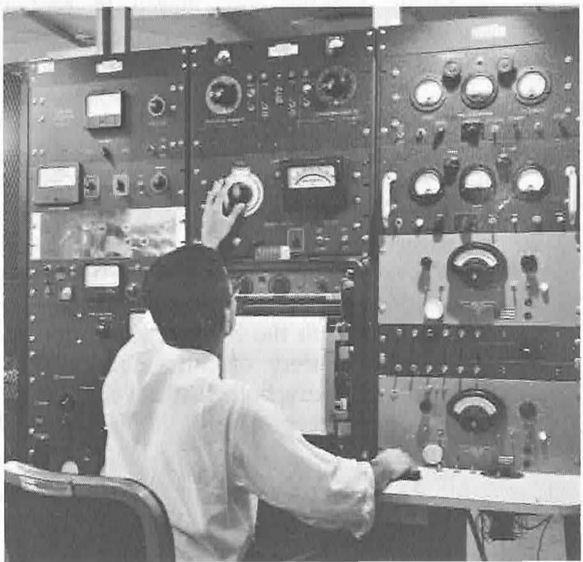
Extensive facilities are provided for the application of techniques of nuclear chemistry to problems in the earth sciences. These facilities include chemical laboratories for trace-element studies, a silicate analysis laboratory, and mass spectrometric and counting facilities for isotopic work. Available 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 pro-

Field work on an Alaskan Glacier



Field class at the bottom of the Grand Canyon



Instrument panel for a mass spectrometer vided by the combination of personnel, reference collections, and modern geochemical tools and techniques available here. 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.

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

The student body is purposely kept small and usually consists of no more than 50 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 science in space 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 highly desirable, even necessary.

Men trained in the earth sciences find employment in research, teaching, and a wide variety of other professional activities. 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 Federal and state bureaus, 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 space sciences.

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 in the general library in the Norman Bridge Laboratory. In addition, there is a reference library of duplicate books and periodicals located on the third floor of the Sloan Laboratory for Mathematics and Physics. Books, not on reserve for special courses, may be borrowed from the general 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 as yet taken this course will take it as their selected course in mathematics during their junior year concurrently with

Ma 108, and will 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 in Section VI of this catalog. The courses Ma 102, 104, 105, 109, 112, 116 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.

Entering graduate students are normally admitted directly to the Ph.D. program. A master's degree is awarded in exceptional cases. General requirements are listed under A and B of Section IV. The program of study for a master's degree must include 27 or more units of graduate humanities electives, at least 135 units of graduate course work in mathematics, and the submission of a thesis. The thesis requirement may be waived at the discretion of the department.

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 211-212; they give information on placement examinations, admission to candidacy and final examinations.

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 program of a 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 general minor. It is advisable for a student to satisfy these requirements as early as possible. In particular, the student should fill out early the form listing his intended courses outside of mathematics and secure approval for this part of his plan of study.

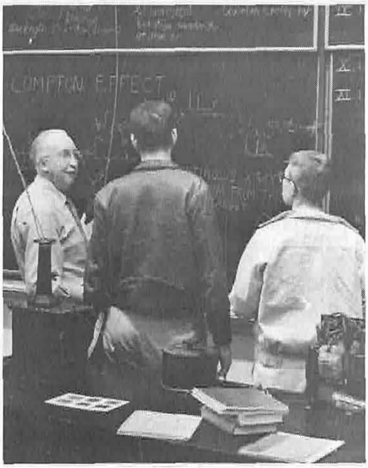
Beginning at the latest with the second year the student will be expected to begin his independent research work and be strongly encouraged to participate in seminars.

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 about any field in pure or applied mathematics and is not restricted to the immediate interests of the staff in mathematics. These include: group theory, matrix theory, lattice theory; algebraic and analytic theory of numbers; topology; and in analysis: differential equations, asymptotic expansions, special functions, functional analysis, mathematical problems of classical mathematical physics and applied mathematics.

A program in Applied Mathematics is being organized as a joint program of the Divisions of Mathematics, Physics, and Astronomy and the Division of Engineering and Applied Science. The course of study will lead to the Ph.D. degree and is expected to require 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.

A special bulletin containing details of the applied mathematics program will be published in the fall of 1962. Interested students should write to the Graduate Office of the Institute for further information.

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 teaching 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 desire to major in physics take during their junior and senior years intensive courses that provide a more than usually thorough preparation for graduate work. The curriculum provides for the teaching of classical and modern physics in parallel 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 given also an opportunity to participate in some of the thirty to sixty research projects which are always under way and the graduate seminars 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 211). The courses required to be passed either regularly or by examination provide an unusually thorough grounding in the fundamentals of physics, and the student learns to use these principles in the solution of problems. 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 research projects in physics. Students so employed are also expected to register for 15 or more units of research.

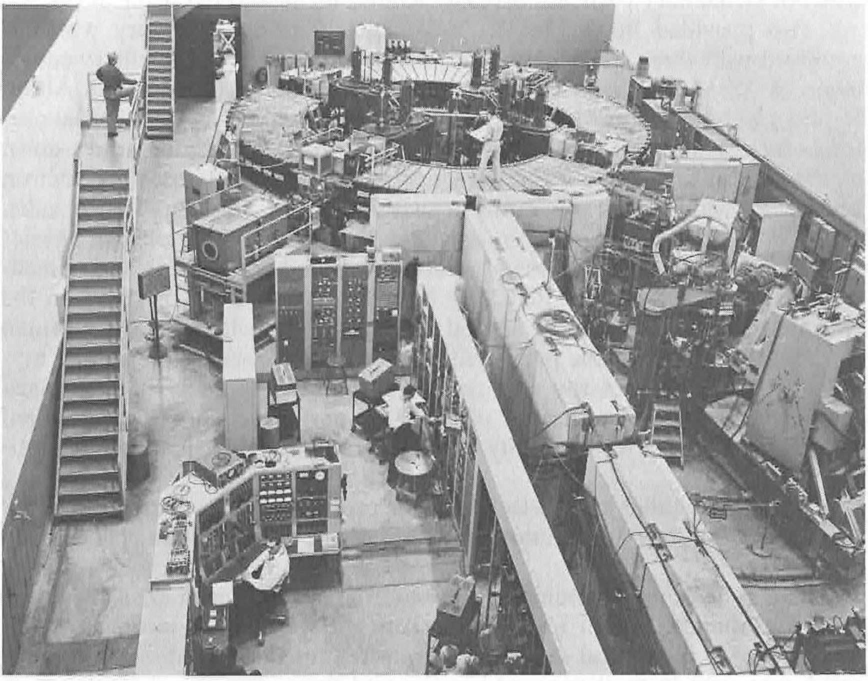
The Norman Bridge Laboratory of Physics is equipped to carry on research in most of the principal fields of physics. An addition to this laboratory has been especially constructed for the work in cosmic rays and the study of elementary particles. Special facilities for research in nuclear physics are 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. 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. Special facilities are available in the Norman Bridge Laboratory for the precision investigation of X-rays and gamma rays and the study of beta ray spectra. 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 either may select his own problem in consultation with the department or may work into some 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. There is at present a continuing demand for physicists in the National Defense activities of the government, and many graduates are engaged in such work.

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 post-doctoral research fellowships are available.



The 1.5 billion-volt Caltech synchrotron is used to study the photoproduction of mesons and hyperons from the proton and neutron

Engineering

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."

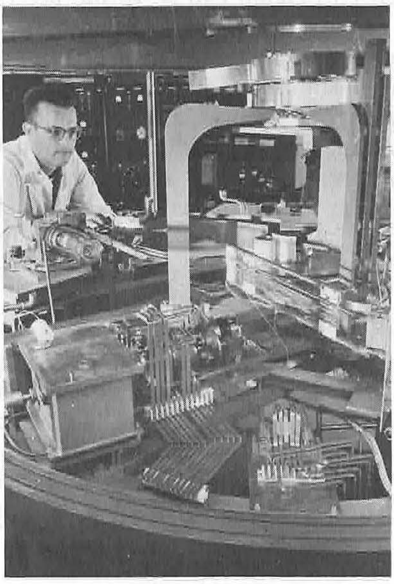
The Course is designed to give the greatest possible flexibility as preparation for graduate study and for professional practice. The Course involves four years of study leading to the degree of Bachelor of Science. The first year is common for all students at the Institute. At the end of this year a 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 in engineering exist in aeronautics, applied mechanics, chemical, civil, electrical, mechanical engineering, and materials science, with courses broadly outlined, leading to advanced degrees. An inter-divisional program in Applied Mathematics is being organized as explained on page 123. 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 more specialized and advanced nature. A sixth year leads to the degree of Aeronautical Engineer, Civil Engineer, Electrical Engineer or Mechanical Engineer. In addition, advanced work is offered in Aeronautics, 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 includes those curricula and facilities which are a part of the options of Civil, Electrical, Mechanical Engineering, Aeronautics, 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 technology, physical metallurgy and environmental health engineering. Some of the specialized laboratory facilities available for instruction and research are the various wind tunnels, the Computer Center, which includes the analog and digital computers, 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, and environmental health.



A graduate student in mechanical engineering uses a high temperature spectrometer to study the X-ray diffraction patterns of metals

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 pages 138-139). 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) will be completed and occupied during the academic year 1961-62. Together with the original Guggenheim Laboratory, to which they are contiguous, they will constitute an integrated group of Graduate Aeronautical Laboratories 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 will for the first time be 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 to be housed in this group of laboratories are actively engaged in the fields of Aeronautics, Jet Propulsion, Hydrodynamics, Space Flight, and the allied sciences. The folowing 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.

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 pp. 138-139 for details).

In all four of the above areas primary emphasis is placed on the underlying mathematics, physics, and chemistry and to 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.m., 10-foot diameter wind tunnel which has been in continuous service for over 30 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, 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. 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, and stress propagation. The laboratory facilities for jet propulsion and hydrodynamics are described in the sections on the Jet Propulsion Center and on Hydrodynamics starting on page 138. 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 which has a staff of some 3300 persons of whom about 1000 are professional engineers and scientists. The JPL is owned and supported by the National Aeronautics and Space Administration and is administered by the Institute. Its primary responsibility is the "development of operations of spacecraft for lunar and interplanteary exploration," which includes an extensive supporting research program on the fundamental problems of jet propulsion, missiles, and space vehicles, with emphasis on supersonic aerodynamics, fuels and combustion, high-temperature materials, rocket motor design, and electronic instrumentation for telemetering and missile guidance. Among the experimental facilities are: two supersonic wind tunnels (a 20-inch tunnel capable of speeds of 4.8 times the velocity of sound and a 21-inch hypersonic wind tunnel capable of speeds of 7 to 9 times sound velocity); 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.

The facilities of the Institute are available to students working towards advanced degrees, and to qualified workers who wish to carry out researches in the fields outlined above. In some cases the off-campus facilities can also be made for such purposes. A few fellowships can be granted to selected students.

As in the fields of physics, chemistry, and mathematics, emphasis is placed primarily upon the development of graduate study and research; but provision has also been made in the four-year undergraduate course 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 fifth-year course. The sixth-year work, however, may be taken only by students who have completed the fifth-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

For information about the planned program in Applied Mathematics see page 123.

APPLIED MECHANICS

Advanced instruction and research leading to the degrees of Master of Science and Doctor of Philosophy in Applied Mechanics is offered in such subjects as Mechanical Vibrations, Structural Dynamics, Earthquake and Blast Effects on Structures, Wave Propagation in Solids, Shell Theory, Theoretical and Experimental Analysis of Stress and Strain in Real and Ideal Solids, Dynamic Instrumentation, and certain subjects in the fields of Hydrodynamics, Propulsion, Heat Transfer, and Nuclear Energy applications. In addition, certain areas of Applied Mechanics are strongly emphasized by the Graduate School of Aeronautics as described in the separate section of Aeronautics.

Research studies in these areas which will illustrate current interests include: non-linear vibrations, randomly excited mechanical systems, shock and vibration tests of multi-degree-of-freedom systems, energy dissipation in structures, dynamic structural analysis and design for earthquake and blast loads, effects of local geology and soil conditions on strong earthquake ground motion, vibrations and buckling of shells, wave propagation in bars and plates, fracture mechanics in metals and polymers, heat transfer to fluids near the critical point, hydrodynamic interactions of submicroscopic particles, and non-Newtonian behavior of dilute solutions of macromolecules. For related research activities in the areas of Aeronautics, Hydrodynamics and Jet Propulsion see the separate sections so designated.

The work for the degree of Master of Science in Applied Mechanics 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. Students who have completed four-year B.S. programs in undergraduate options such as Applied Mechanics, Engineering Science, Applied Physics, 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 sixth year of specialized 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, such as the extensive analog and 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 well equipped with a good selection of basic instrumentation for Shock and Vibration testing and measurement, 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 special purpose electric analog computers of both the direct and the electronic differential analyzer type are available in these laboratories. Other specialized laboratories which might be mentioned include 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 of streaming birefringence.

Chemical Engineering

(See pages 116-118)

Civil Engineering

In civil engineering instruction is offered leading to the degrees of Master of Science, Civil Engineer, and Doctor of Philosophy.

The fifth year of study at the Institute is organized to be a logical continuation of the first four years of study. The emphasis during the first four years at the Institute is on the basic subjects in science and engineering. In particular, strong emphasis is placed on physics, mathematics, and solid and fluid mechanics. The fifth year of study involves more specialized engineering subjects but the student is not encouraged to overspecialize in one particular field of civil engineering.

Greater specialization is provided by the 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 studies, and is encouraged to elect related course work of advanced nature in the basic sciences. The engineer's 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. Research leading to a thesis is required for the engineer's degree and for the doctor's degree.

In some instances a student who has not specialized in civil engineering as an undergraduate will be admitted for graduate study in that field if he intends to pursue a program of study leading toward the Civil Engineer or Ph.D. degree. 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 undergraduate work. However, in every case the student will be urged to take some courses which will broaden his understanding of the overall field of civil engineering, as well as courses in his specialty. Most graduate students are also required to take further work in applied mathematics.

The general areas of civil engineering in which advanced work is offered are (1) structural engineering and applied mechanics, (2) soil mechanics and foundation engineering, (3) hydraulics: hydrodynamics, hydraulic engineering and hydrology, and (4) environmental health engineering. Emphasis is placed on the application of mathematics and basic scientific principles to the solution of civil engineering problems, and the student is discouraged from depending on handbooks and empirical formulas.

Excellent research facilities are available to qualified graduate students in all the fields above. Facilities for structural engineering and soil mechanics 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 below. The Laboratory for Environmental Health Engineering is also located in the W. M. Keck Engineering Laboratories, and some of this work is closely integrated with the research work in hydraulics and water resources.

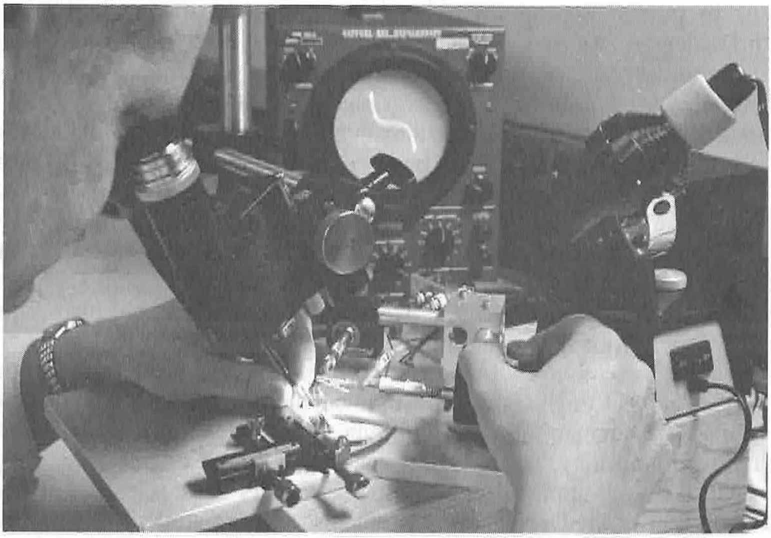
In recent years, graduate students and members of the staff have pursued a variety of research programs such as analysis of structures subjected to dynamic loadings (such as earthquakes); compaction of soil by vibration; design criteria for various hydraulic structures; investigation of laws of sediment transportation by streams and settling in sedimentation tanks; water quality criteria; and sterilization of sewage.

Electrical Engineering

In electrical engineering instruction is offered leading to the degrees of Master of Science, Electrical Engineer, and Doctor of Philosophy.

Electrical engineering affords opportunity for many choices of life work relating to research, design, production, operation, and management. Some phases of these activities and the commercial semi-technical phases of the electrical industry require only the preparation of the four-year course, but the better, or more normal, preparation for an electrical engineering career requires the completion of the five-year course leading to the degree of Master of Science.

The instruction pattern for electrical engineering is therefore designed on a five-year basis, the fifth-year courses being open to qualified students who



Electrical engineer investigating the solid state physics of thin film

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.

Other fields of endeavor call for a knowledge of mathematics, physics and electrical engineering in excess of that obtainable in the five-year curricula. To meet this need the Institute has provided courses of graduate study and research in electrical engineering leading to the degrees of Electrical Engineer and Doctor of Philosophy. These courses provide for advanced work in the application of mathematical analysis and physical laws to mechanical and electrical problems and may be taken by a limited number of exceptional students who have completed the five-year electrical engineering course at the Institute or by students from other colleges who have substantially the same preparation.

The distinctive features of undergraduate work and graduate work in electrical engineering at the California Institute of Technology are the creative atmosphere in which the student finds himself and the large amount of physics and mathematics courses included in the engineering curricula. The graduate work in electrical engineering in particular brings graduate students into close touch with research men and current problems.

Of the several electrical engineering laboratories at the California Institute, the Computing Center, the Solid State Physics Laboratories, and the Electromagnetic Radiation Laboratory are outstanding:

The *Computing Center* provides comprehensive facilities for research and instruction in the development of data processing systems and their application to the solution of complex mathematical problems in engineering and science. The Computing Center itself is set up as a general campus-wide facility. The Center contains a large-scale, direct analog computer, a Burroughs 220 digital computer, and an LGP-30 digital computer. Also, an IBM 7090 digital computer is available.

A new IBM system consisting of a 7090 and a 7040 computer is being planned for the expanded Center operation in 1963.

Electrical Engineering research in this area ranges from switching theory, switching circuit instrumentation, engineering analysis, and advanced programming. There is also a newly created joint research program with the Biology Division on the nervous system and sensory perception as these biological systems relate to engineering and data processing systems.

The *Electromagnetic Radiation Laboratories* are devoted to theoretical and experimental studies of electromagnetic radiation phenomena. They provide facilities for the investigation of basic problems arising from recent developments in antenna theory and design, quantum electronics, and plasma physics. Theoretical research now in progress includes topics in the mathematical theory of diffraction, wave propagation and oscillations in plasmas, fundamental laser research, artificial dielectrics, and surface wave antennas. Experimental work in progress includes the generation, propagation and detection of coherent optical radiations, the study of magnetohydrodynamics, and microwave interactions with plasmas.

The *Solid State Physics Laboratories* are involved principally, but not exclusively in the understanding of thin films. Facilities are available for the making of thin films by vacuum evaporation and electrodeposition. Research now in progress concerns tunneling phenomena in thin dielectric layers and transmission characteristics of superconducting thin films. The nature of flux reversal and anisotropy in thin magnetic films is being investigated as well as the interaction between magnetic materials and microwaves. Other investigations are involved with semiconductor devices and their applications to modern electronic circuits.

A *Servomechanism Laboratory* has been established for instruction and research on feedback control systems. The facilities of this laboratory provide excellent opportunities for research leading to all graduate degrees. One important feature is an electric analog computer suitable for general mathematical analysis and detailed studies of control system components in a complete system. Other laboratories and equipment for research work in electronics, communications, information theory and circuit synthesis are available.

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. These programs are designed to meet the needs of currently developing fields of engineering and applied science that are not emphasized in already established engineering disciplines. The general requirements for advanced degrees in Engineering Science are similar to those in the other fields of engineering and include for the doctorate the completion of satisfactory thesis research. The program for the Master of Science degree in Engineering Science is described on page 240. The fields of study may include such topics as fluid mechanics, reactor physics, plasma physics, combustion and other application of modern physics and chemistry to engineering.

Note: Students who have majored in physics, mathematics or engineering science as undergraduates and who are applicants for AEC Special Fellowships in Nuclear Science and Engineering should apply for admission to graduate study in this option.

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

Study for the degree of Master of Science in Materials Science ordinarily will consist of three terms of course work totaling at least 140 units. The student is allowed considerable freedom in choosing his courses. However, he should consult with one or more of the members of the Faculty Advisory Committee to ensure that he selects a sequence of courses suitable to his background and plans for future work. 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 doctorate 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.

Ample facilities are available for education and research in materials science. 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 and polymers, behavior of metals under dynamic loading conditions, model representation of material behavior for viscoelastic media on both micro and macro scales, 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.

Mechanical Engineering

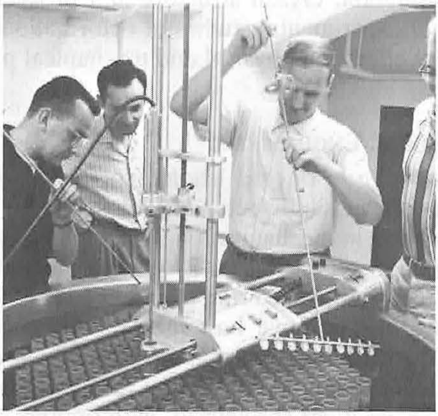
Instruction in mechanical engineering is offered leading to the degrees of Master of Science, Mechanical Engineer, and Doctor of Philosophy.

The general program of instruction in mechanical engineering is organized on a five-year basis in which the fifth-year schedule 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 fifth year, therefore, is somewhat more specialized, with options in general mechanical engineering, jet propulsion, physical metallurgy, or nuclear engineering. A schedule of subjects is specified for each of these fifth-year options which may be modified by petition to 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 five general areas: (1) hydrodynamics, (2) design, mechanics, and dynamics, (3) physical metallurgy and mechanics of materials, (4) thermodynamics and heat power, and (5) nuclear energy. Extensive facilities are available in hydrodynamics as described on page 139. 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. Instruction and research in materials science including physical metallurgy is carried on in the Laboratory of Engineering Materials occupying two floors of the W. M. Keck Engineering Laboratories. Extensive laboratory facilities have been developed for the study of mechanics of materials, particularly under conditions of dynamic loading, which are located in a special laboratory. 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



Determination of neutron flux distribution in a subcritical nuclear reactor

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.

Jet Propulsion

During 1948 at the California Institute of Technology, a Jet Propulsion Center was established 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 peace-time 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 peace-time 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 include material from both of these engineering fields. In general, students entering the course work in jet propulsion will have had their undergraduate preparation in mechanical engineering or aeronautics, but the courses are also available to students whose preparation has been in applied mechanics, engineering science, or physics. 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.

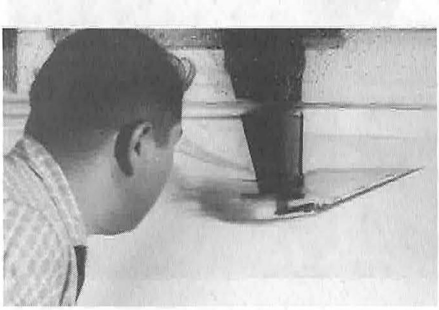
The Jet Propulsion Center will be located in the new Kármán Laboratory of Fluid Mechanics and Jet Propulsion upon its completion during the coming academic year. Facilities for experimental research are available to students working toward advanced degrees. Particle flows in rocket nozzles, heat transfer to the electrodes of plasma accelerators, emissivities of gases at very high temperature, and unsteady flame theory represent a few of the topics that are currently under investigation.

HYDRODYNAMICS

Instruction and research in hydrodynamics and hydraulic engineering are concerned with various subjects which complement other Institute work in fluid mechanics. Current interest in this field include, for example, water waves, hydrodynamics of submerged or floating bodies, physics of cavitation, jets, and cavity flows, flows of stratified fluids, turbulence and diffusion, open channel flow, sediment transportation, and flow through porous media. 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 or Engineering Science, depending upon their field of interest. The laboratories described below provide excellent facilities for graduate student research.

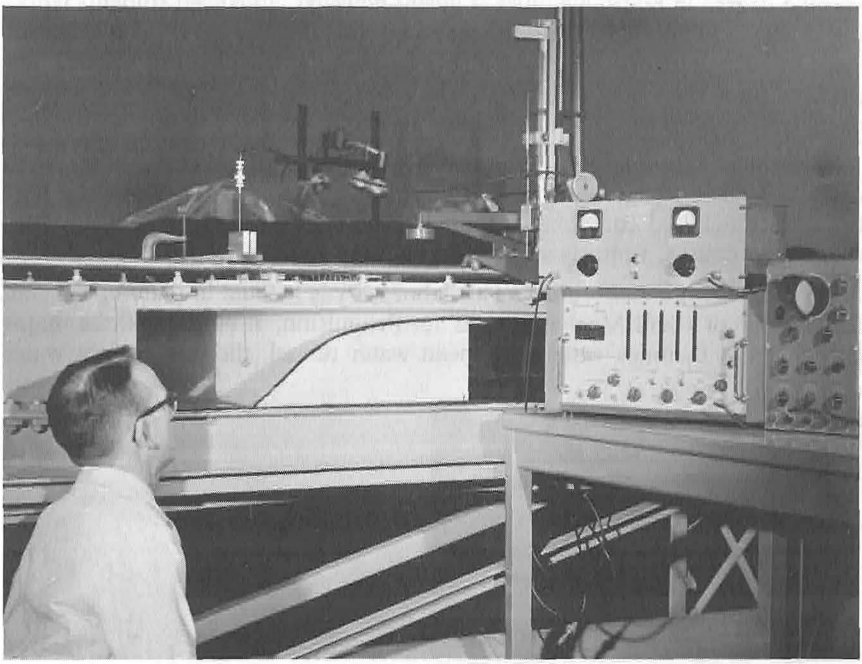
Hydraulic Machinery Laboratory. The purpose of this laboratory is to carry out basic research in the hydrodynamics of centrifugal and axial flow turbomachines and components thereof. The facilities include basins, dynamometers, pumps, venturis and calibrating tanks.

Hydrodynamics Laboratory. This laboratory is located in the von Karman Laboratory of Fluid Mechanics and Jet Propulsion. It contains three major experimental facilities—the high speed water tunnel, the free surface water

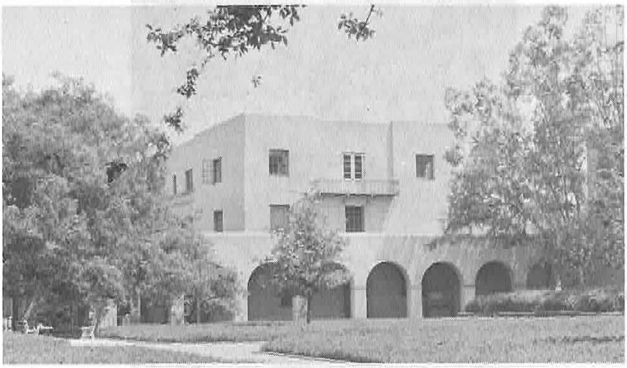


In the Hydrodynamics Laboratory, an investigator works on a fundamental flow problem in fluid mechanics tunnel and the controlled atmosphere launching tank. The high-speed water tunnel has a closed working section 14 inches in diameter and an alternate two-dimensional working section 6 by 30 inches, in which a maximum flow velocity of 100 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. The ambient pressure in the launching tank can be controlled down to 1/11 atmospheric pressure for modeling water entry and underwater trajectories.

Hydraulic and Water Resources Laboratory. The recently completed W. M. Keck Engineering Laboratories building provides 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 three recirculating tilting flumes for research in open channel flow and sediment transport (one is 130 feet long with cross section 43 inches wide by 24 inches deep; another is 60 feet long, and the third is 40 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; special tanks and circulation systems needed in research; and miscellaneous equipment for a variety of student laboratory experiments. Research projects are an integral part of the academic program and are carried out by the faculty, and by graduate students as thesis projects.



Flume experiment on sediment entrainment in a growing boundary layer



Dabney Hall of the Humanities

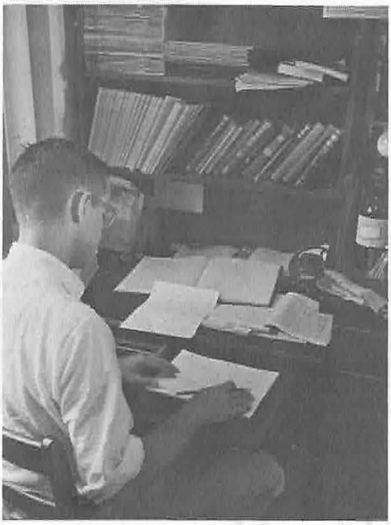
The Humanities

One of the distinctive features of the California Institute is its emphasis upon the humanistic side of the curriculum. The faculty is in thorough symphathy with this aim and gives full support to it. Every student is required to take in each of his four undergraduate years one or more humanistic courses. These courses in the Division of the Humanities include the subjects English and foreign literatures, European and American history, philosophy and social ethics, economics (including industrial relations), and government. All of them are so planned and articulated that the student obtains a solid ground and not merely the superficial acquaintance which is too often the outcome of a free elective system. The standards of intellectual performance in these studies are maintained on the same plane as in the professional subjects.

Ample quarters for the work in humanities are provided in Dabney Hall, which was given to the Institute in 1928 by Mr. and Mrs. Joseph B. Dabney of Los Angeles as an evidence of their interest in the humanities program of the Institute and their desire to support it. Besides the usual class and lecture rooms, Dabney Hall of the Humanities contains a divisional library and reading room, offices for members of the humanities faculty, a public affairs room, and a student lounge which opens upon a walled garden of olive trees.

In connection with the acceptance of the gift of Dabney Hall, a special fund of $400,000 for the support of instruction in the humanistic fields was subscribed by several friends of the Institute. In 1937 Mr. Edward S. Harkness gave the Institute an additional endowment fund of $750,000 for the same purpose.

In addition to the regular staff of the Institute, scholars from other institutions give instruction or lectures in the Division of the Humanities. The proximity of the Huntington Library, with its unique opportunities for research in literature, history and economics, is assurance that the instruction given at the Institute in these fields will continue in the future, as in the past, to be strengthened by the association of visiting scholars.



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.

All seven Houses have their own elective officers and are given wide powers in the matter of arranging their own social events, preserving their own traditions, and in promoting the general welfare. 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 the 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 Dean 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 Dean of Freshmen. Students failing to obtain admission to the Student Houses, who wish to avoid commuting, can find comfortable rooms for rent in private homes near the Institute campus.

Off-Campus Housing. The Housing Office, 208-A Throop, maintains a file of listings for rooms, apartments, and houses. Assistance will be given upon arrival, but no arrangements or reservations can be accomplished in advance.

Blacker

Dabney

Ricketts

Fleming

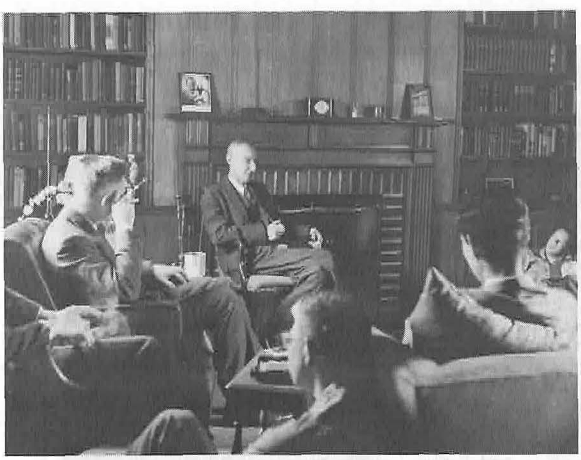
The Student Houses are pleasantly located in the east campus

If specific information is desired, it should be requested through this office, and not through the office of the Master of Student Houses.

Interhouse Activities. The presidents and vice presidents of the Student Houses make up 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.

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 the Student Houses and commemorates his interest and effort in the field of undergraduate scholarship.

"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 extra-curricular activities, authorizes expenditures from the corporation funds, and exercises all other powers in connection with the corporation not otherwise delegated.



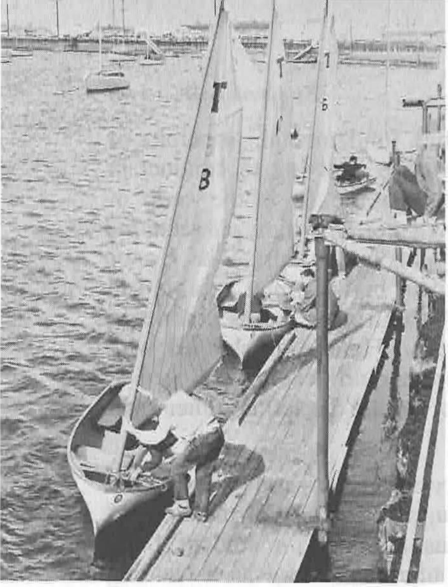
An informal discussion
with a distinguished visitor to the campus

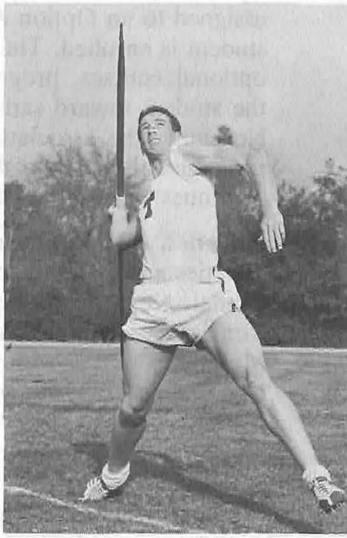
Board of Control. The Honor System is the fundamental principle of conduct for all students. More than merely a code applying to conduct in examinations, it extends to all phases of campus life. It is the code of behavior governing all scholastic and extra-curricular activities, all relations among students, 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.

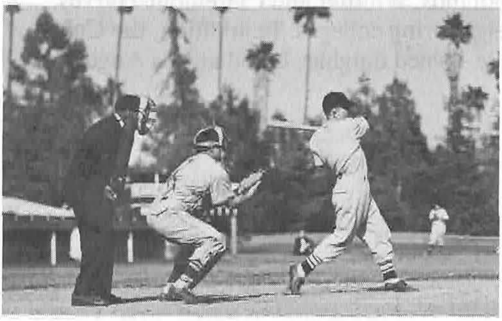
Faculty-Student Relations. Faculty-student coordination and cooperation with regard to campus affairs is secured through periodic joint meetings of the Faculty Committee on Student Relations and certain student body officers and elected representatives. These conferences serve as a clearing house for suggestions as to policy organization, etc., originating with either students or faculty.

Option Advisors. Each member of the three undergraduate upper classes is assigned to an Option Advisor, a faculty member in the option in which the student is enrolled. The advisor 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 advisor, 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 with many other neighboring colleges. In addition, the Caltech Sailing Club sails a fleet of Institute-owned dinghies based at Los Angeles Harbor.







The California Institute Athletic Field, of approximately twenty-three acres, includes football field, standard track, 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 remains in the possession of one group only so long as that group can defeat the challengers from any of the other groups.

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 undergraduates. 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 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, 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 was 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 tournament, and the annual Caltech invitational debate tournament held at the Institute. Bi-annually the Institute is represented at the National Pi Kappa Delta Speech tournament. Local activities include the annual Conger Peace Prize oration contest, and the interhouse speech contest for the Lincoln trophy. Student toastmasters' clubs, panels, and students competing for public speaking prizes of the national engineering societies are given guidance.

Y.M.C.A. The California Institute Y.M.C.A. 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. It also sponsors an annual freshman tea dance. 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. Friends of the Institute "Y" have provided a residence near the campus for the executive secretary, especially built to accommodate informal meetings of discussion groups.

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, many reference books and many extra-curricular items—athletic supplies, stationery, fountain pens, etc. Net income from operation of the store is used for undergraduate scholarships and for payment of a dividend to the Associated Students for student body activities.

AIR FORCE RESERVE OFFICERS TRAINING CORPS

THE California Institute sponsors an Air Force ROTC squadron. Career officers of the U.S. Air Force staff the Department of Air Science to provide the instruction essential for commissioning students who complete the four-year program in the Air Force Reserve, with up to one-third being offered regular commissions. Participation is voluntary for the first two years, called the Basic Course. The Advanced Course, given during the junior and senior years, is offered to those who complete the Basic Course, qualify physically and mentally, and who are willing to sign an agreement to accept a commission and serve on active duty for a period of four years. Graduates are assigned to engineering or scientific work in the Air Force, or if physically qualified, may apply for pilot or navigator training. A special provision is made for sending an engineer or a scientist to graduate school as his first military assignment if he states that he intends to pursue an Air Force career.

In addition to the academic work described on page 254 weekly training is given in drill, ceremonies, and leadership. Field trips to nearby Air Force bases such as Edwards and Vandenberg, and to the Air Force Academy, give Basic cadets the insight needed to decide for themselves the merits of a service career. The squadron also sponsors a drill and a rifle team. These voluntary activities provide opportunities for leadership and entertainment. Cadets make several trips to meets in the western United States.

Deferment from Selective Service may be granted if required. The Air Force furnishes books and uniforms, as well as a ration allowance of $240.00 per year, to the Advanced Course cadets.

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 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 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

Two applications are needed. One, for admission, is made on a form furnished by the California Institute on request, and is returned directly to the Institute together with an application fee of $10. The other, to take examinations, may be secured by writing to the College Entrance Examination Board either in Los Angeles or Princeton (see below).

Completed admission application blanks and the $10 application fee must reach the Admissions Office not later than February 15, 1963. (Application to take entrance examinations must be made directly to the College Board at an earlier date, for which see page 151.

Applicants living outside of the United States must submit their credentials by November 1, 1962.

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, 1963. 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.

Arrangements to take the tests must be made by writing to the College Entrance Examination Board in advance of the closing dates and according to the instructions listed below.

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 cover the principal topics of first-year algebra, intermediate algebra, trigonometry, and plane geometry, preferably including the basic notions of solid geometry. An introduction to elementary analytic geometry and the calculus is desirable but not necessary.

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, basic elementary shop work, 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 achievement tests in advanced mathematics and any two of the following: physics, chemistry, English. Note that the Scholastic Aptitude and the Advanced 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.

For admission in September, 1963 the Scholastic Aptitude Test and achievement tests must be taken no later than the January 12 College Board Test date. *It is important to note that no applicant can be considered in 1963 who has not taken the required tests by January 12, but tests taken on any prior date are acceptable.* No exception can be made to the rule that all applicants must take these tests and no substitution of other tests for those listed above can be permitted.

Full information regarding the examinations of the College Entrance Examination Board is contained in the *Bulletin of Information* which may be obtained without charge 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 27896, Los Angeles 27, California:

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.

Each examination application submitted for registration must be accompanied by the examination fee of $5 for the Scholastic Aptitude Test and $8 for the three Achievement Tests. Please note that the examination fee is *not* sent to the California Institute, but to the appropriate College Board office. The application fee of $10 is the only fee sent to the California Institute at the time an application is made.

All examination applications and fees 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 1, 1962	November 3	October 13
January 12, 1963	December 15	November 24

Candidates are urged to send in their examination applications and fees 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. Under no circumstances will an examination application be accepted if it is received at a Board office later than one week prior to the date of examination. 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 February15, 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, which is the date before which 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. 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 this 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 August 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 1 of his senior year. He will be notified by December 15 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.

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. The freshman chemistry course at the Institute now contains much material formerly given in the sophomore year and not usually covered in advanced placement courses in the schools. For this reason all freshmen must take the first term work (Chemistry 1 a). Those who took the College Board Advanced Placement examination in Chemistry and received a score of 5 or 4 and who received a grade of B or better in Chemistry 1 a may be excused from the lecture portion the last two terms if the advanced course they took in school covered the substantial equivalent of the work given here in these terms. They may also be excused from the laboratory portion of Chemistry 1 bc if they have covered the substantial equivalent, but it is less likely that they will have done so. Anyone who feels that prior to entrance he has covered the equivalent of the 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 courses 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. No advanced placement or credit will be given in English because the freshman course at the Institute (En 1 abc) is an advanced course of a level formerly (before 1959-60) given in the junior year.

History. An entering freshman may be excused from freshman history (H 1 abc: History of European Civilization) on the basis of a one-year college-level course, completed with a high mark, and a high score in the College Advanced Placement examination in that subject; units must be made up by Advanced Placement in any of the Senior Humanities Electives. He may be excused from sophomore history and government (H 2 abc: History and Government of the United States) on the same basis; units must be made up by Advanced Placement in any of the Senior Humanities Electives. (Note: Because of a California State law requiring colleges to give instruction in the Constitutions of the United States and of the State of California, it will be necessary for students to do a small amount of supplementary reading if they are excused from H 2 abc.)

Mathematics. An entering freshman who has achieved a sufficiently high score on the College Board Advanced Placement test in Mathematics will be sent during the summer a questionnaire concerning the advanced work in mathematics which he has taken. If an entering freshman believes that he has covered the equivalent of the first-year mathematics but has not taken the College Board Advanced Placement test he may take the California Institute transfer mathematics examination covering the first-year work. On the basis of the College Board test or the transfer examination and of the information in the questionnaire he may be placed in a special mathematics section which will cover some topics of the freshman course not usually touched on in advanced placement courses and will cover in addition the material of the first two terms of the sophomore year (Mathematics 2 ab). He will then take the third term sophomore work (Mathematics 2 c) in either the first or third terms of the sophomore year. In exceptional cases an entering freshman may be placed immediately in the sophomore course (Mathematics 2 abc). The special mathematics course in the freshman year is taken in place of the regular freshman Mathematics 1 abc and upon successful completion of this special course full credit is given for Mathematics 2 ab. Those who are permitted to enter immediately the sophomore Mathematics 2 abc will receive full credit for Mathematics 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.

PHYSICAL EXAMINATION

Prior to final acceptance for admission, each applicant is required to submit a report of 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 results of the examination are unsatisfactory. (See page 168.)

Vaccination and a standard two-injection tetanus innoculation (or booster shot if appropriate) are required at the time of the examination. Students will not be admitted unless the physical examination form bears evidence of such vaccination and innoculation.

Students who have been on leave of absence for three terms or more must submit reports of a physical examination under the same conditions as for new students.

SCHOLARSHIPS AND LOANS

For information regarding scholarships for entering freshmen see pages 175-182. Note that there is a distinction between Honors at Entrance and scholarship grants and that the latter are awarded on the basis of financial need as well as high standing on the entrance examinations. No one can be considered for a scholarship grant who has not sent in a scholarship form according to the instructions on page 175. In computing need the California Institute uses the figure of $2900 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 $300 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 $400 for one academic year. The figure of $2150 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 171-174.

NEW STUDENT CAMP

All undergraduate students entering the Institute for the first time, either as freshmen or as transfer students, are required to attend the New Student Camp as part of the regular registration procedure. This meeting occupies three days of registration week preceding the fall term, and is usually held at Camp Radford, a large well-equipped camp owned by the city of Los Angeles and located in the San Bernardino mountains east of Redlands.

A large number of faculty members and student leaders attend the camp. During the three-day program the new students hear what life at the Institute is like. They learn what is expected of them and what aids are available to them to help them live up to these expectations. 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 of each year. 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.

AIR FORCE ROTC

For details of admission to the AFROTC see page 149.

ADMISSION TO UPPER CLASSES BY TRANSFER FROM OTHER INSTITUTIONS

The Institute admits to its upper classes (i.e., sophomore year and beyond) a limited number of able men who have made satisfactory records at other institutions of collegiate rank. 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, 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 150-153 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 English, mathematics, and physics, will be classified as freshmen and should apply according to the instructions on pages 150-153. 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, 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 152) to send the scores to the Institute. If the SAT has not been taken previously, it must be taken by the March 3 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, physics, and English composition covering the work for which they desire credit, except that in addition an examination in chemistry is required of those desiring to major in chemistry or chemical engineering. Students must offer courses, both professional and general, substantially the same as those required in the various years at the Institute (see pages 220-234) 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 page 157.

The Institute is presently making a radical revision of its basic two-year course in physics which is required of all students. The new course will be a course in Classical and Modern Physics in which the emphasis will be on modern ideas and applications, to be introduced to the student as early as possible. The revised first-year course was given for the first time in 1961-62 and 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 each of the three subjects, mathematics, physics, and chemistry. 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 English examination covers composition only and is the same, regardless of the level at which the applicant is seeking admission. 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 of 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.

Applications will not be considered unless the applicant has had the substantial equivalent of the mathematics, physics, and English courses given at the California Institute at the first-year level for sophomore standing, and at the first- and second-year levels for junior standing in the option of the applicant's choice.

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, except that 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. For admission to the sophomore year this examination will cover general chemistry and qualitative analysis. The examination for admission to the third year is a comprehensive test covering general chemistry, qualitative and quantitative analysis. 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 26, 1963, is as follows:

Chemistry	(3 hours)	1:00 P.M.	May 10, 1963
English	(1 hour)	9:00 A.M.	May 11, 1963
Mathematics	(2 hours)	10:30 A.M.	May 11, 1963
Physics	(3 hours)	2:00 P.M.	May 11, 1963

No other examinations for admission to upper classes will be given in 1963.

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 Dean of Admissions from the person directing the tests stating that the required supervision will be given.

The attention of students planning to transfer to junior standing is called to the fact that, until they have satisfactorily completed three full terms of residence at the Institute, they are subject to the same scholastic requirements as are freshmen and sophomores (see pages 163-167). In addition, they should note that to be permitted to register for any science or engineering options during their junior and senior years they must meet the scholastic requirements of the divisions concerned (see page 165).

Physical examinations and vaccination are required as in the case of students entering the freshman class (see page 155). 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. Transfer students are expected to attend the New Student Camp for information on which see page 156.

Scholarship grants for transfer students are awarded on the same basis as are those for freshmen: namely, high 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	*Payable Fees*	*Instruction Begins*
Freshmen and Transfer Students	Sept. 20, 1962	Sept. 20, 1962	Sept. 25, 1962
Upperclassmen and Graduate Students	Sept. 24, 1962	Sept. 24, 1962	Sept. 25, 1962

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 and class assignment cards for a program approved by his registration officer 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 similar fee is 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. Registered 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 only after the student has turned in to the Registrar's Office a drop card properly filled out and signed by the instructor concerned and any other required persons. 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 Curriculum 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 58 including 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 167). 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 only after a student has turned in to the Registrar's Office an add card properly filled out and signed by the instructor concerned. No credit will be given for a course for which a student has not properly registered.

General Regulations

Every student is expected to attend all classes and to satisfy the requirements in each of the courses in such ways 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 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 be 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 $25.00 per term, per lecture hour. Registration cards for auditing of courses by such persons may be obtained in the Registrar's Office. Regularly enrolled students and 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 turned in to the Registrar's Office and no official record is kept of the work done.

SCHOLASTIC GRADING AND REQUIREMENTS

SCHOLASTIC GRADING

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 164), 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 and is likewise not used in computing the grade-point average.

"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 by the instructor on a form which will be sent with each grade sheet and only if, in the opinion of the appropriate committee (Undergraduate Academic Standards and Honors Committee for undergraduates, and Graduate Study for graduate students), the reasons justify an incomplete. If, in the opinion of the committee, the incomplete is not justified, a condition will be recorded.

An incomplete or a condition in any term's work must be removed during the next term in residence by the date fixed for the removal of conditions and incompletes. Each student receiving such grades should consult with his instructor at the beginning of his next term in residence. Any condition or incomplete not so removed becomes a failure automatically unless otherwise recommended in writing to the Registrar by the instructor prior to the date for removal of conditions and incompletes.

"Failed" means that no credit will be recorded for the course. The units, however, count in computing the student's grade-point average. He may register to repeat the subject in a subsequent term and receive credit without regard to his previous grade, the new grade and units being counted as for any other course. In special cases the Undergraduate Academic Standards and Honors Committee may, with the instructor's approval, authorize the completing of a *failed* course by three 3-hour examinations, the *units* and new grade being recorded as in the case of repeating the subject. The original "F" and units for the course remain on the record and are counted in computing the grade-point average.

SCHOLASTIC REQUIREMENTS

All undergraduates and Master of Science candidates 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 class-

*Except that C − is considered poor.

work, 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

Credits are not given for work in physical education. The following system of grades is used: P denotes Passed, H denotes Intercollegiate Team Participation and F denotes Failed.

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 units for honor elective courses are not included in computing grade-point average. A grade of Pass may be given for courses bearing a number 200 or greater, for Ph 172, for research conferences and undergraduate research, and is not used in computing the grade-point average.

Ineligibility for registration. Any undergraduate student or Master's candidate 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 or Master's year shall no longer be subject to the requirement that he make a grade-point

*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.

average of at least 1.9 for the academic year. Seniors and Master's candidates 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 166.)

(c) Any undergraduate student, including Seniors, who has been *reinstated* and who fails to make a grade-point average of at least 1.9 for the following term is ineligible to register.

(d) An undergraduate student is ineligible to register for any term if he fails during the preceding term to remove a deficiency in physical education from an earlier term.

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 appropriate Dean 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 Dean can, after consultation with the student and examination of his record, reinstate him or at the Dean's discretion refer special cases to the Undergraduate Academic Standards and Honors Committee. A reinstated student who again fails to fulfill the scholastic requirements for registration must petition the Undergraduate Academic Standards and Honors Committee through the appropriate Dean. In any case the student may, if he wishes, appear before the committee and may at the discretion of the Dean be required to appear. A second reinstatement will be granted only under very exceptional conditions.

Deficiency. Any freshman whose grade-point average during a term falls between 1.4 and 1.9 must obtain the approval of the Dean of Freshmen before registering. 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, but he shall not be required to obtain the approval of the Dean of Students before registering.

Leave of Absence. Leave of absence involving non-registration for one or more terms must be sought by written petition. 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 (credits divided by units) is less than 1.9 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 schedules 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 1.90. 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 49 units each.

Honor standing. At the close of each academic year the Committee on Undergraduate Academic Standards and Honors awards Honor Standing to fifteen or twenty students in each of three classes remaining 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 1961-62 appears on page 333.

Graduation with honor. Graduation *with honor* will be granted a student who has received on the average throughout his course 130 credits per term which result from grades of "A" and "B" exclusively, provided also that he achieves such an average in the senior year. In addition, a student may be graduated with honor under joint recommendation of his division and the Committee on Undergraduate Academic Standards and Honors with the approval of the Faculty.

Term examinations will be held in all subjects unless the instructor in charge of any subject shall arrange otherwise. No student will be exempt from these examinations. Permission to take a term examination at other than the scheduled time will be given only in the case of sickness or other emergency and upon the approval of the instructor in charge and of one of the Deans. A form for applying for such permission may be obtained in the Registrar's Office. Another form must be filled out 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 to request the instructor to leave a copy of the examination in the Registrar's Office to be given at the time and place scheduled for conflict examinations.

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 must obtain the recommendation of the Option Advisor and the approval of the Undergraduate Academic Standards and Honors Committee. Master's candidates, see page 190. Petitions to carry excess units will not be accepted later than the last day of pre-registration.

Registration for fewer than 33 units must be approved by the Undergraduate Academic Standards and Honors Committee. See page 187 for graduate students.

Freshman honor electives. A freshman with a grade-point average for the previous term greater than 1.9 may, in the second or third term, undertake one "Honor Elective" (3 units) in one field, providing he earned at least a B— the previous term in the prescribed course in the chosen field, or obtains the approval of the instructor in such course. If satisfactory work is done, a grade of "H" will be recorded and three units of credit will be allotted on the record; however, these units will not be included in computing the grade-point average.

Selection of course and option. Students who wish to enter one of the options in science must select their options and notify the Registrar's Office thereof shortly before the close of the freshman year. Students who wish to enter the engineering course must also notify the Registrar's Office thereof shortly before the close of the freshman year and should select some specialty in engineering.

Graduation in two different options. 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.

STUDENT HEALTH AND PHYSICAL EDUCATION

Physical Education

All undergraduate students, except members of the Air Force ROTC, are required to participate in some form of physical training for at least one hour a day three days a week. This requirement may be satisfied by engaging in organized sports, which include both intercollegiate and intramural athletics, or by regular attendance at physical education classes. Men who drop Air Force ROTC are required to register for Physical Education immediately.

Men may be excused from the requirement of physical education by petitioning the Physical Education and Athletics Committee for such excuse (1) because of physical disability, (2) when they become 24 years of age, or (3) can show credit for 12 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.

For Graduate Students there is no required work in physical education, but opportunities are provided for recreational exercise.

Student Health

PHYSICAL EXAMINATION AND VACCINATION

All admissions, whether graduate or undergraduate, are conditional until a report of physical examination is received and approved by the Director of Student Health. See page 155. Required are smallpox vaccination, tetanus immunization and tuberculosis testing, all within six months of matriculation.

THE DISPENSARY AND INFIRMARY

The Archibald Young Health Center is located on Arden Road, 50 feet south of California Boulevard. The services offered by the dispensary are available to graduate and undergraduate students; and faculty for emergency care and innoculations. The service offered to employees is for on-the-job injuries and innoculations. Only graduate and undergraduate students (and male employees for emergencies) are admitted to the infirmary. Ten beds are maintained and six emergency beds are available in the infirmary.

The staff consists of attending physicians, retained consultants, and nurses. A medical consultant in radiological safety is on the consulting staff. Diagnostic psychiatric and psychologic service is provided with limited treatment opportunity. Long term or cases requiring sanitarium care are referred to private outside physicians.

The infirmary is operated twenty-four hours a day, seven days a week during the academic year except during holidays (Thanksgiving, Christmas and spring recesses). The dispensary is open during the academic year from 9 a.m. to 5 p.m. Monday through Friday, and 9 a.m. to noon on Saturday. During the vacation periods, a somewhat restricted dispensary service is offered.

General office medical care is provided, minor emergency surgery is performed, and complete laboratory facilities are available at the dispensary through the Pasadena Clinical Laboratory. Close cooperation is maintained with medical specialists in all fields within Pasadena. The services of these doctors are used freely in maintaining high standards of modern medical care. The medical services do not include optometric or dental care.

EMERGENCY HEALTH SERVICES

Over and above the routine medical services available to students at the Health Center, the Institute maintains and supervises a fund to assist both undergraduate and graduate students in meeting the costs of emergency medical, surgical, and hospitalization services in case of an accident or illness. The funds that allow the Institute to support this phase of its health program are derived from the Emergency Health Fund to which the following regulations appertain:

1. The sum of ten dollars of the student's tuition is annually credited to a special account. The Institute, as the custodian, invests these funds and credits the Emergency Health Fund with the income earned. The Fund will not be used for any other purpose than for the payment of the student's medical, surgical, and hospital expenses, including infirmary charges. Whether a case is one within the scope of the Fund will be decided by the Medical Director in consultation with the Health Committee.

   Whenever the expenses for emergency care in any one fiscal year are less than the total deposited in the account for that year, the balance remaining shall be kept in the Fund, and shall remain invested. A balance kept over from one year will be used to render emergency medical and surgical aid to students in later years. The Fund is now stabilized at near $20,000.

2. The Fund is not, in general, applicable to accidents, as distinguished from other emergency medical conditions, which occur away from the grounds of the Institute, unless these occur during authorized activities of the Institute.

3. Each student is insured up to $500 in case of an accident suffered while on Institute property or while engaged in a recognized Institute activity. This coverage is provided by a policy contracted by the Institute and financed by the Emergency Health Fund.

4. The Fund does not cover conditions requiring treatment which arise during the vacation period.

5. The Fund does not cover conditions which existed at the time of admission to the Institute; nor does it cover chronic disease conditions which may develop while the student is at the Institute.

6. The Fund does not cover injuries incurred in connection with authorized intercollegiate athletics. However, the Department of Physical Education maintains two insurance plans, one for lesser and one for major expense, both for intercollegiate athletic participants.

7. The Fund does not provide for the families of graduate or undergraduate students.

8. The maximum that has been allowed from the Fund for any one illness or injury is $250, but the Fund is not obligated to pay this maximum, nor is

there any obligation to pay for such expenses beyond the available balance of the Fund. The Health Committee reviews each case with the Medical Director and determines the amount of assistance to be granted from the Fund.

ELIGIBLE EXPENSES

1. The cost of a student's stay in the infirmary is charged to the Emergency Health Fund.

2. The costs of all medical and surgical services and hospitalization which need to be secured outside of the infirmary and dispensary are the responsibility of the student, although the Fund may help defray these costs.

3. Accidents occurring off the campus and out of the jurisdiction of the Institute (e.g., non-authorized athletics or automobile accidents) may be cared for in the infirmary but the charges will be borne by the student.

4. Medical services not falling within the purview of the Institute's health program may be obtained by students on a non-profit basis at the infirmary. A schedule of charges for cost of medicines, injections, and laboratory work is posted in the dispensary.

SUMMER HEALTH COVERAGE

All students, undergraduate and graduate, registered for summer work for academic credit are charged a health fee of $7.50 per student. The fee makes the student eligible for (1) the benefits of the Emergency Health Fund on the same basis as during the regular academic year (Fall Registration to Spring Commencement), and (2) the extended protection of accident insurance coverage, up to $500, over the same summer period .

The only students exempt from paying this mandatory fee are graduate students who pay regular tuition during the summer months.

During the summer vacation, graduate and undergraduate students who are not registered for summer work pay a fee of $2.00 per visit to the Health Center, plus cost of medicine and laboratory services.

RESPONSIBILITY OF THE STUDENT

The responsibility for securing adequate medical attention in any contingency, whether an 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 medical advice and attention in any case are entirely the responsiblity of the student, except as specified above.

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.

ANNUAL EXPENSE SUMMARY

Tuition (3 terms) 1962-63		$1,575.00	
General Deposit		25.00	
Student Body Dues		19.00	
Subscription to *California Tech*		1.50	1,620.50
Books and Supplies (approx.)			80.00
Student House Living Expenses (21 meals per week)			
Board	$560.00		
Room	365.00[1]	925.00	
Dues		21.00	946.00
			2,646.50

The following is a list of undergraduate student expenses at the California Institute of Technology for the Academic Year 1962-63, together with the dates on which the various fees are due. These charges are subject to change at the discretion of the Institute.

			Fee
	First Term		
Sept. 20, 1962: Freshmen and transfer students	General Breakage Deposit		$ 25.00
	Tuition		525.00
	Board and Room		335.00[1]
Sept. 24, 1962: All others	*Incidental Fees:*		
	Associated Student Body Dues	$ 5.50	
	Subscription to *California Tech* for 1962-63	1.50	
	Total		7.00
	Student House Dues		7.00
	Second Term		
January 2, 1963	Tuition		525.00
	Board and Room		297.00[1]
	Incidental Fees:		
	Associated Student Body Dues		6.75
	Student House Dues		7.00
	Third Term		
March 25, 1963	Tuition		525.00
	Board and Room		293.00[1]
	Incidental Fees:		
	Associated Student Body Dues		6.75
	Student House Dues		7.00

[1]There are a few large rooms available which will rent for $425.00 per year. Rates for room and board subject to revision prior to beginning of any term upon notice to student.

Tuition Fees for fewer than normal number of units:

Over 32 units	Full Tuition[1]
32 to 25 units	$400.00 per term
24 to 10 units	$16.00 per unit per term
Minimum per term	$160.00
Auditor's Fee (page 162)	$25.00 per term, per lecture hour

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 for time in attendance.[2] No portion of the Student Body Dues, or subscription to CALIFORNIA TECH, is refundable upon withdrawal at any time.

Associated Student Body Fee. The Associated Student Body Fee of $19.00 is payable by all undergraduate students. This fee is used for the support of athletics, the BIG T, 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,* $1.50 per year, is collected from every undergraduate.

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.

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 142).

Special Fees. Students taking the Spring Field Trip in Geology (Ge 122) and the Summer Field Geology course (Ge 123) are charged for travel at an estimated rate of one cent per automobile mile plus reasonable subsistence expense.

The fee for auditing courses (see page 162) is $25.00 per term, per lecture hour.

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.

[1]Although the Institute charges full tuition for over 32 units, the Veterans Administration allows the following subsistence percentages: 25% for 10 through 20 units per term; 50% for 21 through 29; 75% for 30 through 41; and 100% for 42 and over. See footnote page 219.

[2]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.

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 two sources of loan funds and the conditions governing each are described below.

1. California Institute loan funds are available in amounts not to exceed $750 in any one year and a maximum of $3000 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 the graduation of their class and is at the rate of $50 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 no later than the fall following their class's graduation, interest is charged at the rate of 3 percent per annum, but no payment 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 $50 per month including interest at 4 percent on the unpaid balance. 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 $1,000.

2. Federal loans under the National Defense Education Act are available in amounts not to exceed $1000 for any individual in a single year up to a total of $5000. The borrower must demonstrate financial need, must be an above average student and must be willing to sign a loyalty oath and an affidavit that he neither believes in, is a member of or supports any organization that advocates overthrow of the United States government by violence or any illegal or unconstitutional means. No interest is charged on these loans nor is any repayment of principal required until one year 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.

To the extent of available funds students who wish to borrow and who meet the stipulated requirements will be given their choice of the foregoing sources of loans.

Deferred Payment Plan. In addition to loans there is available a plan under which any student in good standing may defer up to $1000 of his college bills each year to a total of $4000 and may pay the deferred portion in installments after his graduation. The sum of $39.00 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 covers in addition the life of the parent or guardian responsible for the student's support. Interest on the amount deferred is charged at the rate of 5½ percent per annum payable quarterly. The interest is the only payment made on this plan during the undergraduate years. The interest payments are as follows: during freshman year $42.82, sophomore year $99.90, junior year $157.00, senior year $214.08. Commencing November 1 following his class's graduation the student commences repayment on the deferred portion at the rate of $55 a month including interest at 6 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 $1300 in any year (maximum of $5200).

Entirely aside from loans and the Deferred Payment Plan a student may 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 HONORS AND SCHOLARSHIP GRANTS

In order that appropriate awards may be made to students as they most deserve or need them, the California Institute makes a clear distinction between recognition of academic honor and achievement and recognition of need for financial assistance. This distinction is made with two types of awards: Honors at Entrance and Scholarship Grants.

HONORS AT ENTRANCE

In recognition of distinguished academic achievement Honors at Entrance are awarded to the top ten percent of those admitted to the freshman class. They are awarded without regard to financial need, and carry no monetary grant. No application for consideration for Honors at Entrance is needed.

FRESHMAN SCHOLARSHIP GRANTS

The recipients of scholarship grants are selected by the Freshman Admissions Committee from the candidates who have stood sufficiently high on the entrance examinations, and have otherwise satisfied the entrance requirements of the Institute, and have submitted a *Parent's 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 grants will be found on pages 177 to 182.

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. The form, called a *Parent's 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 152. 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 152) 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 fee of three dollars is charged by the service for sending a copy of the form to one college, and an additional two dollars each for copies sent to additional colleges. This fee must accompany the form when it is returned to the College Board office.

Parent's Confidential Statement forms must be sent to the appropriate College Board office not later than February 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 College Scholarships, and the Regional Scholarships described below are given without consideration of financial need. All applicants for admission are automatically considered for the Sloan and General Motors College Scholarships. Candidates for Regional Scholarships are nominated by the principals or headmasters of their schools. Only when need exists is it necessary to file a *Parent's 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, the General Motors National 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 a rank in the upper half of the class. 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 freshmen 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 SCHOLARSHIPS

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 grade-point average of at least 2.0. Awards are made in order of rank in class to the extent of the funds available. Most awards are for full or part tuition. When individual scholarships carry amounts in excess of full tuition that fact is noted in the list of scholarships below. A student who ends the academic year with a grade-point average of 2.0 or higher 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.

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 *Parent's Confidential Statement* on file will be considered for the best award to which their relative need and standing on the entrance examinations entitle them. For Honorary Scholarships see above.

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.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Southern California Chapter: The A.S.H.R.A.E. will in 1962 award a $250 prize scholarship to an engineering student nominated by the Engineering Faculty.

ARCS Foundation (Achievement Rewards for College Scientists) of Los Angeles: The ARCS Foundation 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 in 1962-63.

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.

Bechtel Foundation Scholarships: The Bechtel Foundation of San Francisco provided funds for two scholarships to be awarded to juniors or seniors in engineering.

Meridan Hunt Bennett Scholarships and Fellowships: Mrs. Russell M. Bennett of Minneapolis, in January 1946, made a gift of approximately $50,000 to the Institute to constitute the Meridan Hunt Bennett Fund as a memorial to her son, Meridan Hunt Bennett, a former student at the Institute. The income of this fund is to be used to maintain scholarships which shall be awarded to undergraduate and graduate students of the Institute, the holders of such scholarships to be known as Meridan Hunt Bennett Scholars.

Blacker Scholarships: Mr. and Mrs. Robert Roe Blacker of Pasadena, in 1923, established the Robert Roe Blacker and Nellie Canfield Blacker Scholarship and Research Endowment Fund. A portion of the income of this fund, as determined by the Board of Trustees, may be used for undergraduate scholarships.

C. F. Braun and Company Scholarships: C. F. Braun and Company of Alhambra, California, established three scholarships of $1000 each to be awarded to entering freshmen. In selecting candidates preference will be given to those who indicate that they wish to pursue a course in engineering.

California Scholarship Federation Scholarship: The California Institute each year awards a scholarship to a C.S.F. member who is also a sealbearer provided that such a candidate is available who has met the Institute's requirements for a freshman scholarship grant. Sealbearer status must be verified by the C.S.F. adviser at the time of submitting the regular application for a scholarship grant.

Chisholm Scholarship: Mr. William Duncan Chisholm made provision for an annual scholarship to be awarded to an undergraduate.

Class of 1927 Scholarship: The Class of 1927 established the Class of 1927 Scholarship Endowment Fund. The income from this fund is to be used for an undergraduate scholarship.

Crellin Scholarships: Mrs. Amy H. Crellin made provision for annual scholarships to be awarded to undergraduates.

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.

Garrett Corporation Scholarships: The Garrett Corporation of Los Angeles gave $3000 for scholarships to be awarded to juniors or seniors majoring in engineering or chemical engineering, and to fifth-year students in mechanical engineering and chemical engineering.

General Motors Corporation Scholarship: The General Motors Corporation established a scholarship at the California Institute to be awarded to an entering freshman. 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. Holders 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 at the California Institute a scholarship to be awarded to a student in the junior class.

Goodyear Scholarship: The Goodyear Foundation, Inc., of Akron, Ohio, established a scholarship of $1000 to be awarded to a junior or senior in engineering who may be interested in a career in business or industry.

Graham Brothers Foundation Scholarship: The Graham Brothers Foundation of Long Beach made possible the award of a scholarship.

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

The Holly Scholarship: The Holly Manufacturing Company has established a half-tuition scholarship to be awarded to a senior in the engineering option.

Walter Humphry Scholarships: Mr. Walter Humphry established a fund the interest from which is used for undergraduate scholarships.

The International Nickel Company Scholarship: The International Nickel Company of New York established a scholarship of $1900 a year for a student studying engineering or geology. The award is made to a student entering the freshman year and he may expect it to be renewed for each of the three upperclass years provided his grades and conduct remain satisfactory.

Earle M. Jorgensen Scholarship: Mr. Earle M. Jorgensen 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.

Ladish Company Scholarships: The Ladish Company is providing a scholarship in the amount of $350.

Lockheed National Engineering Scholarship: The Lockheed Aircraft Corporation of Burbank, California, established a scholarship covering tuition and certain other expenses totaling $2100 a year. 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 established a tuition scholarship to be awarded to an undergraduate student in one 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.

Mobil International Oil Company Scholarship: The Mobil International Oil Company gave a scholarship for an undergraduate majoring in geology.

Seeley Mudd Scholarships: The Seeley W. Mudd Foundation of Los Angeles provided funds for scholarships to cover non-tuition expenses of students in the geology option.

David Lindley Murray Educational Fund: Mrs. Katherine Murray of Los Angeles, by her will, established the David Lindley Murray Educational Fund, the income to be expended in assisting worthy and deserving students to obtain an education, particularly in engineering courses.

Neely Enterprises Scholarships: Neely Enterprises gave $2000 for scholarships for sophomore students majoring in physics or engineering whose homes are in Arizona, California, Nevada or New Mexico.

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 provided for two four-year undergraduate scholarships in the amount of $1700 a year each. These four-year awards are open to entering freshmen only.

Radio Corporation of America Scholarship: The Radio Corporation of America provided funds for an undergraduate scholarship for 1961-62 in the amount of $800. Freshmen are not eligible for this award.

Rayonier Foundation Scholarship: The Rayonier Foundation is providing two scholarships of $500 each for undergraduates majoring in chemical engineering or engineering.

Regional Prize Scholarships: A Regional Prize Scholarship is awarded to one entering freshman student each year in each of seven regions in the United States. The scholarship carries a stipend of $1400 for the freshman year. Regional Scholarships are an academic honor and are awarded, without regard to financial need, on the basis of high scholastic grades, high scores on the College Board Examinations required for admission, the recommendations of teachers and principals or headmasters, and on the result of a personal interview with a member of the Admissions Committee. To be eligible to compete for these scholarships an applicant must be nominated by the principal or headmaster of his school and must be attending school in one of the following regions: Region I: California; Region II: Idaho, Montana, Oregon, Washington, Wyoming; Region III: Arizona, Colorado, Nevada, New Mexico, Texas, Utah; Region IV: Illinois, Iowa, Minnesota, Missouri, Nebraska, Wisconsin; Region V: Indiana, Michigan, Ohio; Region VI: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont; Region VII: Delaware, Maryland, New Jersey, New York, Pennsylvania. Nomination forms will be sent on request to principals or headmasters of schools in these regions.

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 $2000 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 holder's grades and conduct remain satisfactory.

Standard Oil Company of California Scholarships: The Standard Oil Company of California provided a scholarship for an undergraduate majoring in chemical engineering and another scholarship for an undergraduate 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 in the amount of $1700 each year. Preference is given to a student interested in geology or chemical engineering as applied to the petroleum industry.

Ray Tenhoff Memorial Scholarship: Donated by the Society of Experimental Test Pilots in honor of its first president. This scholarship provides up to $1000, depending on need, to be awarded to a student entering the junior class in engineering or physics, in that order of preference. The holder of this scholarship may expect it to be renewed for his senior year, provided holder's grades and conduct remain satisfactory.

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.

Timken-Sturgis Foundation Scholarship: The Timken-Sturgis Foundation of San Diego made possible the award of one or more undergraduate scholarships.

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.

Claudia Wheat Scholarship: Mr. C. A. Wheat established a full-tuition scholarship in memory of his wife. The award goes to an entering freshman, and preference is given to a graduate of Alhambra High School in Alhambra, California.

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.

The R. C. Baker Foundation
Crown Zellerbach Foundation
Cyprus Mines Corporation
Douglas Aircraft Company, Inc.
Garrett Corporation
General Motors Corporation, College Plan
Goodyear Foundation, Inc.
Graham Brothers Foundation
Kennecott Copper Corporation
Lockheed Leadership Fund
Mobil Oil Company
The Procter & Gamble Fund
Radio Corporation of America
Alfred P. Sloan Foundation
The Superior Oil Company
Texaco Inc.

4. STUDENT AID LOAN FUNDS

Institute Loan Funds (see page 173)

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 173-174. Borrowers must be making satisfactory progress toward their degrees; and, in general, preference is given to students who have earned part of their expenses. The Institute Loan Funds are named as follows:

The Gustavus A. Axelson Loan Fund
The Olive Cleveland 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
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
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
The Sloan Foundation Loan Fund
The Albert H. Stone Educational Fund

National Defense Student Loan Program (see page 173)

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. Students with superior grades take precedence over others.

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 an affidavit disclaiming belief or membership in subversive organizations; 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 173-174.

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 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.

During the second and third terms, schedules are arranged for students to be interviewed by representatives of organizations who visit the campus. 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.

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.

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 $1,000 provides for a first and second prize to be awarded at a public contest and announced at Commencement. The contest is under the direction of representatives of the Division of the Humanities.

THE MARY A. EARL MCKINNEY PRIZE IN ENGLISH

The Mary A. Earl 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 recipient, an upperclassman, is selected on the basis of his capacity to take advantage of and to profit from these opportunities rather than on the basis of his scholastic standing.

THE AMERICAN CHEMICAL SOCIETY PRIZE

A prize of $250 is awarded each year in connection with the annual high school contest of The American Chemical Society, Southern California Section. The prize goes to the highest ranking man in the contest who applies, is admitted, and registers at the California Institute in the fall following his senior high school year, provided that the candidate does not rank below the top five in the contest.

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.

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; the degrees of Aeronautical Engineer, Civil Engineer, Electrical Engineer, Geological Engineer, Geophysical Engineer, and Mechanical Engineer, after a minimum of two years of graduate work; and the degree of Doctor of Philosophy.

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. 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. Women students are admitted only in exceptional cases. 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 214) 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 155 and 168.

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. Foreign students who are admitted to graduate standing may be required to confine their work during their first term of residence to undergraduate courses when this is necessary in order to familiarize them with American teaching methods and vernacular English.

II. GRADUATE RESIDENCE

One term of residence shall consist of one term's work of not fewer than 45 units of advanced work in which a passing grade is recorded. If fewer than 45 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 190, 192, 196 for special requirements for residence.

Graduate students will be required to carry at least 36 units during each of their first three terms of attendance at the Institute.

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.

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 between May 15 and June 15. Students who are registered for summer research will not in general be required to pay tuition for the research units, but will be required to pay minimum tuition of $160 if Ph.D. or engineer's degree thesis requirements are completed during the summer.

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 Registrar, and must carry the recommendation of the student's major department before submission to the Graduate Office.

A graduate student will be considered to be ineligible for registration at the beginning of his second term at the Institute 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.

III. 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 164), the grade "P," which denotes passed,

may be used at the discretion of the instructor, in the case of seminar or other work which does not lend itself to more specific grading. In graduate research, only the grades "P" and "F" are given.

IV. TUITION FEES

The tuition charge for all students registering for graduate work is currently $1575 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. 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. Students desiring permission to register for fewer than 33 units should petition therefor on a blank obtained from the Registrar. If reduced registration is permitted, the tuition is at the rate of $400 a term for 32 to 25 units, and at the rate of $16 a unit for fewer than 25 units, with a minimum of $160.00 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.

The tuition includes the cost of the routine medical services available to students at the Health Center, as well as the sum of ten dollars which is credited annually to the Emergency Health Fund (see page 169). A summer accident fee of $7.50 must be paid by graduate students who register for summer work (see page 170). 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.

No degrees are awarded until all bills due the Institute have been paid.

In regard to *fellowships and assistantships*, see page 214 of this catalog. In addition, to students of high scholastic attainments there may be awarded *graduate scholarships* covering the whole or a part of the tuition fee. For such students *loans* also may be arranged, for which application should be made 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, provided that they meet the same conditions that apply to undergraduate loans.

GRADUATE EXPENSES

Tuition (3 terms) 1962-63	$1,575.00	
General Deposit	25.00	$1,600.00
Books and Supplies (approx.)		80.00

Graduate House Living Expenses (see page 213 for details)
Room—$382.50 to $585.00 per Academic Year
Meals—Available at the Chandler Dining Hall
or the Athenaeum (members only)

	First Term	
September 24, 1962	Tuition	525.00
	General Deposit (see page 172)	25.00
	Second Term	
January 2, 1963	Tuition	525.00
	Third Term	
March 25, 1963	Tuition	525.00
*Summer Accident Insurance Fee		7.50

Tuition fees for fewer than normal number of units:

Over 32 units	Full Tuition[1]
32 to 25 units	$400.00 per term
24 to 10 units	$16.00 per unit per term
Minimum per term	$160.00
Auditor's Fee (page 162)	$25.00 per term, per lecture hour

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 for time in attendance.[2]

B. REGULATIONS CONCERNING WORK FOR THE DEGREE OF MASTER OF SCIENCE

I. GENERAL REQUIREMENTS

To receive the degree of Master of Science the student must complete in a satisfactory way the work indicated in the schedule of fifth-year courses (see pages 235-248) as well as in the schedule of the four-year course in science or in engineering, except that, in the case of students transferring from other institutions, equivalents will be accepted in subjects in which the student shows by examination or otherwise that he is proficient, and except in so far as substitutions may be approved by special vote of the committee in charge.

Senior students at the Institute desiring to return for a fifth year should consult with the faculty in the field in which they expect to do their major work, and apply for admission to work towards the master's degree on a form obtained from the Dean of Graduate Studies. Such students will be

*An Accident Insurance Fee of $7.50 will be charged to all students taking summer research.

[1]Although the Institute charges full tuition for 32 units, the Veterans Administration allows the following subsistence percentages: 25% for 10 through 20 units per term; 50% for 21 through 29; 75% for 30 through 41; and 100% for 42 and over.

[2]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.

expected to present satisfactory scholarship qualifications, and to have demonstrated a capacity for doing advanced work.

All programs of study and applications for admission to candidacy for the degree of Master of Science shall be in the charge of the Curriculum Committee; and recommendations to the Faculty for the award of the degree shall be made by this committee, all such actions being taken in general after consideration of recommendations by the department concerned.

A student before entering upon work for the degree of Master of Science should, after consultation with the department concerned, submit a plan of study, and make application to the committee in charge for acceptance as a candidate for that degree. Application forms for admission to candidacy for these degrees may be obtained from the Registrar, and must be submitted not later than the sixth week of the academic year in which the degree is to be granted.

II. REGISTRATION

1. The regulations governing registration and student responsibilities as given for undergraduate students on pages 161-162 of the catalog apply also to students working toward the master's degree.

2. Before registering, the graduate student should consult with members of the department in which he is taking his work to determine the studies which he can pursue to the best advantage.

3. A student will not receive credit for a course unless he is properly registered, and at the first meeting of each class should furnish the instructor with a regular assignment card for the course, obtained on registration.

4. Students registering for more than 50 units but fewer than 63 units in any term must have the approval of their department. Registration for more than 62 units must in addition have the approval of the Dean of Graduate Studies.

5. In the case of a student registered for the degree of Master of Science and holding a position as a graduate assistant, 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.

III. SCHOLASTIC REQUIREMENTS

1. A minimum of 140 units of graduate residence at this Institute is required for the master's degree, but specific departmental requirements often exceed this number. All or any part of this residence may be acquired prior to the completion of the work for the bachelor's degree provided a total of fifteen terms of acceptable college work equivalent to 45 units per term is completed. 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.

2. Scholastic requirements for undergraduate students (see page 163) also apply to students working toward the master's degree. In meeting the graduation requirements on page 166, the following rule will apply for master's degree candidates: only those courses shown on the candidacy

blank and approved by the department representative shall be counted in figuring the grade-point average. Students who become ineligible to register, having failed to meet the scholastic requirements stated on pages 163-165 of the catalog, may submit to the Dean of Graduate Studies a petition for reinstatement. This petition should have the endorsement of the department in which the student is registered. The Dean of Graduate Studies will pass on this petition if he concurs with the departmental recommendation; otherwise the petition will be referred to the Committee on Graduate Study for final action. Changes on the candidacy blank which are not initialed by the proper authority are not to be recognized. No course which appears on the candidacy blank and for which the candidate is registered may be removed after the last date for dropping courses as listed in the catalog.

3. Students admitted to work toward the degree of Master of Science who have completed the senior year at the Institute are subject to the same regulations as are seniors, as listed on pages 163-165.

4. Students admitted to work toward the degree of Master of Science who have completed their undergraduate work at other institutions are subject to the scholastic regulations applying to new transfer students as listed on pages 157-160.

5. Students admitted to work toward the master's degree in the Division of Chemistry and Chemical Engineering are required to take placement examinations. See page 238.

6. Students admitted to work toward the degree of Master of Science in Electrical Engineering must take placement examinations to be used as a guide in selecting the proper course of study. These examinations are given on Friday of the week preceding registration. These examinations will cover essentially the content of the courses given to seniors in the Engineering Division, EE 101 a, b and EE 115 a, b. In addition, the examination will cover the field of physical electronics. This examination has no bearing on a student's admission to graduate school. It is simply to assist the faculty in evaluating the individual's undergraduate training. Notices of this examination are sent well in advance of the examination date.

7. A written placement examination is required of incoming graduate students in the Division of Geological Sciences. For details see page 206. 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.

8. 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 209.

IV. THESIS

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 186. Regulations governing registration will be found on page 194. 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 187) 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 the end of the second week of the first term of the academic year in which the student expects to receive the degree he must file in the office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. Upon receipt of this application, the Dean, in consultation with the chairman of the appropriate division, will appoint a committee of three members of the faculty to supervise the student's work and to certify to its satisfactory completion. One of the members of the committee must be in a field outside 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 a ribbon copy, a reproduced copy, and the vellum of a satisfactory individual thesis describing his research, including a one-page digest or summary of the main results obtained. In form, the thesis must satisfy the requirements for theses for the degree of Doctor of Philosophy. (See page 197.)

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 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 204, except that a grade of D in Ph 131 abc is acceptable.

Special Requirements for the Degree of Mechanical Engineer. Each student admitted to work for the degree of Mechanical Engineer shall be required to take an oral placement examination given by the faculty in mechanical engineering before his registration. The results will be used as a guide in 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, 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 247.

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, and he must satisfy the foreign language requirements.

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 198-213.

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. 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 regular courses 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. 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.*

4. 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.

5. 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 shall 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.

6. Registration, with at least minimum tuition (see page 172), is required for the term or summer period in which the requirements for the Ph.D. degree are completed, including either the final examination or submission of thesis. Registration with minimum tuition will be allowed for at most one term.

7. Graduate students studying for the doctor's degree who are devoting their whole time to their studies will be allowed to register for not more than 60 units in any one term. (See pages 190, 192 with reference to total work load of graduate students.)

IV. 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 45 units of advanced work in one or more disciplines in the humanities or science 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 in any discipline listed on pages 198-212, under special requirements adopted by the various divisions of the Institute. The program must be approved by both major and minor divisions on a form obtainable from the Graduate Office. The candidate will be examined on this work (see page 197). 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 187 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 in charge of 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 been in residence at least one term thereafter; 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 the language requirements; has shown ability in carrying on research with a research subject approved by the chairman of the division concerned; and has initiated a program of study approved by his major department and, if needed, by his minor department. For special departmental regulations concerning admissions to candidacy, see pages 198-213. Members of the Institute staff of rank higher than that of Assistant Professor are not admitted to candidacy for a higher degree.

A regular 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 beginning of the fourth academic year after admission to graduate standing at the Institute. A student not admitted to candidacy at that time must petition through his division to the Dean of Graduate Studies for permission to register for further work.

4. *Language requirements.* To be admitted to candidacy for the degree of Doctor of Philosophy a student must have a good reading knowledge of at least two foreign languages chosen among French, German and Russian. With the permission of the department concerned and the Dean of Graduate Studies, another modern language may be substituted for one of these languages. As soon as possible after beginning their graduate study, students are urged to consult with the department of languages to determine the best means of satisfying these requirements early. The language requirements in either or both of the approved languages can be met in one of three ways:

i. To pass language examinations. Examinations in French and German are given three times a year. The dates are announced on the calendar on pages 4, 5.

ii. To pass with a grade of B- or better one of the following courses: L 1 abc in French, L 35 in German, or L 51 a in Russian.

iii. With the approval of the department of languages, to complete a translation project. A knowledge of the fundamentals of the language is presupposed in such a case.

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, and if the candidate has a subject minor, on the subject of that program. These examinations, 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 they must take place at least two weeks before the degree is to be conferred.

The examinations 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 examination relating to the subject minor need not be included in the final examination. It may be given at a time to be determined by agreement between the minor and the major departments. The student must petition for these examinations on a form obtained from the Dean of Graduate Studies. For special departmental regulations concerning candidacy and final examinations, see pages 198-213.

6. *Thesis.* Two weeks before the degree is to be conferred, the candidate is required to submit to the Dean of Graduate Studies a ribbon copy, a reproduced copy, and the vellum of a satisfactory thesis describing his research. For special departmental regulations concerning theses, see pages 198-213.

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 193.

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.*

V. 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 IV, page 195, 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 will include 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).

2. *Admission.* Applicants are expected to meet the following minimal requirements: Mathematics through calculus, general physics, organic chemistry, physical chemistry, and biology approximately equaling the content of two of the following courses: Bi 3 (Plant Biology), Bi 10 (Animal Biology) and Bi 9 (Cell 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.

3. *Placement Examinations.* All students admitted to graduate work towards the Ph.D. in the Division of Biology are required either to take place-

ment examinations in two of the following areas: cell biology, plant biology, animal biology; or to pass or have passed two of the equivalent courses (Bi 3, Bi 10, Bi 9), with a grade of B– or better. These examinations or courses must be taken 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 committee consists of a chairman and three other members of the faculty representing diverse fields of biology. The committee will advise the student of deficiencies in his training; will design a remedial study program where necessary; and will recommend an individual study program of advanced course work in accordance with item (c), section 1. The committee will also be available for consultation and advice throughout his graduate study. 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 Fellows.* A graduate student who holds a national fellowship to do graduate work in the Division of Biology may be assigned to give limited assistance in teaching undergraduate courses if his advisory committee considers it to be of value for him to gain 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	Molecular Biology
Biophysics	Neurophysiology
Cell Biology	Plant Physiology
Developmental Biology	Psychobiology
Genetics	Virology

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 Virology and Chemistry). When he takes a general minor, his degree designates only his major discipline (e.g., Biochemistry or Neurophysiology).

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, or a combination of these disciplines.

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.

9. *Final Examination and Thesis.* A final oral examination covering principally the work of the thesis will be held at least two weeks before the degree is to be conferred. The original typed copy of the thesis, the vellum copy, and two reproduced copies must be submitted at least two weeks before the date of the final examination. One of the two reproduced copies is retained by 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.* During 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 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.

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 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.

A student admitted to work for the Ph.D. degree in chemistry who fails to satisfy the Division's requirements for candidacy by the end of his fifth term 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.

1B. *Chemical Engineering.* The requirements in chemical engineering are essentially the same as those in chemistry except that the placement examinations will be required in the fields of engineering thermodynamics of one-component systems (on the Wednesday before registration), the unit operations of chemical engineering including fluid flow topics (on Thursday), and either industrial chemistry (on Monday) or physical chemistry (on Tuesday). Students who have in earlier residence at this Institute demonstrated proficiency in the subjects covered by the placement examinations may be excused from them.

The Division's requirements for candidacy in chemical engineering are to be completed by the end of the student's fifth term of graduate residence at the Institute. The candidacy examination covers thermodynamics, chemical engineering unit operations, physical chemistry, and industrial chemistry.

2. It is expected that the applicant 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 of Chemistry and Chemical Engineering 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 to the Chairman of the Division of Chemistry and Chemical Engineering four copies of his thesis, in final form (the original copy, a copy on vellum, and two copies reproduced from the vellum), at least two weeks before the date of his final examination. Three copies are returned to the candidate after his examination.

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.

A copy of the set of propositions in final form must be submitted as part of each copy of the thesis to the Chairman of the Division of Chemistry and Chemical Engineering at least two weeks before the date set for the examination.

6. Graduate students taking chemistry as a subject minor shall complete a program of study which in general shall include Ch 125 or Ch 144 or Ch 148-149 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

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 20 units of research in his chosen field. Thus, upon completion of his fifth year's work, he will be admitted to work towards the engineer's degree. If his course work and research during the sixth year show that he is capable of carrying on work at the doctorate level and if he satisfactorily passes a qualifying oral examination, he may then be admitted to work towards the doctor's degree. Upon being admitted to work towards the doctor's degree, his admission to work for the engineer's degree will be cancelled.

To be recommended for candidacy for the doctor's degree in aeronautics the applicant must pass one of the following subjects with a grade of C or better:

AM 125 abc	Engineering Mathematical Principles
Ma 108 abc	Advanced Calculus
Ph 129	Methods of Mathematical Physics
Ph 108 abc	Theoretical Mechanics

and two of the following subjects:

Ae 210 abc	Fundamentals of Solid Mechanics
Ae 201 abc	Fundamentals of Fluid Mechanics
JP 121 abc	Rockets and Air Breathing Engines

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.

2. *Applied Mechanics.* To be recommended for candidacy for the Ph.D. degree in Applied Mechanics, the student must, in addition to the general Institute requirements:

a. Complete 12 units of research.

b. Complete not less than 50 units of advanced courses arranged by the student in conference with his advisor and approved by the faculty in Applied Mechanics. 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, acceptable to the faculty in Applied Mechanics. Such course shall be in addition to requirement (b) above.

d. Pass a three-hour oral examination on his major subject, and if the student has a subject minor, examination on the subject of that program shall be included.

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 faculty in Applied Mechanics, elect a discipline in the field of Applied Mechanics 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, demonstrating his knowledge of the field of civil engineering. The examination will include, but will not be limited to, presentation and defense of two or three propositions which should be controversial or unresolved topics in civil engineering for which there is more than one point of view. At least eight weeks before the examination the student must submit a list of 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 (2 to 6 pages each), and (b) a brief statement of his proposed thesis research.

To be recommended for admission to candidacy the applicant must (a) pass the qualifying examination described above, (b) submit a satisfactory written progress report on his thesis research, (c) pass the courses required for the M.S. degree, and other advanced courses as required by the staff, and (d) 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 and AM 116 or Ma 112 will be an acceptable substitution for the mathematics requirement.

Minor. The purpose of the minor program of study in Civil Engineering is to broaden the student's outlook by acquainting him with subject matter outside his major field and by introducing him to different approaches to problems closely related to his field. The student may follow either a subject minor or a general minor. For a subject minor, the work must be outside the Division of Engineering. For a general minor, at least a portion of the work should preferably be outside the Division, but none of it shall include any of those courses in the fifth-year Civil Engineering schedule of courses which are usually taken by M.S. candidates in Civil Engineering. The choice of program must be approved by the student's advisor and the faculty in Civil Engineering.

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. If his course work and research during the 5th year show that he is capable of carrying on work at the doctorate level and if he satisfactorily passes a qualifying oral examination, he may then be admitted to work towards the doctor's degree.

Note: For students entering with a Bachelor of Science degree, placement examinations are required (see page 191).

To be recommended for candidacy the applicant must satisfactorily complete 18 units of research in his field of interest and pass the following subject with a grade of C or better:

Ph 131 abc	Electricity and Magnetism

and one of the following subjects:

Ma 108 abc	Advanced Calculus
AM 125 abc	Engineering Mathematical Principles
Ph 129 abc	Methods of Mathematical Physics

An applicant may also satisfy any of the course requirements described above 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.

Students working toward the doctorate are required to take three oral examinations. The first of these, which is normally given during the fifth year, may be waived at the discretion of the faculty. The second, normally taken in the third term of the second year of graduate study, must be taken prior to admission to candidacy and covers broadly his major field and his minor program of study. The third, which is taken after admission to candidacy, covers his doctorate 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 thesis has been presented in final form and prior to its approval.

5. *Engineering Science.* The program of study leading to advanced degrees in Engineering Science must be approved by the Engineering Science Committee. To be recommended for candidacy for the Ph.D. degree in Engineering Science the student must complete at least 12 units of research and pass a comprehensive candidacy examination, in addition to the general Institute requirements. The candidate must submit a satisfactory thesis and take a final examination. The final examination will cover the thesis and fields related to it.

6. *Materials Science.* To be recommended for candidacy for the Ph.D. de-

gree in Materials Science, the student must, in addition to the general Institute requirements:

a. Complete 12 units of research.

b. Complete not less than 50 units of advanced courses arranged by the student in conference with his advisor and approved by the faculty in Materials Science. 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, acceptable to the faculty in Materials Science. Such course shall be in addition to requirement (b) above.

d. Pass a three-hour oral examination on his major subject, and if the student has a subject minor, examination on the subject of that program shall be included.

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 faculty in Materials Science, elect a discipline in the field of Materials Science as a minor subject, consisting of a group of courses that differ markedly from the major subject of study or research.

7. *Mechanical Engineering.* To be recommended for candidacy for the Ph.D. degree in Mechanical Engineering, the student must, in addition to the general Institute requirements:

a. Complete 12 units of research.

b. Complete not less than 50 units of advanced courses arranged by the student in conference with his advisor and approved by the faculty in 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, acceptable to the faculty in Mechanical Engineering. Such course shall be in addition to requirement (b) above.

d. Pass a three-hour oral examination on his major subject, and if the student has a subject minor, examination on the subject of that program shall be included.

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 faculty in Mechanical Engineering, elect a discipline in the field of Mechanical Engineering as a minor subject, consisting of a group of courses that differ markedly from the major subject of study or research. Such a group may consist of fluid mechanics, thermodynamics, jet propulsion, physical metallurgy, or nuclear energy.

Division of the Geological Sciences

The following statement summarizes the regulations governing the doctorate program. A circular which provides more detail on these matters is available upon request at the Division Office.

1. *Placement Examinations.* Applications for admission to graduate study in the Division of Geological Sciences should be supported by a report of the student's score on both the aptitude test and the advanced test in geology of the Graduate Record Examination. This is not an absolute requirement but compliance is strongly urged. 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 abler 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. All students who do not demonstrate adequate proficiency in mathematics will be required to register for Ge 108 in their first year of graduate residence.

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, as to who his advisor is to be, and prior to registration day in the fall the student should seek the counsel of his advisor in planning his program for the first term.

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 10 units of research in two out of the first four terms of residence. Each of these terms of research shall be under the direction of *different* staff members. Guidance in arranging for research should be sought from that 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.

2. *Field Requirement.* Many problems in the earth sciences require for their solution an understanding of field techniques and field relations. All students in the Division of Geological Sciences will therefore be required to pursue at least a minimal program of study in field geology; a program which develops a competence in the solution of field problems equivalent to that achieved in Ge 120 abc. In general, all entering graduate students should expect to take at least one year of field geology during his first year at the Institute, or to take Ge 123 during the first summer. Graduate students majoring in geology in general will be required to take more than the minimal one-year program; the equivalent of the undergraduate field geology program (Ge 120 abc, Ge 121 abc, Ge 123) at the Institute being the basic requirement.

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 field geology. Individual decisions on these matters are made by a special committee appointed by the Division Chairman upon request of the student's advisor.

3. *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

4. *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 pages 195-196 of this catalog. However, the student may propose a subject minor in one of the four fields listed in section 3 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. These proposals are subject to review and approval by the Division and the Dean of Graduate Studies.

5. *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: Ph.D. candidates in geophysics are required to take and pass with a grade of C or better Ph 129 abc plus 45 units selected from the following: Ph 131, Ph 201, Ph 202, Ph 205, Ph 212, Ph 218, Ph 219, Ph 227, Ph 235, Ma 105, Ma 118, Ma 185, Ma 211, Ma 280, Ch 223, and Ch 225. This list is not exhaustive but does give the student an idea of the acceptable level. Mature students may satisfy any or all of these requirements by examinations.

6. *Admission to Candidacy*. An otherwise qualified student is eligible for admission to candidacy for the doctorate in the Division of the Geological Sciences as soon as he has passed his qualifying oral examination. This examination will consist of the oral defense of a set of propositions prepared by the candidate. The propositions should be from 3 to 5 in number and about half of them should relate to the branch of earth sciences of major interest to the candidate. The remaining propositions should cover aspects of the sciences in fields other than that of the major interest. As prepared by the candidate himself, each proposition should represent his grasp of the basic features and his critical evaluation of a significant scientific point or question. The entire group of propositions should display scholarship, originality, and breadth of interest. A clear statement of the basic problem and of the candidate's specific approach to, or evaluation of, it should be incorporated in a succinct paragraph for each proposition. Candidates in Geology should realize that propositions based on field investigations are just as acceptable as those arising from laboratory work, or theoretical deductions. The candidate will be judged upon his selection and formulation of the propositions and upon his defense of them. In addition the examining committee will ask questions designed to evaluate his basic background in the earth sciences and allied fields as related to the propositions and to determine his capabilities in applying fundamental scientific principles to specific problems.

A copy of a list of propositions which has been drawn from past qualifying examinations is on file in the Division office, for student reference. This list is offered as a guide to satisfactory form and treatment rather than as a yardstick for choice of subject matter and originality.

Three copies of the propositions should be filed in the office of the Division of the Geological Sciences, not later than midterm of the fifth term of graduate residence, for approval by the core members of the Qualifying Examination Committee in consultation with other members of the staff (see page 197). An examining committee will then be appointed and a date will be set for the examination which is mutually agreeable to those concerned. The list of propositions, as approved by the core committee, must be filed by the candidate in the Division office at least two weeks in advance of the date set for the examination.

A candidate may register for as much as 15 units of research, or advanced study under appropriate staff members to gain time, and advice toward the preparation of his propositions. This will enable him to carry a normal load of 45 units during the term in which he takes his examination.

A student admitted to work for the Ph.D. degree who fails to satisfy the Division's requirements for candidacy by the end of his fifth term of residence will not be allowed to register in a subsequent academic year except by special permission of the Division of the Geological Sciences. Successful completion of the qualifying examination is a necessary step in admission to candidacy. The remaining steps are outlined on page 196, item 3.

7. *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 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.

8. *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

1. Major and Minor Fields

The disciplines offered by the Division in which major or minor work may be undertaken, as specified on page 195, are Astronomy, Mathematics, and Physics.

2. 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 treated in Electricity and Magnetism; Theoretical Mechanics; Atomic and Nuclear Physics, and Advanced Calculus approximately as covered in Ph 107, Ph 108, Ph 112, and Ma 108. 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.

If the placement examinations reveal a need for courses prerequisite to those listed in section c, the student will be required to register for a prescribed course or courses. If he does not obtain grades of C or better in these courses he will be allowed to continue his graduate studies only by special permission of the Physics Department Graduate Committee.

b. *Course Groups.* In the statements below of courses required for the oral candidacy examination, admission to candidacy, and recommendation for the Ph.D. degree, the courses are divided into groups as follows:

	Group I, Required Courses	*Units*
Ph 129	Methods of Mathematical Physics	18
Ph 205	Principles of Quantum Mechanics	18
Ph 209	Electromagnetism and Electron Theory	27

	Group II, Elective Courses
Ph 131	Electricity and Magnetism
Ph 201	Analytical Mechanics
Ph 203	Nuclear Physics
Ph 204	Low Temperature Physics
Ph 207	X- and Gamma-rays
Ph 217	Spectroscopy
Ph 220	Introduction to 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 Theory
Ay 131	Astrophysics I
or	
Ay 132	Astrophysics II

Since the purpose of the Group II course requirements is to broaden the student's knowledge of physics and acquaint him with material outside his own field of specialization, no more than 18 units of any given course may be counted toward any requirement for courses in Group II.

The student is expected to obtain a grade of C or better in each of his courses. If he obtains grades below C in the courses of Group I and those courses he elects from Group II, or in the courses presented to fulfill the requirements for 45 units in a discipline other than physics, or in the oral candidacy examination, the Physics Department 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. *Oral Candidacy Examination*: Prior to the oral candidacy examination, a student must have taken at least 18 units of research and should have passed (or passed the written candidacy examination in) 45 units of the courses listed in Group I and in 27 units of the courses in Group II. The requirement for 18 units of research may be waived if the student has clearly demonstrated his familiarity with research in a particular field. The oral candidacy examination will cover those subjects in physics and the minor subject with which the student may be expected to have gained familiarity through course work, independent study, and laboratory research. It may also include material from the advanced undergraduate courses required of physics majors at the California Institute. At the discretion of the examining committee this examination may be supplemented by a written examination and, in special cases, may be broken off early without reaching any decision, adjourning to a later date.

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 (or pass the written candidacy examinations in) all 63 units of Group I and 36 units of Group II, pass the Physics oral candidacy examination, and be accepted for thesis research by a staff member.

A student, admitted to work toward the Ph.D. degree, who does not satisfy the Division requirements for 63 units of Group I, 36 units of Group II, and the Physics oral candidacy examination by the end of the second year of graduate study at the Institute will not be allowed to register in a subsequent academic year without special permission of the Physics Department Graduate Committee. When a student is required to take courses prerequisite to those listed in section b, this committee ordinarily will grant at that time a suitable extension of the time allowed to complete the candidacy requirements.

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 the 63 units from Group I and a total of 54 units from Group II. 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 (see page 195) in Physics will be approved by the minor division if it includes Ph 112 abc and 18 units of Physics courses from Groups I and II, excluding Ph 129 ab, Ay 131 ab, Ay 132 ab, and any specified course in Physics required for the major.

3. 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. To be recommended for candidacy for the degree of Doctor of Philosophy in Mathematics the applicant must satisfy the general requirements and pass an oral candidacy examination. This examination will be held at the end of the first term of the second year of graduate study. The student will choose two among the three major fields of mathematics (Algebra, Analysis, Geometry). The candidacy examination will cover (a) the fundamentals of the two chosen fields and (b) the independent work done by the candidate during his first year. At the discretion of the department this examination may be supplemented by a written examination. The department may in special cases change the date of the candidacy examination.

c. In the course of his studies the candidate for the degree of Doctor of Philosophy must pass the equivalent of a full year's course in each of the three major fields of mathematics with a grade of C or better in each term (except that no grade requirements are made for a course taken in the last year). A candidate may satisfy any of these course requirements by passing an examination covering the full course in question.

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 printed copy of his completed thesis, in final form, to his supervisor. 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.

4. ASTRONOMY

The Placement Examinations in Physics, page 208, Section 2a, covering the material of Ph 107, Ph 108, Ph 112, and an additional oral examination in astronomy, covering the material in Ay 2, will be required of first-year students. Their goal is to ascertain whether the student's background of atomic and nuclear physics, mathematical physics, and astronomy is sufficiently strong to permit advanced study in these subjects.

To be recommended for candidacy for the doctor's degree in astronomy the applicant must complete satisfactorily (a) 18 units of research, Ay 142, (b) pass with a grade of C or better, or by special examination Ay 131 ab, Ay 132 ab, Ay 133 a, Ay 210, and Ay 211, and (c) a satisfactory program, approved by the Department in fields which will depend on the student's specialty. Students in radio astronomy may substitute Ay 133 b or Ay 134 for the required course Ay 132 b.

The student's program during the first two years of graduate study should include a minimum of 63 units of advanced subjects in physics; for those students specializing in radio astronomy or in applied astronomical electronics, advanced courses in electrical engineering and applied mechanics can be substituted. This program of study must be planned, and approved by the Department, during the first year.

For admission to candidacy an oral examination will be given covering the entire field of study. 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.

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.

LIVING ACCOMMODATIONS FOR GRADUATE STUDENTS

Housing Facilities. The Institute has four resident houses providing single rooms for 160 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 Foundation, and the family of Carl F. Braun. The rates per academic year vary from $382.50 to $585.00, 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 Student Houses, California Institute of Technology.

The Athenaeum has a limited number of rooms available for women graduate students. Information about membership and rates may be obtained from The Athenaeum, 551 South Hill Avenue, Pasadena.

There are no facilities available on the campus at present for married graduate students. They should write to the Housing Office, 208-A Throop Hall, 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 daily from 7 A.M. to 11 P.M., serving breakfast, lunch, dinner, and late snacks cafeteria style.

FINANCIAL ASSISTANCE

The Institute offers in each of its divisions a number of fellowships, scholarships, and graduate assistantships. In general, scholarships carry tuition grants; assistantships, cash stipends; and fellowships often provide both tuition and cash grants. Graduate assistants are eligible to be considered for scholarship grants.

Forms for making application for fellowships, scholarships, or assistantships may be obtained on request from the Dean of Graduate Studies. In using these forms it is not necessary to make separate 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.

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 note-books and papers, as well as that spent in classroom and laboratory. The usual assistantship assignment calls for fifteen hours per week at most and ordinarily permits the holder to carry a full graduate residence schedule as well.

GRADUATE SCHOLARSHIPS AND FELLOWSHIPS*

Institute Scholarships: The Institute offers a number of tuition scholarships to graduate students of exceptional ability who wish to pursue advanced study and research.

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 fellowships annually, one in each of the following fields: electrical engineering, mechanical engineering, and physics. The recipients are designated as Cole Fellows.

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.

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.

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.

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.

Meridan Hunt Bennett Scholarships: The scholarships for graduate students are granted from the Meridan Hunt Bennett Fund as stated on pages 177-178.

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.

*Fellows receiving grants equivalent to tuition and $1000 or more per academic year are permitted to accept employment or other appointment from the Institute during the academic year only with special approval of the Dean of Graduate Studies.

Frederick Roeser Scholarship: This scholarship is granted from the Frederick Roeser Loan, Scholarship, and Research Fund. The recipient is designated as the Roeser Scholar.

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.

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.

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 Section.

Lucy Mason Clark Fellowship: This fellowship, in the field of plant physiology, is supported by a fund contributed by Miss Lucy Mason Clark.

Van Maanen Fellowship: One or more pre-doctoral or post-doctoral fellowships are provided in the department of astronomy from the Van Maanen Fund. The recipients are known as Van Maanen Fellows.

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.

Von Kármán Scholarship Fund: Given by Dr. William Bollay for scholarships for sons or daughters of Aerophysics Development Corporation employees. The recipients are designated as von Kármán Scholars.

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 Ray G. Coates Scholar.

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.

Earle C. Anthony Scholarship: A fund has been established by Mr. Earle C. Anthony for scholarships for graduate students.

Elbert G. Richardson Scholarship and Fellowship Fund: The income of this fund is used to maintain scholarships and fellowships for graduate students.

Eben G. Rutherford Scholarship Fund: The income derived from this fund is used for graduate scholarships.

Samuel H. and Dorothy Breed Clinedinst Foundation: The income of this fund is designated for graduate scholarship aid.

SPECIAL FELLOWSHIPS AND RESEARCH FUNDS

In addition to the National Science Foundation, the Department of Health, Education and Welfare, the Institute for Defense Analyses, 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: Allied Chemical and Dye Corporation, American Society for Testing Materials, R. C. Baker Foundation, Barry Wright Corporation, Bendix Aviation Corporation, The Boeing Company, California Research Corporation, Consolidated Electrodynamics Corporation, Convair, Corning Glass Works Foundation, Douglas Aircraft Company, Dow Chemical Company, E. L. duPont de Nemours and Company, Eastman Kodak Company, Electro-Optical Systems, Inc., Fluor Foundation, Garrett Corporation, General Atomic, General Electric Foundation, Librascope Division of General Precision, Inc., Gillette-Paper Mate Manufacturing Company, Lawrence A. Hanson Foundation, Hughes Aircraft Company, International Business Machines Corporation, International Nickel Company, Inc., Kaiser Aluminum & Chemical Corporation, Kennecott Copper Corporation, Paul E. Lloyd, Lockheed Leadership Fund, Arthur McCallum Fund, Mobil Oil Company, Pacific Scientific Company, Pan American Petroleum Foundation, Inc., Radio Corporation of America, Rand Corporation, Richfield Oil Corporation, Schlumberger Foundation, Shell Companies Foundation, Alfred P. Sloan Foundation, Space Technology Laboratories, Standard Oil Company of California, Stauffer Chemical Company, Stauffer Foundation, John Stauffer, Tektronix Foundation, Union Carbide Corporation, United States Rubber Company, United States Steel Foundation.

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.

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 244, and note under Engineering Science, pages 135-136.

POST-DOCTORAL 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 work. Applications for these appointments, as well as for other special fellowships listed below, should be made on forms provided by the Institute. These forms, which should be filed with the Dean of the Faculty, may be obtained either from his office or 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 post-doctoral 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. Dr. Noyes further provided that "no portion of the income of said fund shall be used for the payment of tuition fees, nor for scholarships or fellowship grants to persons still registered as students, or in general for the education of persons as to existing knowledge; but on the contrary the whole thereof shall be used for promoting, in the manner aforesaid in the field aforesaid, the search for new or more exact knowledge by persons who have completed their period of formal study and are devoting at least one-half of their working time to scientific investigations."

Millikan Fellowship: Established by Dr. Robert A. and Greta B. Millikan. Post-doctoral 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.

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 overall 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]

Besides the subjects shown in the course schedules, students are required to take either military or physical education[2] in each term of the four school years.

KEY TO ABBREVIATIONS

Aeronautics	Ae	English	En
Air Science	AS	Geology	Ge
Applied Mechanics	AM	History and Government	H
Astronomy	Ay	Hydraulics	Hy
Biology	Bi	Jet Propulsion	JP
Chemical Engineering	ChE	Languages	L
Chemistry	Ch	Mathematics	Ma
Civil Engineering	CE	Mechanical Engineering	ME
Economics	Ec	Philosophy	Pl
Electrical Engineering	EE	Physical Education	PE
Engineering Graphics	Gr	Physical Metallurgy	PM
Engineering Science	ES	Physics	Ph

[1]The units used at the California Institute may be reduced to semester hours by multiplying the Institute units by the fraction of 2/9. Thus a twelve-unit course taken throughout the three terms of an academic year would total thirty-six Institute units or eight semester hours. If the course were taken for only one term, it would be the equivalent of 2.6 semester hours.

Note to Veteran Students: Inasmuch as subsistence allowances for Veterans are based on total "standard semester hours of credit *for a semester*, or their equivalent," it must be borne in mind that 1½ Institute terms are equivalent to one semester. Therefore, for purposes of determining your subsistence entitlement each term, multiply total Institute units by 2/9 (to reduce to semester hours per term) and then by 1½ (to evaluate your course in terms of semester hours per semester). This is more simply accomplished by multiplying total units for the term by ⅓.

[2]See page 168 for rule regarding excuses from physical education.

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.[1]

		Units per Term 1st	2nd	3rd
Ma 1 abc	Calculus, Vector Algebra, Analytic Geometry (4-0-8)	12	12	12
Ph 1 abc	Kinematics, Particle Mechanics, and Electric Forces (4-3-5)	12	12	12
Ch 1 abc	General and Quantitative Chemistry (3-6-3)	12	12	12
En 1 abc	English Literature (3-0-3)	6	6	6
H 1 abc	History of European Civilization (2-0-3)	5	5	5
Gr 1	Basic Graphics (0-3-0)	3	.	.
PE 1 abc[2]	Physical Education (0-3-0)	3	3	3
		53	50	50

SENIOR HUMANITIES ELECTIVES

Pl 1	Introduction to Philosophy
Pl 2	Logic
Pl 3	Contemporary European Philosophies
Pl 4	Ethics
Pl 6	Psychology
En 8	Contemporary English and European Literature
En 9	American Literature
En 10	Modern Drama
En 11	Literature of the Bible
En 17	Technical Report Writing
En 18	Modern Poetry
En 19	Seminar in Literature
L 5	French Literature
L 40	German Literature
Ec 48	Introduction to Industrial Relations
Ec 104	Government Regulation
Ec 124	Economic Problems of Underdeveloped Areas
Ec 125	Technical Cooperation
H 4	The British Empire and the Commonwealth
H 7	Modern and Contemporary Germany
H 8	Modern and Contemporary Russia
H 15	Europe Since 1914
H 16	American Foreign Relations
H 17	The Far West and the Great Plains
H 19	Modern America
H 21	Medieval England
H 22	Modern Britain
H 23	Modern War
H 25	Political Parties and Pressure Groups
H 26	The Political Novel
H 30	Individual and Society in America
H 35	Modern India and Pakistan
H 124	Seminar in Foreign Area Problems
H 125	National Security
H 150	African Studies

[1]Honor electives (3 units) to be given second and third terms. See page 167.

[2]AFROTC students will substitute AS 1 abc (2-1-1) for PE 1 abc.

ASTRONOMY OPTION

(For First Year see page 220)

Attention is called to the fact that any student whose grade-point average is less than 1.9 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 165.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ph 2 abc	Electricity, Optics and Modern Physics (3-6-3)	12	12	12
Ma 2 abc	Calculus, Vectors and Differential Equations (4-0-8)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
Ay 1	Introduction to Astronomy (3-1-5)	.	.	9
	Electives (see below)	15-19	15-19	6-10
PE 2 abc[1]	Physical Education (0-3-0)	3	3	3
		48-52	48-52	48-52

Sophomore electives should include at least 27 units of science and engineering courses. At least 18 units of science and engineering electives shall be in subjects other than mathematics or physics. It is desirable for a student to acquire as broad as possible a background in other related fields of science or engineering.

THIRD YEAR

		1st	2nd	3rd
En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ph 107 abc	Electricity and Magnetism (3-0-6)	9	9	9
Ph 111 abc	Structure of Matter (3-0-6)	9	9	9
Ay 2 abc	General Astronomy (3-3-3)	9	9	9
PE 3 abc[2]	Physical Education (0-3-0)	3	3	3
	Electives (see below)	9-15	9-15	9-15
		47-53	47-53	47-53

FOURTH YEAR

		1st	2nd	3rd
	Humanities Electives[3] (3-0-6)	9	9	9
Ec 4 ab	Economic Principles and Problems (3-0-3)	.	6	6
H 5 abc	Public Affairs (1-0-1)	2	2	2
Ph 108 abc	Theoretical Mechanics (3-0-6)	9	9	9
Ph 112 abc	Atomic and Nuclear Physics (4-0-8)	12	12	12
PE 4 abc[4]	Physical Education (0-3-0)	3	3	3
	Electives (see below)	11-18	9-11	9-11
		46-53	50-52	50-52

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 some of the courses that are useful to work in various fields of astronomy.

		1st	2nd	3rd
Ge 1	Physical Geology (4-2-3)	9	.	.
Bi 1	Elementary Biology (3-3-3)	.	9	.
EE 5	Introductory Electronics (3-0-6)	.	.	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
AM 8 abc	Mechanics of Solids I. (3-0-6)	9	9	9
ME 17 ab	Thermodynamics (3-0-6)	9	9	.
L 32 abc	Elementary German (4-0-6)	10	10	10
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
AM 95 ab[5]	Engineering Mathematics (4-0-8)	12	12	.
	or	.	12	12

AM 116[5]	Complex Variables and Applications	12	or	12
Ma 108 abc[5]	Advanced Calculus (4-0-8)	12	12	12
Ma 112	Elementary Statistics (3-0-6)	9 or	9	.
Ge 2	Geophysics	.	.	9
EE 1 abc	Basic Electrical Engineering (3-0-6)	9	9	9
EE 2 ab	Basic Electrical Engineering Laboratory (0-3-0) ...	.	3	3
EE 101 abc	Electric Circuit Theory (3-0-6)	9	9	9
EE 106 ab	Electronic Circuits (3-0-6)	9	9	.
Ph 115 ab[5]	Geometrical and Physical Optics (3-0-6)	9	9	.
Ma 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
Ph 217[5]	Spectroscopy (3-0-6)	.	.	9
Ay 108 ab[5]	Astronomical Instruments and Radiation Measurement (3-1-5), (3-2-4)	9	9	.
Ay 133[5]	Radio Astronomy (3-0-6)	.	.	9
Ay 131 ab[5]	Stellar Atmospheres (3-0-6)	9	9	
Ay 132 ab[5]	Stellar Interiors (3-0-6)		9	9
Ay 141 abc[5]	Research Conference in Astronomy (1-0-1)	2	2	2

[1]AFROTC students will substitute AS 2 abc (2-1-1) for PE 2 abc. Sophomore AFROTC students may elect Pl 7 (3-0-4) in the third term.

[2]AFROTC students will substitute AS 3 abc (4-1-3) for PE 3 abc.

[3]For list of Humanities electives, see page 220.

[4]AFROTC students will substitute AS 4 ab (0-1-2) for PE 4 ab and AS 4 c (4-1-3) for PE 4 c. They must elect H 23 (3-0-6) in first term and H 16 (3-0-6) in second term.

[5]Students who plan to do graduate work in astronomy or radio astronomy should elect some of these courses during their third and fourth years, on consultation with their advisers.

BIOLOGY OPTION

(For First Year see page 220)

Attention is called to the fact that any student whose grade-point average is less than 1.9 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 165.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Calculus, Vectors, Differential Equations (4-0-8)	12	12	12
Ph 2 abc	Electricity, Optics, and Modern Physics (3-3-6)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
PE 2 abc[1]	Physical Education (0-3-0)	3	3	3
	Electives	19	19	19
		52	52	52

Electives

27 units of the electives must be in Science or Engineering.
The following Sophomore electives are recommended* for Biology majors:

Ch 41 abc	Basic Organic Chemistry (2-0-2)	4	4	4
Ch 46 abc	Basic Organic Chemistry Laboratory (1-5-0)	6	6	6
Bi 1	Elementary Biology (3-3-3)	.	9	.
Bi 9	Cell Biology (3-3-3)	.	.	9
	Non-Biology elective	9	.	.

*Biology majors not electing Ch 41 abc and Ch 46 abc in the second year are required to take these courses in the third year and postpone Bi 107 to the fourth year. Biology majors who have not elected Bi 1 and Bi 9 in the second year are expected to elect them or approved alternatives in the third or fourth year.

THIRD YEAR

Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
En 7 abc	Advanced Literature (3-0-5)	8	8	8
Bi 107 abc	Biochemistry (3-0-7; 3-3-4; 3-5-2)	10	10	10
Bi 3	Plant Biology (3-6-3)	12	.	.
Bi 10	Animal Biology (3-6-3)	.	12	.
PE 3 abc[2]	Physical Education (0-3-0)	3	3	3
	Electives	10	10	22
		52	52	52

Electives

Electives, additional to those available in the sophomore year, may, with the approval of the student's advisor, be selected from the following:

Bi 114	Immunology (2-4-3)	9	.	.
Bi 122	Genetics (3-3-4)	10	.	.
Bi 126	Genetics of Microorganisms (2-4-4)	.	10	.
Bi 127	Biochemical Genetics (2-4-4)	.	.	10
Bi 106	Embryology (2-6-4)	.	.	12
Bi 20	Mammalian Anatomy and Histology (2-6-4)	.	.	12
L 32 abc	Elementary German (4-0-6)	10	10	10
L 50 abc	Elementary Russian (4-0-6)	10	10	10

[1]AFROTC students will substitute AS 2 abc (2-1-1) for PE 2 abc. Sophomore AFROTC students may elect Pl 7 (3-0-4) in the third term.

[2]AFROTC students will substitute AS 3 abc (4-1-3) for PE 3 abc.

FOURTH YEAR

		Units per Term 1st	2nd	3rd
	Humanities Electives[4]	9	9	9
H 5 abc	Public Affairs (1-0-1)	2	2	2
Ec 4 ab	Economic Principles and Problems (3-0-3)	6	6	.
Bi 118	General Physiology (3-3-4)	10	.	.
Bi 122*	Genetics (3-3-4)	10	.	.
PE 4 abc[3]	Physical Education (0-3-0)	3	3	3
	Electives	12	32	38
		52	52	52

Electives

In addition to those listed for the third year:

Bi 117	Psychobiology 1 (3-3-3)	.		.		9
Bi 129 ab	Biophysics (2-0-4)	6		6		.
Ch 132	Biophysical Chemistry (2-0-4)	.		.		6
Bi 214 abc	Chemistry of Bioorganic Substances (1-0-2)	3		3		3
Bi 218	Virology (2-3-4)	.		9		.
Bi 220 abc	Experimental Embryology (2-0-4)	6		6		6
Bi 230	Psychobiology 2 (units to be arranged)	x	or	x	or	x
Bi 240 abc	Plant Physiology (2-0-4)	6		6		6
Bi 241 abc	Advanced Biochemistry (2-0-4)	6		6		6
Bi 260	Advanced Physiology (units to be arranged)	.		x		.
Bi 109	Advanced Genetics Laboratory (units to be arranged)	.		x		.
Bi 22	Special Problems (units to be arranged)	x	or	x	or	x
	Any advanced course offered by other Divisions subject to approval by the student's advisor.					

[3]AFROTC students will substitute AS 4 ab (0-1-2) for PE 4 ab and AS 4 c (4-1-3) for PE 4 c. They must elect H 23 (3-0-6) in first term and H 16 (3-0-6) in second term.

[4]For list of Humanities electives, see page 220.

*Required of Biology majors unless Bi 22 or Bi 122 has been taken earlier.

CHEMICAL ENGINEERING OPTION

(For First Year see page 220)

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

(Identical with the Chemistry Option)

		Units per Term 1st	2nd	3rd
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
Ma 2 abc	Calculus, Vectors, and Differential Equations (4-0-8)	12	12	12
Ph 2 abc	Electricity, Optics, and Modern Physics (3-3-6)	12	12	12
Ch 41 abc	Basic Organic Chemistry (2-0-2)	4	4	4
Ch 46 abc	Basic Organic Chemistry Laboratory (1-5-0)	6	6	6
	Electives in Science and/or Engineering[1,2]	9	9	9
PE 2 abc	Physical Education (0-3-0)[3]	3	3	3
		52	52	52

THIRD YEAR

		1st	2nd	3rd
En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ec 4 ab	Economic Principles and Problems (3-0-3)	.	6	6
Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ch 26 ab	Physical Chemistry Laboratory (0-6-2)	.	8	8
ChE 63 abc	Chemical Engineering Thermodynamics (3-0-6; 2-0-4)	9	6	9
AM 95 ab	Engineering Mathematics (4-0-8)	12	12	.
EE 5	Introductory Electronics (3-0-6)	.	.	9
PE 3 abc	Physical Education (0-3-0)[4]	3	3	3
		51	52	52

FOURTH YEAR

		1st	2nd	3rd
	Humanities Electives (3-0-6)[5]	9	9	9
H 5 abc	Public Affairs (1-0-1)	2	2	2
ChE 61 ab	Industrial Chemistry (3-0-6)	9	9	.
AM 8 ac	Mechanics of Solids I (3-0-6)	9	.	9
ChE 66 abc	Chemical Engineering Operations (3-0-9)	12	12	12
ChE 67 ab	Chemical Engineering Laboratory (0-7-2)	.	9	9
	Electives[6,2]	6-10	6-10	6-10
PE 4 abc	Physical Education (0-3-0)[7]	3	3	3
		50-54	50-54	50-54

[1]No more than 9 units in chemical engineering and no units in chemistry courses may be elected.

[2]If ChE 80 units are to be used as electives in the Chemical Engineering Option, a thesis must be submitted in duplicate before May 10 of the year of graduation and be approved by the research director.

[3]AFROTC students will substitute AS 2 abc (2-1-1) for PE 2 abc. Sophomore AFROTC students may elect Pl 7 (3-0-4) in third term.

[4]AFROTC students will substitute AS 3 abc (4-1-3) for PE 3 abc.

[5]For list of Humanities electives, see page 220.

[6]These elective units must be approved by the advisor. If Ch 41 abc and Ch 46 abc have not been taken, they must be substituted in place of these electives.

[7]AFROTC students will substitute AS 4 ab (0-1-2) for PE 4 ab and AS 4 c (4-1-3) for PE 4 c. They must elect H 23 (3-0-6) in first term and H 16 (3-0-6) in second term.

CHEMISTRY OPTION

(For First Year see page 220)

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

(Identical with the Chemical Engineering Option)

		Units per Term 1st	2nd	3rd
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
Ma 2 abc	Calculus, Vectors, and Differential Equations (4-0-8)	12	12	12
Ph 2 abc	Electricity, Optics, and Modern Physics (3-3-6)	12	12	12
Ch 41 abc	Basic Organic Chemistry (2-0-2)	4	4	4
Ch 46 abc	Basic Organic Chemistry Laboratory (1-5-0)	6	6	6
	Electives in Science and/or Engineering[1]	9	9	9
PE 2 abc	Physical Education (0-3-0)[3]	3	3	3
		52	52	52

THIRD YEAR

		1st	2nd	3rd
En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ec 4 ab	Economic Principles and Problems (3-0-3)	.	6	6
L 32 abc	Elementary German[4] (4-0-6)	10	10	10
Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ch 26 ab	Physical Chemistry Laboratory (0-6-2)	.	8	8
Ch 90	Oral Presentation (1-0-1)	2	.	.
	Electives[5,2]	8-12	6-10	6-10
PE 3 abc	Physical Education (0-3-0)[6]	3	3	3
		50-54	50-54	50-54

FOURTH YEAR

		1st	2nd	3rd
	Humanities Electives (3-0-6)[7]	9	9	9
H 5 abc	Public Affairs (1-0-1)	2	2	2
	Electives[8,2]	36-40	36-40	36-40
PE 4 abc	Physical Education (0-3-0)[9]	3	3	3
		50-54	50-54	50-54

[1]Any courses in science and engineering for which the student has the required prerequisites are acceptable, but no more than 9 units in chemical engineering and no units in chemistry may be elected.

[2]If Ch 80 units are to be used as electives in the Chemistry Option, a thesis must be submitted in duplicate before May 10 of the year of graduation and be approved by the research director.

[3]AFROTC students will substitute AS 2 abc (2-1-1) for PE 2 abc. Sophomore AFROTC students may elect Pl 7 (3-0-4) in the third term.

[4]May be taken in either third or fourth year.

[5]In addition to approved elective courses listed on page 227 any science and engineering course will be accepted if approved by the advisor. If Ch 41 abc and Ch 46 abc have not been taken, they must be substituted in place of these electives.

[6]AFROTC students will substitute AS 3 abc (4-1-3) for PE 3 abc.

[7]For list of Humanities electives see page 220.

[8]Approved elective courses listed on page 227.

[9]AFROTC students will substitute AS 4 ab (0-1-2) for PE 4 ab and AS 4 c (4-1-3) for PE 4 c. They must elect H 23 (3-0-6) in first term and H 16 (3-0-6) in second term.

APPROVED ELECTIVE COURSES FOR THIRD AND FOURTH YEARS IN THE CHEMISTRY OPTION

The choice of electives must include courses which require a total of 18 units of laboratory work (for example, Ch 16, Instrumental Analysis (0-6-2) requires 6 units of laboratory) or a total of 36 units of research (Ch 80). These elective laboratory units can be accumulated throughout the undergraduate years. 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 13 abc	Inorganic Chemistry (2-0-4)	6	6	6
Ch 16	Instrumental Analysis (0-6-2)	8	.	.
Ch 80	Chemical Research (units to be arranged)	.	.	.
Ch 81	Special Topics in Chemistry (units to be arranged)	.	.	.
Ch 117	Electroanalytical Chemistry (2-0-2)	.	4	.
Ch 118 ab	Electroanalytical Chemistry Laboratory (0-6-0)	.	6	6
Ch 125 abc	Introduction to Chemical Physics (3-0-6)	9	9	9
Ch 127 abc	Radioactivity and Isotopes (2-0-4)	6	6	6
Ch 129	Surface and Colloid Chemistry (3-0-5)	.	.	8
Ch 130	Photochemistry (2-0-4)	.	6	.
Ch 144 abc	Advanced Organic Chemistry (3-0-6)	9	9	9
Ch 148 abc	Characterization of Organic Compounds (2-0-2)	4	4	4
Ch 149 abc	Laboratory in Characterization of Organic Compounds (0-6-0)	6	6	6
ChE 61 ab	Industrial Chemistry (3-0-6)	9	9	.
ChE 63 abc	Chemical Engineering Thermodynamics (3-0-6; 2-0-4)	9	6	9
ChE 65	Economics of Chemical Technology (1-0-8)	.	9	.
ChE 66 abc	Chemical Engineering Operations (3-0-9)	12	12	12
ChE 68	Introductory Chemical Engineering Kinetics (3-0-6)	9	.	.
ChE 80	Undergraduate Research (units to be arranged)	.	.	.
ChE 170	Chemical Process Dynamics (2-0-7)	.	.	9
Ph 107 abc	Electricity and Magnetism (3-0-6)	9	9	9
Ph 108 abc	Theoretical Mechanics (3-0-6)	9	9	9
Ph 111 abc	Structure of Matter (3-0-6)	9	9	9
Ph 112 abc	Atomic and Nuclear Physics (4-0-8)	12	12	12
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
AM 95 ab	Engineering Mathematics (4-0-8)[1]	.	.	.
AM 102 abc	Applied Nuclear Physics (2-0-4)	6	6	6
Bi 107 abc	Biochemistry (3-0-7; 3-3-4; 3-5-2)	10	10	10
Bi 110	General Microbiology (3-4-5)	.	.	12
Bi 127	Biochemical Genetics (3-4-3)	.	.	10
Ge 3	Mineralogy (3-3-3)	.	9	.
Ge 30	Introduction to Geochemistry (3-0-7)	.	.	10
Ge 151	Laboratory Techniques in the Earth Sciences (0-5-0)	.	5	.
L 35	Scientific German (4-0-6)	10	.	.

[1]May be taken first and second or second and third terms.

ENGINEERING OPTION

(For First Year see page 220)

Attention is called to the fact that any student whose grade-point average is less than 1.9 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 165.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Calculus, Vectors, & Differential Equations (4-0-8)	12	12	12
Ph 2 abc	Electricity, Optics, and Modern Physics (3-3-6)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
PE 2 abc[1]	Physical Education (0-3-0)	3	3	3
	Science or Engineering Electives	9	9	9
	Electives*	6-12	6-12	6-12
		48-54	48-54	48-54

THIRD YEAR

		1st	2nd	3rd
En 7 abc	Advanced Literature (3-0-5)	8	8	8
AM 95 ab	Engineering Mathematics			
AM 116	Complex Variables and Applications	12	12	12
	or			
Ma 108 abc	Introduction to Real & Complex Analysis (4-0-8)			
PE 3 abc[2]	Physical Education (0-3-0)	3	3	3
	Electives*	25-31	25-31	25-31
		48-54	48-54	48-54

FOURTH YEAR

		1st	2nd	3rd
	Humanities Elective[3] (3-0-6)	9	9	9
H 5 abc	Public Affairs (1-0-1)	2	2	2
E 10 ab or E 11 ab	Technical Presentations (1-0-1)	2	2	.
PE 4 abc[4]	Physical Education (0-3-0)	3	3	3
	Electives*	32-38	32-38	32-38
		48-54	48-54	46-52

1AFROTC students will substitute AS 2 abc (2-1-1) for PE 2 abc. Sophomore AFROTC students may elect Pl 7 (3-0-4) in the third term.

2AFROTC students will substitute AS 3 abc (4-1-3) for PE 3 abc.

3*For list of Humanities electives, see page 220.*

4AFROTC students will substitute AS 4 ab (0-1-2) for PE 4 ab and AS 4 c (4-1-3) for PE 4 c. *They must elect H 23 (3-0-6) in first term and H 16 (3-0-6) in second term.*

*Electives must be approved by the student's advisor. Ec 4 ab, 6 units each term, must be included in the electives for graduation. *All courses for B.S. in Engineering must total at least 583 units.*

Note 1: Every course listed on the approved course program of a student in the Engineering option must be completed satisfactorily before the student will be recommended for the Bachelor of Science degree. All changes in a student's course program must be approved in writing by the advisor.

Note 2: 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.

GEOLOGICAL SCIENCES OPTION

(For First Year see page 220)

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, may at the discretion of the Division of the 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 during any term may, at the discretion of the Division, be refused permission to continue in the Geological Sciences Option.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
Ph 2 abc	Electricity, Optics, and Modern Physics (3-3-6)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
Ge 1	Physical Geology (4-2-3)	9	.	.
Ge 3	Mineralogy (3-3-3)	.	.	9
PE 2 abc[1]	Physical Education (0-3-0)	3	3	3
	Electives (see suggested Electives listed below)*	10	18	9
		52	51	51

*The following courses are suggested as being especially suitable for a balanced program of study. 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.

Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Bi 1	Elementary Biology (3-3-3)	.	9	.
Ge 2	Geophysics (3-0-6)	.	9	.
Ge 5	Geobiology (3-0-6)	.	9	.

Bi 10 Animal Biology is strongly recommended for those interested in paleontology.

[1]AFROTC students will substitute AS 2 abc (2-1-1) for PE 2 abc. Sophomore AFROTC students may elect Pl 7 (3-0-4) in the third term.

THIRD YEAR

Common to All Options in the Division

En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ge 120 abc	Field Geology (4-5-1; 0-8-2; 0-6-4)	10	10	10
PE 3 abc	Physical Education (0-3-0)	3	3	3
	AFROTC students will substitute AS 3 ab (4-1-3) and AS 3 c (0-1-2) for PE 3 abc (0-3-0); Pl 7 (3-0-4) is required in the third term.			

Geology and Geochemistry Options

Ge 104 a	Petrology, Igneous (3-3-2)	8	.	.
Ge 104 b	Petrology, Sedimentary (3-4-3)	.	10	.
Ge 104 c	Petrology, Metamorphic (2-3-2)	.	.	7
Ch 24 ab	Physical Chemistry for Geologists (4-0-6)	10	10	.
	Electives (select from electives listed below)	11	9	22
		50	50	50

Add electives with advice and consent of advisor to bring load up to a minimum of 45 units but not to exceed the allowable limit. Ec 4 a, b must be included in the electives by or before the 4th year as it is an Institute requirement for graduation. Special attention is called to the opportunity to take L 32 abc or L 50 abc. Other desirable elective subjects include Ay 1, Bi 2 (for paleontologists), Ma 112, Ch 14, ChE 50, Hy 134, Hy 210 a, b, AM 8 abc, AM 110 a, CE 155 among others, provided student has proper prerequisites. Geochemists are urged to take Ch 21 abc and Ge 30 ab instead of Ch 24 ab. Students in geochemistry option are urged to register for Ge 30 ab as soon as is conveniently possible. A geochemist can also substitute other courses for Ge 104 c with the advice and consent of his advisor.

Summer Field Geology, Ge 123, 30 units, required after third year in Geology and Geochemistry Options.

Geophysics Option

Ph 107 abc	Electricity and Magnetism (3-0-6)	9	9	9
	Electives (select from Electives listed below)	20	20	20
		50	50	50

Add electives to bring unit load up to a minimum of 45 units but not to exceed the allowable limit, selected with the advice and consent of the advisor from the following courses for which prerequisites have been completed. Any Ge course, Ay 1, AM 95 abc, Ch 21 abc, EE 160, EE 140, Ma 108 abc, Ph 108 abc. Special attention is called to the opportunity to take L 32 abc or L 50 abc. Ec 4 ab must be elected by or before the 4th year as it is an Institute requirement for graduation.

FOURTH YEAR

Common to All Options in the Division

L 32 abc or L 50 abc	Elementary German (4-0-6) or Elementary Russian	10	10	10
H 5 abc	Public Affairs (1-0-1)	2	2	2
Ge 100	Geology Club (1-0-0)	1	1	1
PE 4 abc[1]	Physical Education (0-3-0)	3	3	3
	Humanities Elective (3-0-6) (Elect from selection listed on page 220)	9	9	9

Geology Option

Ge 121 abc	Advanced Field Geology (4-8-2; 0-8-2; 0-5-6)	14	10	11
	Electives	9-11	12-15	11-14
	Electives to be selected from any advanced courses in the Division of Geological Sciences or courses in other Science or Engineering Divisions. (See list under third year.) The elective courses must be approved by the student's advisor.			
		48-50	47-50	47-50

Geochemistry Option

	Electives (see statement immediately below)	25	25	25
	A suitable program will be worked out by the student and his advisor. This program will include courses from the Chemistry and Geology options. For example: Ch 13 abc, Ch 127 ab, Ch 129, Ge 105, Ge 106 ab, and Ge 151 a.			
		50	50	50

Geophysics Option

Ph 108 abc	Theoretical Mechanics (3-0-6)	9	9	9
	Geology Electives	7-10	7-10	7-10
	General Electives	.	.	.
	Add other electives in Physics, Mathematics, Chemistry, Astronomy, or Engineering to bring unit load to a minimum of 45 units, but not to exceed the allowable limit. Elective courses must be approved by the student's advisor.			
		45-50	45-50	45-50

[1]AFROTC students will substitute AS 4 ab (0-1-2) for PE 4 ab and AS 4 c (4-1-3) for PE 4 c. They must elect H 23 (3-0-6) in first term and H 16 (3-0-6) in second term.

MATHEMATICS OPTION

(For First Year see page 220)

Attention is called to the fact that any student whose grade-point average is less than 1.9 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 165.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
Ph 2 abc	Electricity, Optics, and Modern Physics (3-3-6)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Electives in Science or Engineering, outside of Mathematics	9	9	9
PE 2 abc[1]	Physical Education (0-3-0)	3	3	3
		51	51	51

THIRD YEAR

		1st	2nd	3rd
En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ec 4 ab	Economic Principles and Problems or a selected course in the Humanities[5] (can be taken in senior year) ... Minimum	6	6	.
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
PE 3 abc[2]	Physical Education (0-3-0)	3	3	3
	Selected courses in Mathematics ... Minimum	9	9	9
	Electives[4] ... Minimum	9	9	9
	For each term the total number of units is required to fall within the range	47-52	47-52	47-52

FOURTH YEAR

		1st	2nd	3rd
H 5 abc	Public Affairs (1-0-1)	2	2	2
Ec 4 ab	Economic Principles and Problems or a selected course in the Humanities[5] (if not taken in junior year) ... Minimum	6	6	.
PE 4 abc[3]	Physical Education (0-3-0)	3	3	3
	Selected courses in Mathematics ... Minimum	9	9	9
	Selected courses in the Humanities[5]	9	9	9
	Electives[4] ... Minimum	8	8	8
	For each term the total number of units is required to fall within the range	41-51	41-51	41-51

Normally a junior will select 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]AFROTC students will substitute AS 2 abc (2-1-1) for PE 2 abc. Sophomore AFROTC students may elect Pl 7 (3-0-4) in the third term.

[2]AFROTC students will substitute AS 3 abc (4-1-3) for PE 3 abc.

[3]AFROTC students will substitute AS 4 ab (0-1-2) for PE 4 ab and AS 4 c (4-1-3) for PE 4 c. They must elect H 23 (3-0-6) in first term and H 16 (3-0-6) in second term.

[4]An elective is any course in any subject other than Mathematics.

[5]For list of electives in the Humanities, see page 220.

PHYSICS OPTION

(For First Year see page 220)

Attention is called to the fact that any student whose grade-point average for any three consecutive terms is less than 1.9 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 165.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ph 2 abc	Electricity, Fields, and Atomic Structure (4-3-5)	12	12	12
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
	Electives[1]	15-19	15-19	15-19
PE 2 abc[2]	Physical Education (0-3-0)	3	3	3
		48-52	48-52	48-52

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 (4-2-3)	9	.	.
Bi 1	Elementary 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
Ch 41 abc	Basic Organic Chemistry (2-0-2)	4	4	4
Ch 46 abc	Basic Organic Chemistry Laboratory (1-5-0)	6	6	6
ChE 50	Applications of Chemistry (3-0-6)	.	9	.
L 32 abc	Elementary German (4-0-6)	10	10	10

THIRD YEAR

		1st	2nd	3rd
Ph 107 abc	Electricity and Magnetism (3-0-6)	9	9	9
Ph 111 abc	Structure of Matter (3-0-6)	9	9	9
En 7 abc	Advanced Literature (3-0-5)	8	8	8
	Electives[3]	18-22	18-22	18-22
PE 3 abc[4]	Physical Education (0-3-0)	3	3	3
		47-51	47-51	47-51

Suggested Electives

		1st	2nd	3rd
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
Ge 165	General Geophysics (3-0-3)	.	.	6
Ge 171	Applied Geophysics (4-2-4)	.	.	10
Bi 9	Cell Biology (3-3-3)	.	.	9
Ay 2 abc	General Astronomy (3-3-3)	9	9	9

[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]AFROTC students will substitute AS 2 abc (2-1-1) for PE 2 abc. Sophomore AFROTC students may elect Pl 7 (3-0-4) in the third term.

[3]Students should note that EE 1 abc is prerequisite to most advanced electrical engineering courses, and that Ma 108 abc is prerequisite to most advanced mathematical courses.

[4]AFROTC students will substitute AS 3 abc (4-1-3) for PE 3 abc.

EE 1 abc	Basic Electrical Engineering (3-0-6)	9	9	9
EE 2 ab	Basic Electrical Engineering Laboratory (0-3-0)	.	3	3
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ch 26 ab	Physical Chemistry Laboratory (0-6-2)	.	8	8
Ph 115 ab	Geometrical and Physical Optics (3-0-6)	9	9	.
Ph 108 abc[3]	Theoretical Mechanics (3-0-6)	9	9	9
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

FOURTH YEAR

Ph 108 abc	Theoretical Mechanics (3-0-6)	9	9	9
Ph 112 abc	Atomic and Nuclear Physics (4-0-8)	12	12	12
	Laboratory Course ... Minimum	6	.	.
Ec 4 ab	Economic Principles and Problems (3-0-3)	.	6	6
H 5 abc	Public Affairs (1-0-1)	2	2	2
	Humanities elective[1]	9	9	9
	Electives	9-11	9-11	9-11
PE 4 abc[2]	Physical Education (0-3-0)	3	3	3
		50-52	50-52	50-52

Laboratory Courses

Ph 77	Experimental Physics Laboratory	6-9 or	6-9	.
EE 7 abc	Experimental Techniques in Electrical Engineering (0-3-2)	5	5	5
Ph 172	Experimental Research in Physics (units as arranged with instructor)	.	.	.

Suggested Electives

Ma 112	Elementary Statistics (3-0-6)	9 or	9	.
Ma 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
Ma 137	Introduction to Lebesgue Integrals (3-0-6)	9	.	.
EE 101 abc	Electric Circuit Theory (3-0-6)	9	9	9
EE 106 ab	Electronic Circuits (3-0-6)	9	9	.
EE 107	Principles of Feedback (3-0-6)	.	.	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9
Ph 171	Reading and Independent Study in Physics (units arranged, maximum 9 units per term)			
Ph 172	Experimental Research in Physics (units arranged)	.	.	.
L 51 abc	Intermediate Russian (4-0-6)	10	10	10

[1]For list of Humanities electives, see page 220.

[2]AFROTC students will substitute AS 4 ab (0-1-2) for PE 4 ab and AS 4 c (4-1-3) for PE 4 c. They must elect H 23 (3-0-6) in first term and H 16 (3-0-6) in second term.

[3]A student may register for Ph 108 abc as a third-year elective only if he has attained an average grade of B+ or better in both Ph 2 abc and Ma 2 abc.

SCHEDULES OF FIFTH- AND SIXTH-YEAR COURSES

GRADUATE HUMANITIES ELECTIVES

H 100 abc	Seminar in History and Government
En 100 abc	Seminar in Literature
Pl 100 abc	Philosophy of Science
Pl 101 abc	History of Thought
Pl 102 abc	Philosophy and Literature
Ec 100 abc	Business Economics
Ec 110	Industrial Relations
Ec 111	Business Cycles and Government Policy
Ec 112	Modern Schools of Economic Thought
Ec 126 abc	Economic Analysis and Policy (Seminar)
H 123	The Growth of Industrial Civilization
H 124	Seminar in Foreign Area Problems
Ec 124	Economics of Underdeveloped Areas
H 125 abc	Seminar on National Security
Ec 104	Government Regulation
Ec 125	Technical Cooperation
H 150	African Studies

AERONAUTICS

FIFTH YEAR

(Leading to the Degree of Master of Science in Aeronautics)

		Units per Term 1st	2nd	3rd
	Humanities Electives	9-10	9-10	9-10
Ae 101 abc	Elements of Gasdynamics	9	9	9
Ae 102 abc	Static and Dynamic Elasticity	9	9	9
Ae 103 abc	Performance and Flight Dynamics of Aircraft and Spacecraft	9	9	9
Ae 104 abc or Ae 104a and Ae 105 bc	Experimental Methods in Aeronautics or Research Laboratory in Fluid Mechanics	9	9	9
AM 116, AM 113 ab	Complex Variable, Engineering Mathematics	9	9	9
Ae 150 abc	Seminar	1	1	1
		55-56	55-56	55-56

NOTE: The above program represents the minimum level of work for the M.S. degree in Aeronautics. If any of the subjects listed have been taken as an undergraduate, more advanced subjects may be substituted for them.

AERONAUTICS

SIXTH YEAR

(Leading to the degree of Aeronautical Engineer)

		Units per Term 1st	2nd	3rd
Ae 200 abc	Research in Aeronautics	20	20	20
Ae 201 abc or Ae 210 abc	Fundamentals of Fluid Mechanics or Fundamentals of Solid Mechanics	9	9	9
Ae 208 abc or Ae 209 abc or JP 290 abc	Fluid Mechanics Seminar or Solid Mechanics Seminar or Jet Propulsion Seminar	1	1	1
AM 125 abc	Engineering Mathematical Principles	9	9	9
	Elective	9	9	9
		48	48	48

AERONAUTICS (JET PROPULSION OPTION)

SIXTH YEAR

JP 208	Research in Jet Propulsion	20	20	20
Ae 201 abc or Ae 210 abc	Fundamentals of Fluid Mechanics Fundamentals of Solid Mechanics	9	9	9
JP 290 abc	Jet Propulsion Seminar	1	1	1
	Electives, as below** (minimum total for year, 81 units)	27-30	27-30	27-30
		48	48	48

*The electives are to be chosen from the Jet Propulsion subjects on pages 296-299 with the approval of the Goddard Professor of Jet Propulsion.

APPLIED MECHANICS

FIFTH YEAR

(Leading to the degree of Master of Science in Applied Mechanics)

		Units per Term 1st	2nd	3rd
	Humanities Elective	9-10	9-10	9-10
AM 125 abc	Engineering Mathematical Principles*	9	9	9
	Electives, as below** (minimum total for year, 81 units)	27-30	27-30	27-30
		45-49	45-49	45-49

*Suggested Electives***

AM 101 abc	Nuclear Reactor Theory	9	9	9
AM 103 ab	Nuclear Engineering Laboratory	9	9	.
AM 110 abc	Theory of Elasticity, etc.	6	6	6
AM 111	Experimental Stress Analysis	.	9	.
AM 130 abc	Applications of Classical Theoretical Physics I	9	9	9
AM 140	Plasticity	6	.	.
AM 141 ab	Wave Propagation in Solids	.	6	6
AM 150 abc	Mechanical Vibrations	6	6	6
AM 155	Dynamic Measurements Laboratory	9	.	.
AM 160	Vibrations Laboratory	.	.	6
AM 174,6 ab	Advanced Dynamics I, II	6	6	6
AM 180	Matrix Algebra	9	.	.
Ae 101 abc	Elements of Gasdynamics	9	9	9
Ae 104 abc	Experimental Methods in Aeronautics	9	9	9
Ae 105 bc	Research Laboratory in Fluid Mechanics	.	9	9
Ae 210 abc	Fundamentals of Solid Mechanics	9	9	9
Ae 216	Structural Dynamics	.	9	.
Ae 217	Aeroelasticity	.	.	9
CE 123	Dynamics of Structures	.	.	9
EE 180	Digital Computer Design	9	.	.
EE 181 ab	Principles of Analog Computation	.	12	12
Hy 101 abc	Fluid Mechanics	9	9	9
Hy 134	Flow in Porous Media	.	.	9
JP 121 abc	Rockets and Air Breathing Engines	9	9	9
Ma 105 ab	Introduction to Numerical Analysis	.	11	11
ME 126	Fluid Mechanics and Heat Transfer Laboratory	.	.	9
Ph 108 abc	Theoretical Mechanics	9	9	9

*Students who have not had the equivalent of AM 95 ab (Engineering Mathematics) and AM 116 (Complex Variables and Applications) should replace AM 125 abc by AM 113 a, b and AM 116. With staff approval, AM 125 abc can be replaced by Ma 108 abc (Advanced Calculus), Ph 129 abc (Methods of Mathematical Physics), or other satisfactory substitute.

**Note that a total of 140 units is required for the M.S. degree. Courses not on the above list of suggestions may be elected with staff approval.

ASTRONOMY

FIFTH YEAR

(Leading to the degree of Master of Science in Astronomy)

	Units per Term 1st	2nd	3rd
Humanities Electives (3-0-6; 4-0-6)[1]	9 or 10	9 or 10	9 or 10
Ay 131 ab, or Ay 132 ab (3-0-6) and Ay 210, Ay 211 or Ay 133	9	9	9
Electives to total	47 to 50	47 to 50	47 to 50

Elective subjects program, to be approved by the department, from advanced subjects in astronomy and physics. Placement examination will be required. (See page 208, section 2(a). Ay 112, Ph 107, Ph 108, Ph 112 may be required of those students whose previous training in some of these subjects proves to be insufficient.

[1]For list of Humanities electives, see page 235.

BIOLOGY

As nearly all biology majors are working for the doctor's degree and following programs arranged by the students in consultation with members of the Division, no specific graduate curricula can be outlined.

CHEMICAL ENGINEERING

FIFTH YEAR

(Leading to the degree of Master of Science in Chemical Engineering)

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; 4-0-6)[1]	9 or 10	9 or 10	9 or 10
ChE 167 abc	Chemical Engineering Laboratory (0-15-0)[2]	15	15	15
	Electives[3] at least	23	23	23
		47-48	47-48	47-48

[1]For list of Humanities electives, see page 235.

[2]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.

[3]Elective subjects are to be approved by a member of the Division and must include AM 115 ab if equivalent has not been taken. A minimum of 27 units of these electives must be in advanced chemical engineering subjects, the remainder are to be chosen from other advanced subjects.

A minimum of 141 units of approved graduate subjects, with three terms of residence (at least 45 units per term), is required for the Master's degree.

Students admitted for work toward the M.S. in Chemical Engineering will be required to take the placement examinations in engineering thermodynamics, the unit operations of chemical engineering, and industrial chemistry. If desired the student can substitute physical chemistry for industrial chemistry.

CHEMISTRY

FIFTH YEAR

(Leading to the 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.

A total of at least 27 units in the Humanities is required for a master's degree. Not fewer than 30 units of courses of science subjects chosen from advanced courses and not fewer than 40 units of Chemical Research must be offered for the master's degree. 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

FIFTH YEAR

(Leading to the degree of Master of Science in Civil Engineering)

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; 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)[2,3]	36-39	36-39	36-39
		46-50	46-50	46-50

Suggested Electives

(Courses are grouped into general areas for ready reference; however, the student is encouraged to select electives from several areas in order to avoid overspecialization).

STRUCTURES

		1st	2nd	3rd
AM 105	Advanced Strength of Materials (2-0-4)	.	6	.
AM 106	Problems in Buckling (2-0-4)	.	.	6
AM 110 abc	Elasticity (2-0-4)	6	6	6
AM 111	Experimental Stress Analysis (1-6-2)	.	9	.
AM 150 abc	Mechanical Vibrations (2-0-4)	6	6	6
CE 120 ab	Advanced Structural Analysis (3-0-6)	9	9	.
CE 121	Analysis and Design of Structural Systems (0-9-0)	.	.	9
CE 123	Dynamics of Structures (3-0-6)	.	.	9
CE 124	Special Problems in Structures (3-0-6)	9	9	9

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

HYDRAULICS AND WATER RESOURCES

CE 155	Hydrology (3-0-6)	9	.	.
CE 160	Advanced Hydrology[4]	.	.	.
Hy 101 abc	Advanced Fluid Mechanics (3-0-6)	9	9	9
Hy 103 ab	Advanced Hydraulics (3-0-6)	9	9	.
Hy 103 c	Hydraulic Structures (3-0-6)	.	.	9
Hy 105	Analysis and Design of Hydraulic Projects[4]	.	.	.
Hy 121	Advanced Hydraulics Laboratory[4]	.	.	.
Hy 134	Flow in Porous Media (3-0-6)	.	.	9

ENVIRONMENTAL HEALTH ENGINEERING

CE 137 abc	Water Supply & Waste-Water Disposal (3-0-6; 1-6-2)	9	9	9
CE 138 abc	Sanitary Sciences (2-3-4)	9	9	9
CE 151 abc	Air Resources Engineering (2-3-4)	9	9	9
CE 152 ab	Environmental Radiation (2-3-4)	.	9	9
CE 153	Seminar in Environmental Health Engineering (2-0-1)	.	.	3
CE 156	Industrial Wastes (3-0-6)	.	.	9

APPLIED MATHEMATICS

AM 113 ab	Engineering Mathematics (4-0-8)	.	12	12
AM 116	Complex Variables & Applications (4-0-8)	12	.	.
AM 180	Matrix Algebra (3-0-6)	9	.	.
Ma 105 ab	Intro. to Numerical Analysis (3-2-6)	.	11	11
Ma 112	Elementary Statistics (3-0-6)	9 or	9	.

[1]For list of Humanities electives, see page 235.
[2]Students who have not had AM 95 ab or its equivalent will be required to include AM 113 as part of their elective units.
[3]Electives must be approved by Civil Engineering faculty.
[4]Six or more units as arranged

ELECTRICAL ENGINEERING

FIFTH YEAR

(Leading to the degree of Master of Science in Electrical Engineering)

	Humanities Electives (3-0-6; 4-0-6)[1]	9 or 10	9 or 10	9 or 10
EE 220 abc	Research Seminar in Electrical Engineering	2	2	2
	Three or more of the following electives:			
EE 132 abc	Network Synthesis (3-0-6)	9	9	9
EE 140 abc	Electric Communication (3-0-6)	9	9	9
EE 150 abc	Electromagnetic Fields (3-0-6)	9	9	9
EE 164 abc	Microwave Electronics and Circuits (3-0-6)	9	9	9
EE 165 ab	Microwave Laboratory (1-3-2)	.	6	6
EE 170 abc	Feedback Control Systems (3-0-6; 3-3-6)	9	12	12
EE 180	Digital Computer Design (3-3-3)	9	.	.
EE 181 ab	Principles of Analog Computation (3-3-6)	.	12	12
EE 190 abc	Advanced Electronics (3-0-6)	9	9	9
EE 191 abc	Physics of Semiconductors and Semiconductor Devices (3-0-6)	9	9	9
Ph 112 abc	Atomic & Nuclear Physics (4-0-8)	12	12	12
	Other electives as approved by Electrical Engineering Faculty			
Ph 129 abc	Methods of Mathematical Physics	9	9	9
Ph 131 abc	Electricity and Magnetism	9	9	9
AM 125 abc	Engineering Mathematical Principles	9	9	9

[1]For list of Humanities electives, see page 235.

SIXTH YEAR

(Leading to the degree of Electrical Engineer)

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 204, except that a grade of D in Ph 131 is acceptable.

ENGINEERING SCIENCE

(Leading to the degree of Master of Science in Engineering Science)

		Units per Term 1st	2nd	3rd
	Humanities Electives	9 or 10	9 or 10	9 or 10
AM 125 abc	Engineering Mathematical Principles	9	9	9
or				
Ph 129 abc	Methods of Mathematical Physics	9	9	9
AM 130 abc	Classical Theoretical Physics I	9	9	9
or				
AM 131 abc	Classical Theoretical Physics II	9	9	9
or				
JP 201 abc	Physical Mechanics	9	9	9

Add electives to bring total to 140 units. Electives must be approved by advisor.

GEOLOGY

FIFTH YEAR

Option leading to degree of Master of Science in Geology

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; 4-0-6) (select from electives listed on page 235)	9	9	9
Ge 100	Geology Club	1	1	1
Ge 121 abc	Advanced Field Geology	14	10	11
Ge 123	Summer Field Geology (30 units)	.	.	.
Ch 124 ab	Physical Chemistry for Geologists	6	6	.
	Add electives to bring total to 140 units. Electives must be approved by advisor.			

Option leading to degree of Master of Science in Geophysics

	Humanities Elective (3-0-6; 4-0-6) (select from electives listed on page 235)	9	9	9
Ge 100	Geology Club	1	1	1
Ge 120 abc	Elementary Field Geology	10	10	10
Ge 282 abc	Geophysics-Geochemistry Seminar	1	1	1
Ph 107 abc	Electricity and Magnetism	9	9	9
Ph 108 abc	Theoretical Mechanics	9	9	9
	Add electives to bring total to 140 units. Electives must be approved by advisor.			

Option leading to degree of Master of Science in Geochemistry

	Humanities Elective (3-0-6; 4-0-6) (select from tives listed on page 235)	9	9	9
Ge 100	Geology Club	1	1	1
Ge 104 abc	Petrology	8	10	7
Ge 120 abc	Elementary Field Geology	10	10	10
Ge 130 ab	Introduction to Geochemistry	4	4	.
Ch 124 ab	Physical Chemistry for Geologists	6	6	.

Add electives to bring total to 140 units, including at least 30 additional units of advanced courses in Chemistry and Geochemistry, and at least 30 units of research in Geochemistry. Equivalent or previous courses may be substituted for Ge 104, Ge 120, Ge 130 ab, and Ch 124. Substitutions and Electives must be approved by advisor.

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 120 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

FIFTH YEAR

(Leading to the degree of Master of Science in Materials Science)

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; 4-0-6)*	9 or 10	9 or 10	9 or 10
E 150 abc	Seminar (1-0-1)	2	2	2
	Electives (Minimum total for year, 108 units)	36	36	36
		47-48	47-48	47-48

Electives (See Notes 1 and 2 below)

		1st	2nd	3rd
Ae 102 abc	Static and Dynamic Elasticity (3-0-6)	9	9	9
Ae 213	Fracture Mechanics (3-0-6)	.	9	.
Ae 215	Theory of Finite Strains (3-0-6)	9	.	.
Ae 219	Mechanics of Inelastic Materials (3-0-6)	Any term		
Ae 221	Theory of Viscoelasticity (3-0-6)	Any term		
Ae 222	Polymer Mechanics (3-0-6)	Any term		
AM 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
AM 102 abc	Applied Nuclear Physics (2-0-4)	6	6	6
AM 103 ab	Nuclear Engineering Laboratory (1-6-2)	9	9	.
AM 110 a	Introduction to the Theory of Elasticity (2-0-4)	6	.	.
AM 110 b	Theory of Plates and Shells (2-0-4)	.	6	.
AM 110 c	Mechanics of Materials (2-0-4)	.	.	6
AM 111	Experimental Stress Analysis (1-6-2)	.	9	.
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 126 abc	Applied Engineering Mathematics (3-0-9)	12	12	12
AM 130 abc	Applications of Classical Theoretical Physics I (3-0-6)	9	9	9
AM 131 abc	Applications of Classical Theoretical Physics II (3-0-6)	9	9	9
AM 140	Plasticity (2-0-4)	6	.	.
AM 141 ab	Wave Propagation in Solids (2-0-4)	.	6	6
AM 150 abc	Mechanical Vibrations (2-0-4)	6	6	6
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
Ch 121 ab	The Nature of the Chemical Bond (2-0-4)	.	6	6
CE 115 ab	Soil Mechanics (3-0-6)	9	9	.
EE 162 abc	Physics of Electronic Devices (2-0-4)	6	6	6
EE 190 abc	Advanced Electronics (3-0-6)	9	9	9
EE 191	Physics of Semiconductor and Semiconductor Devices (3-0-6)	.	9	.
Ma 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
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 127	High Frequency Measurements in Fluids and Solids (2-6-1)	.	9	.
Ph 107 abc	Electricity and Magnetism (3-0-6)	9	9	9
Ph 112 abc	Atomic and Nuclear Physics (4-0-8)	12	12	12
PM 102	Pyrometry (1-6-2)	.	.	9
PM 103 ab	Physical Metallurgy Laboratory (0-9-0) (0-6-0)	9	6	.
PM 104	Photography (1-6-2)	9	.	.

*For list of Humanities electives, see page 235.

Note 1: Students who have not had a course in Engineering Mathematics, Advanced Calculus, or the equivalent in their undergraduate work, are required to include AM 113 ab and AM 116 among the elective units.

Note 2: Substitution for electives listed above may be made with the specific approval of the faculty in Materials Science.

PM 105	Mechanical Behavior of Metals (2-0-4)	6	.	.
PM 112 ab	Advanced Physical Metallurgy (3-0-6)	.	9	9
PM 115 ab	Crystal Structure and Properties of Metals and Alloys (3-0-6)	.	9	9
PM 116	X-Ray Metallography Laboratory I (0-6-3)	.	.	9
PM 120	Physics of Solids (3-0-6)	9	.	.

MATHEMATICS

As nearly all mathematics majors are working for the doctor's degree and follow programs arranged by the student in consultation with members of the Division, no specific fifth year curriculum is outlined.

MECHANICAL ENGINEERING OPTION

FIFTH YEAR

(Leading to the degree of Master of Science in Mechanical Engineering)

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; 4-0-6)[1]	9 or 10	9 or 10	9 or 10
E 150 abc	Seminar (1-0-1)	2	2	2
	Electives as below. See Notes 1 & 2, page 246 (Minimum total for year 108)	36	36	36
		47 or 48	47 or 48	47 or 48

Electives (See Notes 1 and 2, page 243)

		1st	2nd	3rd
AM 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
AM 102 abc	Applied Nuclear Physics (2-0-4)	6	6	6
AM 103 ab	Nuclear Engineering Laboratory (1-6-2)	9	9	.
AM 110 a	Introduction to the Theory of Elasticity (2-0-4)	6	.	.
AM 110 b	Theory of Plates and Shells (2-0-4)	.	6	.
AM 110 c	Mechanics of Materials (2-0-4)	.	.	6
AM 111	Experimental Stress Analysis (1-6-2)	.	9	.
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 126 abc	Applied Engineering Mathematics (3-0-9)	12	12	12
AM 150 abc	Mechanical Vibrations (2-0-4)	6	6	6
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
AM 180	Matrix Algebra (3-0-6)	9	.	.
Hy 101 abc	Advanced Fluid Mechanics (3-0-6)	9	9	9
JP 170	Jet Propulsion Laboratory (0-9-0)	.	.	9
Ma 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
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 127	High Frequency Measurements in Fluids and Solids (2-6-1)	.	9	.
Ph 107 abc	Electricity and Magnetism (3-0-6)	9	9	9
PM 102	Pyrometry (1-6-2)	.	.	9
PM 104	Photography (1-6-2)	9	.	.

[1]For list of Humanities electives, see page 235.

MECHANICAL ENGINEERING (JET PROPULSION OPTION)

FIFTH YEAR

(Leading to the degree of Master of Science in Mechanical Engineering)

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; 4-0-6)[1]	9 or 10	9 or 10	9 or 10
E 150 abc	Seminar (1-0-1)	2	2	2
JP 120 abc	Chemistry Problems in Propulsion (3-0-6)	9	9	9
JP 121 abc	Rockets and Air Breathing Engines (3-0-6)	9	9	9
	Electives as below. See Notes 1 & 2, page 246 (Minimum total for year 54)	18	18	18
		47 or 48	47 or 48	47 or 48

Electives (See Notes 1 and 2, page 246)

		1st	2nd	3rd
AM 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
AM 102 abc	Applied Nuclear Physics (2-0-4)	6	6	6
AM 103 ab	Nuclear Engineering Laboratory (1-6-2)	9	9	.
AM 110 a	Introduction to the Theory of Elasticity (2-0-4)	6	.	.
AM 110 b	Theory of Plates and Shells (2-0-4)	.	6	.
AM 110 c	Mechanics of Materials (2-0-4)	.	.	6
AM 111	Experimental Stress Analysis (1-6-2)	.	9	.
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 126 abc	Applied Engineering Mathematics (3-0-6)	9	9	9
AM 150 abc	Mechanical Vibrations (2-0-4)	6	6	6
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
AM 180	Matrix Algebra (3-0-6)	9	.	.
Hy 101 abc	Advanced Fluid Mechanics (3-0-6)	9	9	9
JP 170	Jet Propulsion Laboratory (0-9-0)	.	.	9
JP 221 abc	Rocket Trajectories and Orbital Mechanics (2-0-4)	6	6	6
JP 240 a	Heat Transfer in Propulsion Systems—Radiative Heat Transfer (3-0-6)	Any term		
Ma 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
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 127	High Frequency Measurements in Fluids and Solids (2-6-1)	.	9	.
Ph 107 abc	Electricity and Magnetism (3-0-6)	9	9	9
PM 102	Pyrometry (1-6-2)	.	.	9
PM 104	Photography (1-6-2)	9	.	.

[1]For list of Humanities electives, see page 235.

MECHANICAL ENGINEERING (NUCLEAR ENERGY OPTION)

FIFTH YEAR

(Leading to the degree of Master of Science in Mechanical Engineering)

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; 4-0-6)[1]	9 or 10	9 or 10	9 or 10
E 150 abc	Seminar (1-0-1)	2	2	2
AM 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
AM 102 abc	Applied Nuclear Physics (2-0-4)[2]	6	6	6
	Electives as below. See Notes 1 & 2, page 246 (minimum total for year 63)	21	21	21
		47 or 48	47 or 48	47 or 48

Electives (See Notes 1 and 2, page 246)

		1st	2nd	3rd
AM 103 ab	Nuclear Engineering Laboratory (1-6-2)	9	9	.
AM 110 a	Introduction to the Theory of Elasticity (2-0-4)	6	.	.
AM 110 b	Theory of Plates and Shells (2-0-4)	.	6	.
AM 110 c	Mechanics of Materials (2-0-4)	.	.	6
AM 111	Experimental Stress Analysis (1-6-2)	.	9	.
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 126 abc	Applied Engineering Mathematics (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (2-0-4)	9	.	.
AM 180	Matrix Algebra (3-0-6)	9	.	.
Hy 101 abc	Advanced Fluid Mechanics (3-0-6)	9	9	9
JP 170	Jet Propulsion Laboratory (0-9-0)	.	.	9
Ma 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
Ma 112	Elementary Statistics (3-0-6)	9 or	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 127	High Frequency Measurements in Fluids and Solids (2-6-1)	.	9	.
Ph 107 abc	Electricity and Magnetism (3-0-6)	9	9	9
PM 102	Pyrometry (1-6-2)	.	.	9
PM 104	Photography (1-6-2)	9	.	.
PM 115 ab	Crystal Structure and Properties of Metals and Alloys (3-0-6)	.	9	9
PM 116	X-Ray Metallography and Laboratory I (0-6-3)	.	.	9
PM 120	Physics of Solids (3-0-6)	9	.	.

[1]For list of Humanities electives, see page 235.

[2]Ph 112 abc may be substituted for AM 102 abc, and the number of elective units for the year reduced to a minimum total of 45 units.

MECHANICAL ENGINEERING
(PHYSICAL METALLURGY OPTION)
FIFTH YEAR

(Leading to the degree of Master of Science in Mechanical Engineering)

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; 4-0-6)[1]	9 or 10	9 or 10	9 or 10
E 150 abc	Seminar (1-0-1)	2	2	2
AM 110 a	Introduction to the Theory of Elasticity (2-0-4)	6	.	.
PM 103 ab	Physical Metallurgy Laboratory (0-9-0; 0-6-0)	9	6	.
PM 112 ab	Advanced Physical Metallurgy (3-0-6)	.	9	9
PM 116	X-Ray Metallography I (0-6-3)[2]	.	.	9
	Electives as below. See Notes 1 & 2, page 246 (minimum total for year 63)	21	21	21
		47 or 48	47 or 48	47 or 48

Electives (See Notes 1 and 2, page 246)

		1st	2nd	3rd
AM 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
AM 102 abc	Applied Nuclear Physics (2-0-4)	6	6	6
AM 103 ab	Nuclear Engineering Laboratory (1-6-2)	9	9	.
AM 110 b	Theory of Plates and Shells (2-0-4)	.	6	.
AM 110 c	Mechanics of Materials (2-0-4)	.	.	6
AM 111	Experimental Stress Analysis (1-6-2)	.	9	.
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 126 abc	Applied Engineering Mathematics (3-0-6)	9	9	9
AM 150 abc	Mechanical Vibrations (2-0-4)	6	6	6
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
Ch 226 abc	Introduction to Quantum Mechanics with Chemical Applications (3-0-6)	9	9	9
JP 170	Jet Propulsion Laboratory (0-9-0)	.	.	9
Ma 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
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 127	High Frequency Measurements in Fluids and Solids (2-6-1)	.	9	.
Ph 107 abc	Electricity and Magnetism (3-0-6)	9	9	9
Ph 205 abc	Principles of Quantum Mechanics (3-0-6)	9	9	9
PM 102	Pyrometry (1-6-2)	.	.	9
PM 104	Photography (1-6-2)	9	.	.

[1]For list of Humanities electives, see page 235.

[2]Students who have not had PM 115 a or the equivalent will take PM 115 a as one of the electives in the second term.

Notes applying to all options in Mechanical Engineering:

Note 1: Students who have not had a course in Engineering Mathematics, Advanced Calculus, or the equivalent in their undergraduate work are required to include AM 113 ab and AM 116 among the elective units.

Note 2: Substitutions for the scheduled electives may be made upon specific approval of the faculty in Mechanical Engineering. The following are examples of substitutions that have been made in some instances and may be used as a guide by those desiring to make substitutions:

AM 105	Advanced Strength of Materials, 6 units second term
AM 106	Problems in Buckling, 6 units third term
Ae 101 abc	Elements of Gasdynamics, 9 units each term
EE 101 abc	Electric Circuit Theory, 9 units each term
EE 106 ab	Electronic Circuits, 9 units first and second terms
EE 170 abc	Feedback Control Systems, 9 units each term
JP 121 abc	Rockets and Air Breathing Engines, 9 units each term
PM 105	Mechanical Behavior of Metals, 6 units first term

MECHANICAL ENGINEERING

SIXTH YEAR

(Leading to the degree of Mechanical Engineer)

Specific requirements for the degree of Mechanical Engineer are given on page 193. The following list will suggest possible subjects from which a program of study may be organized:

Ae 201 abc	Fundamentals of Fluid Mechanics
Ae 210 abc	Fundamentals of Solid Mechanics
Ae 213	Fracture Mechanics
Ae 216	Structural Dynamics
AM 201 abc	Advanced Reactor Theory
Ch 163 ab	Chemical Engineering Thermodynamics
Ch 226 abc	Introduction to Quantum Mechanics
Ch 227 abc	The Structure of Crystals
Ch 229	Diffraction Methods of Determining the Structure of Molecules
Ch 262 abc	Thermodynamics of Multi-Component Systems
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 203 abc	Ionized Gas Theory
JP 212 ab	Flame Theory and Combustion Technology
JP 240 ab	Heat Transfer in Propulsion Systems
JP 250 abc	Fluid Mechanics of Axial Turbomachines
ME 200	Advanced Work in Mechanical Engineering
ME 300	Thesis—Research
PM 103 ab	Physical Metallurgy Laboratory
PM 112 ab	Advanced Physical Metallurgy
PM 205	Theory of Mechanical Behavior of Metals
PM 217	X-Ray Metallography II
Ph 112 abc	Atomic and Nuclear Physics
Ph 205 abc	Principles of Quantum Mechanics
Ph 227 ab	Thermodynamics, Statistical Mechanics, and Kinetic Theory

MECHANICAL ENGINEERING (JET PROPULSION OPTION)

SIXTH YEAR

(Leading to the degree of Mechanical Engineer)

		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

FIFTH YEAR

(Leading to the degree of Master of Science in Physics)

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; 4-0-6)[2]	9 or 10	9 or 10	9 or 10
	Electives as below (At least 54 of these units must be from courses in Groups I and II as listed on page 210)	39	39	39
		48 or 49	48 or 49	48 or 49
Ph 107 abc	Electricity and Magnetism (3-0-3)[1]	6	6	6
Ph 108 abc	Theoretical Mechanics (3-0-3)[1]	6	6	6
Ph 112 abc	Atomic and Nuclear Physics[1]	12	12	12
Ph 115 ab	Geometrical and Physical Optics (3-0-6)	.	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9
Ph 131 abc	Electricity and Magnetism (3-0-6)	9	9	9
Ph 203 abc	Nuclear Physics (3-0-6)	9	9	9
Ph 205 abc	Principles of Quantum Mechanics (3-0-6)	9	9	9
Ph 207 abc	X- and Gamma-Rays (3-0-6)	9	9	9
Ph 217	Spectroscopy (3-0-6)	.	.	9
Ma 108 abc	Advanced Calculus (4-0-8)[3]	12	12	12
Ma 118 abc	Functions of a Complex Variable (3-0-6)	9	9	9

[1]Prerequisite for most other fifth-year courses.

[2]For list of Humanities electives, see page 235.

[3]Prerequisite for Ma 118.

NOTE: With the department's approval, students who have the proper preparation may substitute other graduate courses in Electrical Engineering, Mathematics, or Physics for some of those listed above. Students who have received credit for Ph 131 abc, Ph 129 abc, or Ph 205 abc as undergraduates may use these credits towards a master of science degree provided they replace them with undergraduate credits in L 32 abc (4-0-6), or L 50 abc (4-0-6) earned during the fifth year.

Section VI

SUBJECTS OF INSTRUCTION

Aeronautics

ADVANCED SUBJECTS

Ae 101 abc. Elements of Gasdynamics. *9 units (3-0-6); each term. Prerequisites: Elementary Thermodynamics and Fluid Dynamics.* The course is intended to give an integrated overall picture of modern gasdynamics and its relation to thermodynamics and kinetic theory. Topics covered include: Thermodynamics of perfect and real gases and gas mixtures; stationary and non-stationary channel flow; shock waves; Euler equations; concepts of vorticity and its relation to entropy and enthalpy distribution; small perturbation theory for subsonic and supersonic flows; viscosity and heat conduction effects; Couette flow and boundary layer concept; elements of kinetic theory. Text: *Elements of Gasdynamics,* Liepmann-Roshko. Instructors: Liepmann, Roshko.

Ae 102 abc. Static and Dynamic Elasticity. *9 units (3-0-6); each term. Prerequisites: AM 5, AM 8, AM 9.* Fundamentals of applied elasticity with examples from aircraft, missile, and spacecraft structures. Exact solutions for two- and three-dimensional problems. Approximate methods of attack on complex problems including energy methods and analog techniques of various types. A concise review of vibration principles supplemented by engineering examples of structural components subjected to dynamic loads. Texts: *Elasticity in Engineering,* Sechler; *Engineering Vibrations,* Jacobsen and Ayre. Instructors: Sechler, Babcock.

Ae 103 abc. Performance and Flight Dynamics of Aircraft and Spacecraft. *9 units (3-0-6); each term. Prerequisite: AM 95 a, b.* Equations of motion for aircraft and spacecraft. Performance of conventional aircraft and rocket-powered vehicles. Engines, propellers, range and endurance, lifting and non-lifting reentry, satellite performance, staging, application of restricted three-body problem to trajectories in the solar system. Optimization of performance. Static and dynamic stability and control. Determination of response characteristics. Effects of non-linear aerodynamics, roll coupling, variable density and velocity, auto-pilot. Estimation of aerodynamic forces and moments on complete aircraft and their dependence on Mach number. Airfoil lift, drag, and moment characteristics. Boundary layers. Calculation of spanwise lift distribution on finite wings. Slender body theory. Similarity. Instructor: Kevorkian.

Ae 104 abc. Experimental Methods in Aeronautics. *9 units (3-0-6); each term.* The first term is devoted to the design and use of instruments. Fundamental principles involved in making precision measurements. Parameters governing the accuracy of instruments. Instrumental and other methods of improving the accuracy of experimental data. The second term consists of experimentation in fluid mechanics. Measurements of the physical properties of fluids and fluid flows, with particular attention to low-speed aerodynamics, turbulence, and steady and non-steady gas dynamics. Examples demonstrate the use of analogies and flow visualization methods. The third term deals with experimental techniques in solid mechanics and applied elasticity. Experiments demonstrate the basic principles established in elasticity and show both the advantages and disadvantages of the experimental method. Solution of structural analysis problems by analog techniques. The analysis and presentation of experimental data are discussed. Text: *Theories of Engineering Experimentation,* Schenk. Instructors: Klein, Coles, Sechler.

Ae 105 bc *Research Laboratory in Fluid Mechanics. *9 units (2-3-4); second and third terms. Prerequisite: Ae 104 a and permission of instructor.* Introduction to experimental research for students who may wish to continue in this field. Closely supervised research covering problem formulation, shop practice, instrumentation and measuring technique, data interpretation, documentation, and technical writing. Instructor: Coles.

*May be substituted for Ae 104 b, c by persons expecting to undertake thesis research in the area of fluid mechanics.

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. Fundamentals of Fluid Mechanics. *9 units (3-0-6); each term. Prerequisites: Ae 101, AM 113, AM 116 or AM 125.* Theoretical foundations of the mechanics of inviscid and viscous fluids pertinent to aeronautics. The first half, covering inviscid fluids, includes: incompressible flow theory; incompressible two-dimensional airfoil, three-dimensional wing, and slender body theories; linearized compressible potential flows and wing theory; oblique shocks; method of characteristics; exact solutions of the two-dimensional compressible flow equations; similarity laws for subsonic, transonic, supersonic, and hypersonic flows; introduction to hypersonic aerodynamics. The second half, dealing with viscous fluids, includes: physical properties of real gases; Navier-Stokes equations and their exact solutions; low Reynolds number approximate solutions; high Reynolds number phenomena emphasizing boundary layer concepts and their mathematical treatments. Instructors: Millikan, Lees, Kubota.

Ae 203 abc. Flight Mechanics and Applied Aerodynamics. *6 units (2-0-4); each term. Prerequisites: Ae 101, Ae 103, AM 113, 116.* 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. Instructor: Stewart.

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. Fundamentals of Solid Mechanics. *9 units (3-0-6); each term. Prerequisite: Ae 102 or equivalent.* A course whose purpose is the laying of the foundation for the study of statics and dynamics of elastic, anelastic, and plastic bodies. General basic methodology is emphasized. By developing the general theory to a reasonably high level, several special fields such as elastic waves, viscoelasticity, thermal stresses, theory of plates and shells, conditions of yield and flow, finite strain, etc. are introduced. The main concepts and features of these special fields are discussed. The course first presents prototypes of general theories for simple configurations and then proceeds to develop in detail the tensor analysis, stress and strain analyses, physical laws of elasticity, yield and flow, various stress and strain potentials, complex function techniques, energy principles, and associated methods for approximate analysis based upon variational methods. The special fields mentioned above are introduced at appropriate times as illustrations and special developments of general principles. Instructors: Fung, Williams.

Ae 211 abc. Systems Concepts. *6 units (2-0-4); each term.* An integrated study of various related subjects in engineering with emphasis on synthesizing the interactions which affect systems design—not necessarily restricted to aeronautics. The interplay between performance requirements, strength-weight analysis, power requirements, logistics, and human economic factors is evaluated in conjunction with familiarizing the student with the more elementary features of the mathematical tools at his disposal, such as operations analysis, digital computations and the variational calculus. (Not necessarily offered each year). Instructors: Staff.

Note: The following group of courses, Ae 212 to 222, represents a series of one term courses in Advanced Solid Mechanics. They will be given as student demand requires and staff facilities permit. It is anticipated that Ae 215, Ae 216, Ae 217, Ae 221 and Ae 222 will be offered in 1962-63. The remaining courses, which are listed by title only, may be offered if sufficient demand exists.

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. Instructor: Fung.

Ae 213. Fracture Mechanics. *9 units (3-0-6); one term.* An advanced course stressing the interdisciplinary approach to the fracture of materials, both metallic and nonmetallic. The Griffith macroscopic theory of brittle fracture. Essential features of dislocation theory. Extensions to ductile materials and dynamic effects of running cracks as well as fatigue fracture are included. Instructor: Williams.

Ae 214. Special Problems of Space Environment. *9 units (3-0-6); one term.* 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 radiation, flares, and storms. Instructor: Sechler.

Ae 215. Theory of Finite Strains. *9 units (3-0-6); first term 1962-63.* Stress-strain relationships in highly deformable media. Application of variational principles. Solutions to crack and wave problems involving large deformations. Discussion of elastic stability of hollow cylinders and spheres under plane stress and plane strain. Form of the strain energy function appropriate to compressible rubbers. Finite elastic analog of Poisson's ratio. Instructor: Blatz.

Ae 216. Structural Dynamics. *9 units (3-0-6); second term 1962-63.* Selected problems of structural dynamics that are of special interest to aerospace engineers. Topics may include 1) the causes, effects, and control of structural dynamics of flight vehicles including free, forced, and self excited oscillations, 2) ground shock, base hardening, ground wind, and silo firing problems, and 3) testing techniques, design criteria, and methods of analysis and calculation pertaining to structural dynamics. Instructors: Fung, Schmidt.

Ae 217. Aeroelasticity. *9 units (3-0-6); third term 1962-63.* Aeroelastic oscillations of cylinders, transmission lines and suspension bridges. Steady state problems; divergence, loss of control, and lift distribution. Flutter, buffeting and stall flutter. General formulation of aeroelastic problems. Texts: *An Introduction to the Theory of Aeroelasticity,* Fung. *Aeroelasticity,* Bisplinghoff, Ashley, and Halfman. Instructors: Fung, Stearman.

Ae 218. Thermal Stress Problems. *9 units (3-0-6); one term.*

Ae 219. Mechanics of Inelastic Materials. *9 units (3-0-6); one term.*

Ae 220. Non-linear Problems in Structures and Aeroelasticity. *9 units (3-0-6); one term.*

Ae 221. Theory of Viscoelasticity. *9 units (3-0-6); one term, 1962-63.* Review of material characterization through the stress-strain law. Thermodynamic basis for linear viscoelasticity. Correspondence rule for viscoelastic and associated elastic solutions. Variational integral for the classical boundary value problems. Dynamic birefringence. Introduction to vibration and wave effects in viscoelastic media. The practical solution of typical stress problems. Failure criteria in uniaxial and multiaxial stress fields. Instructor: Williams.

Ae 222. Polymer Mechanics. *9 units (3-0-6); one term, 1962-63.* Microscopic description of filled and unfilled polymers in terms of the topology of linear and cross-linked networks. Mechanisms of polymer chain formation and rupture. Relation of the micro- and macro-properties in terms of continuum mechanics, and the analysis of voids and defects utilizing theories of finite and infinitesimal deformations. Basis for the time-temperature shift factor. Finite element model or spectral representation of viscoelastic stress-strain behavior. Instructor: Blatz.

Note: The following group of courses Ae 231-Ae 239 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 1961-62 are indicated.

Ae 231. Molecular Theory of Fluid Motion. *(3-0-6); one term. 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. Instructors: Lagerstrom, Lees, Liepmann. (Not offered in 1961-62).

Ae 232. Gasdynamics of Upper Atmosphere Flight. *9 units (3-0-6); one term. Prerequisites: Ae 101; AM 113 ab and AM 116, or AM 125.* Fluid mechanical problems of upper atmosphere flight. Properties of the planetary atmospheres. "Free-molecule" flows and surface interactions. Drag and heat balance of satellites. Maxwell-Boltzmann equation and method of solution. Low Reynolds number flows according to the Navier-Stokes equations, including boundary layer-shock wave interactions. Ionized gases at low density. Plasma waves and the wake of a satellite in the ionosphere. Instructor: Lees. (Offered first term 1961-62.)

Ae 233. Mathematical Fluid Dynamics. *9 units (3-0-6); one term. Prerequisites: Ae 101, AM 125.* Topics chosen from characteristic theory, simple waves, shock waves, interactions, similarity solutions, singular perturbation theory, with applications to one-dimensional unsteady flow, supersonic flow, blast wave theory, Stokes flow, and boundary layer theory. Instructors: Lagerstrom, Cole, Kaplun. (Not offered in 1961-62).

Ae 234. Hypersonic Aerodynamics. *9 units (3-0-6); one term. 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 (Offered second term 1961-62).

Ae 235. Magneto-Fluid Dynamics. *(3-0-6); one term. Prerequisites: Ae 101, AM 125, Ph 107 or equivalent.* Review of Electrodynamics: Maxwell Stresses, Field- and Momentum-Energy tensors. Thermodynamics of fluids in electromagnetic fields. Equations of motion of a conducting gas. Characteristics, shock waves. Discussion of some typical flow problems such as Couette flow, Rayleigh's problem, piston problem, etc. Limitation of the one fluid approach and discussion of possible generalizations. Instructors: Cole, Liepmann. (Offered first term 1961-62).

Ae 236. Topics in Plasma Physics. *(3-0-6); one term. Prerequisites: Permission of instructor.* A lecture course on current problems in the dynamics of ionized gases offered jointly with the Astronomy department. The course will be given by resident or visiting faculty members. The subject matter will vary from year to year and may include e.g., plasma waves, plasma stability problems, radiation from plasma sources, statistical mechanics of ionized gases, etc. Instructor: Lüst. (Offered second term 1961-62).

Ae 237. Shock Tube Theory and Techniques. *9 units (3-0-6); one term. Prerequisites: Ae 101, AM 95 or AM 113, AM 116.* Review of shock waves in moving co-ordinate systems, in real and perfect gases. Simple expansion waves. Basic shock tube equation; various shock tube parameters. Reflected shock waves. Effects of area charge. 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. Instructors: Roshko, Sturtevant. (Offered third term 1961-62).

Ae 238. Stochastic Processes in Fluid Mechanics. *9 units (3-0-6); one term. Prerequisites: AM 125, Ae 201.* Fundamental concepts; probability, random variables, statistical distributions. Stochastic processes; fluctuations in thermodynamic systems, shot effect, Brownian motion. Spectra and correlation functions. Kinematics and dynamics of isotropic homogeneous turbulence. Experimental methods and results. Instructors: Lagerstrom, Liepmann, Coles. (Not offered in 1961-62).

Ae 239. Turbulent Shear Flows. *9 units (3-0-6); one term. Prerequisites: Ae 101, AM 113, 116.* 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, and separation. Applications in geophysics and astrophysics Instructors: Coles, Liepmann. (Offered third term 1961-62).

JET PROPULSION

(For Jet Propulsion see pages 294-297)

AIR SCIENCE

AS 1 abc. Foundations of Aerospace Power. *4 units (2-1-1). (The freshman year.)* An introductory examination of the factors of aerospace power, major ideological conflicts, requirements for military forces in being, responsibilities of citizenship, development and traditions of the military profession, role and attributes of the professional officer in American democracy, organization of the armed forces as factors in the preservation of national security, and the United States Air Force as a major factor in the security of the free world. An average of not less than two classroom hours per week for the academic year (a total of 60 classroom hours). Instructors: Air Force Staff.

AS 2 abc. Fundamentals of Aerospace Weapon Systems. *4 units (2-1-1). (The sophomore year.)* An introductory survey of aerospace missiles and craft, and their propulsion and guidance systems; target intelligence and electronic warfare; nuclear, chemical, and biological warhead agents; defensive, strategic, and tactical operations; problems, mechanics, and military implications of space operations; and a survey of contemporary military thought. An average of not less than two classroom hours per week for the academic year (a total of 60 classroom hours). Instructors: Air Force Staff.

***AS 3 abc. Air Force Officer Development.** *8 units (4-1-3). (The junior year.)* Staff organization and functions and the skills required for effective staff work, to include oral and written communication and problem solving; basic psychological and sociological principles of leadership and their application to leadership practices and problems; and an introduction to military justice. An average of not less than four classroom hours per week for the academic year (a total of 120 classroom hours). Instructors: Air Force Staff.

*During the junior and senior years certain Institute courses may be substituted for some of the areas of instruction depicted above. When this occurs, and no military classroom instruction is provided, only three units will be granted for Air Science that term.

***AS 4 abc. Global Relations.** *3 or 8 units (0-1-2 first and second terms, 4-1-3 third term). (The senior year.)* An intensive study of global relations of special concern to the Air Force officer, with emphasis on international relations and geography, and briefing for commissioned service. An average of not less than four classroom hours per week for the academic year (a total of 120 classroom hours). Instructors: Air Force Staff.

APPLIED MECHANICS

UNDERGRADUATE SUBJECTS

AM 8 abc. Mechanics of Solids I. *9 units (3-0-6); first, second and third terms. Prerequisites: Ph 1 abc, Ma 1 abc.* Dynamics of particles, groups of particles and rigid bodies; general principles of statics including energy, stability and an introduction to statically indeterminant structures; kinematics of relative motion; periodic and non-periodic motion of vibrating systems; planetary motion; Euler's equations of motion and gyroscopes; momentum relations in flow of matter. Concept of stress and strain in continuous solids; stress states; deformation of continuous solids, displacement-strain and stress-strain-temperature relations; strain energy and energy methods; equilibrium and compatibility equations for stresses; uniqueness theorem, St. Venant's principle. Emphasis is on development of fundamental principles with application to selected problems. Text (AM 8 ab): *Principles of Mechanics of Solids and Fluids, Vol. 1,* Yeh and Abrams. Instructors: Crede, Vreeland.

AM 9 abc. Mechanics of Solids II. *9 units (3-0-6); first, second and third terms. Prerequisite: AM 8 abc.* Analysis of stress, strain and deflection in torsion, bending, columns, beams, plates and shells, pressure vessels and rotating discs. Hamilton's principle; generalized coordinates; Lagrange's equation; vibration of multiple degree-of-freedom systems; vibration of systems with distributed mass and stiffness; longitudinal and flexural vibrations of bars; wave propagation; Rayleigh's principle; representation of continuous vibrating systems by lumped parameters; matrix formulation of vibration problems; orbital mechanics. Emphasis is on more advanced methods of analysis and application to physical problems. Instructors: Crede, Vreeland.

ADVANCED SUBJECTS

Note: Other subjects in the general field of Applied Mechanics will be found listed under the departments of Aeronautics, Electrical Engineering, Mechanical Engineering, and Physics.

AM 95 ab. Engineering Mathematics. *12 units (4-0-8); first and second, and second and third terms. (Graduate students needing this material should take AM 113 ab.) 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; 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, Miklowitz, Wayland, and Staff.

*During the junior and senior years certain Institute courses may be substituted for some of the areas of instruction depicted above. When this occurs, and no military classroom instruction is provided, only three units will be granted for Air Science that term.

AM 101 abc. Nuclear Reactor Theory. *9 units (3-0-6); each term. Prerequisite: AM 113 ab or equivalent (may be taken concurrently).* Neutron chain reactions and the criticality condition; the slowing down of neutrons in an infinite medium; one-speed diffusion of neutrons in multiplying and non-multiplying systems; combined slowing down and diffusion; bare and reflected homogeneous reactors; effects of heterogeneity; time dependent behavior of reactors; control rod theory; elements of transport theory. Instructor: Lurie.

AM 102 abc. Applied Nuclear Physics. *6 units (2-0-4); each term. Prerequisites: Ph 2 abc; AM 95 ab or equivalent.* An introductory course covering those aspects of nuclear physics which are encountered in nuclear engineering. Topics covered will include radioactivity, the interactions of charged particles and gamma rays with matter, nuclear reactions, neutron physics and nuclear fission. Part of the third term will be devoted to such specialized topics as radiation shielding including bulk and thermal shields. Instructors: Plesset, Hsieh.

AM 103 ab. Nuclear Engineering Laboratory. *9 units (1-4-4); first and second terms. Prerequisite: Ph 2 abc.* A laboratory course divided into two parts. In the first term, basic radiation detection devices and techniques are studied. The instruments are used to determine the properties of various types of radiation and to observe the nature of their interaction with matter. In the second term, measurements associated with nuclear reactor parameters are made. Neutron flux distributions in pure water and in a subcritical assembly are measured and analyzed. Instructor: Shapiro.

AM 105. Advanced Strength of Materials. *6 units (2-0-4); second term. Prerequisites: AM 8, AM 9.* Analysis of problems of stress and strain that are described by ordinary differential equations, such as beams on elastic foundation, curved bars, combined bending and axial loading of beams, combined bending and torsion of beams. Energy methods of solution. Instructor: Housner.

AM 106. Problems in Buckling. *6 units (2-0-4); third term. Prerequisites: AM 8, AM 9.* Analysis of problems dealing with the elastic instability of columns, beams, arches and rings, and the inelastic buckling of columns. Instructor: Housner.

AM 110 a. Introduction to the Theory of Elasticity. *6 units (2-0-4); first term. Prerequisites: AM 8, AM 9.* Fundamental concepts of elasticity theory. Equations of stress equilibrium and strain compatibility. Solution of two-dimensional problems. Photoelastic method of stress measurements. Analysis of stress and strain in three dimensions. Solution of torsion problems. Wave propagation in elastic solids. Instructors: Housner, Miklowitz.

AM 110 b. Theory of Plates and Shells. *6 units (2-0-4); second term. Prerequisites: AM 8, AM 9.* Simplifications introduced in elasticity theory. Laterally loaded plates with various boundary conditions. Elastic stability of plates. Membrane theory of shells. General theory of shells. Instructors: Housner, Miklowitz.

AM 110 c. Mechanics of Materials. *6 units (2-0-4); third term. Prerequisites: AM 8, AM 9, AM 110 a.* Use of tensors in elasticity theory. Non-linear stress-strain relations. Theory of plasticity. Theories of failures of stressed materials. Instructors: Housner, Miklowitz.

AM 111. Experimental Stress Analysis. *9 units (1-6-2); second term. Prerequisite: AM 8 abc or equivalent.* Static and dynamic stress and strain measurements, including the use of piezoelectric materials; wire resistance strain gages; mechanical, optical, inductance, and capacitance displacement gages; photoelastic materials; brittle lacquer coatings; X-rays, and associated instrumentation and recording systems. Instructor: Staff.

AM 113 ab. Engineering Mathematics. *9 units (4-0-5); first and second, or 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 ab. Emphasis is placed on the setting up of problems as well as their mathematical solution. The topics studied include: vector analysis, ordinary differential equations emphasizing power series solutions; special functions such as the Bessel functions and Legendre functions; partial differential equations and boundary value problems, with emphasis on application of series of orthogonal functions; and an introduction to transform methods. Text: *Differential Equations Applied in Science and Engineering,* Wayland. Instructors: Knowles, Miklowitz, Wayland, and Staff.

AM 116. Complex Variables and Applications. *12 units (4-0-8); first term and third term. Only six units credit for those students who have completed or are simultaneously enrolled in Ma 108. Prerequisites: Ma 1 abc, Ma 2 abc, or equivalent.* A basic introduction to analytic functions of a complex variable. Emphasis is placed on application of conformal mapping to boundary value problems and on techniques and applications of contour integration. Text: *Introduction to Complex Variables and Applications,* Churchill. Instructors: Miklowitz, Wayland, and Staff.

AM 125 abc. Engineering Mathematical Principles. *9 units (3-0-6); each term. Prerequisites: AM 95 ab and AM 116, Ma 108, or equivalent.* Topics from ordinary and partial differential equations with applications to vibrations, elasticity, theory of sound, fluid mechanics, and diffusion. Instructor: Cole.

AM 126 abc. Applied Engineering Mathematics. *12 units (3-0-9); each term. Prerequisites: AM 95 ab and AM 116, Ma 108, or equivalent.* A problem and lecture course in engineering mathematics. Preparation of approximately six reports per term on problems taken from all branches of engineering. First term lectures cover topics in ordinary differential equations including: Lagrange's equations, normal modes of vibration, and nonlinear systems. Second and third term lectures cover topics in partial differential equations including: characteristics, vibration theory, Rayleigh-Ritz method, conformal mapping, Laplace transform, difference equations, relaxation methods. Instructor: Lindvall.

AM 130 abc. Applications of Classical Theoretical Physics I. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 95 ab, AM 116, or equivalent.* Analytical mechanics of systems of particles, heat conduction, thermodynamics, mechanics of continuous media. Instructors: Plesset and Wu.

AM 131 abc. Applications of Classical Theoretical Physics II. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 96 ab, AM 116, or equivalent.* Kinetic theory, classical and quantum statistical mechanics, electrodynamics, and special relativity. Instructors: Plesset and Wu.

AM 140. Plasticity. *6 units (2-0-4); first term. Prerequisites: AM 110 ac, AM 113 ab.* Further study in theory of plasticity and applications. Yield criteria and strain hardening in metals. Rules of flow and the general stress-strain laws. Application to problems of combined stress. Creep and relaxation in metals and polymers. Plastico-viscous solid. Introduction to theory of visco-elasticity. Instructor: Miklowitz.

AM 141 ab. Wave Propagation in Solids. *6 units (2-0-4); second and third terms. Prerequisites: AM 95 ab, AM 110 a, AM 116.* Theory of wave propagation in solids with application to problems. Waves in elastic media. Dispersion of waves in bounded solids. Approximate elasticity theories governing waves in rods, beams, plates and shells. Use of Laplace transform techniques, asymptotic expansion of integrals in deriving wave solutions for these theories. Related experiments. Waves in plastic and viscoelastic media. Damage due to wave action. Instructor: Miklowitz.

AM 150 abc. Mechanical Vibrations. *6 units (2-0-4); first, second, and third terms. Prerequisites: AM 8, AM 95 a, b or permission of instructor.* A study of the theory of vibrating systems, and the application of such theory to problems of mechanical design. Subjects considered include theory of resonant systems; elimination of undesirable vibrations; design of vibration instruments; periodic disturbing forces such as engine vibration problems; critical speed phenomena; transient excitations; general normal mode theory. The third term is an introduction to non-linear vibration theory. Instructors: Caughey, Crede, Hudson.

AM 155. Dynamic Measurements Laboratory. *9 units (1-6-2); first term.* Theory and technique of making measurements encountered in engineering practice and research, with special reference to dynamic measurements. Experiments in vibrations and stability using the latest electro-mechanical and electronic instruments are performed. Instructors: Caughey, Crede, Hudson.

AM 160. Vibrations Laboratory. *6 units (0-3-3). Prerequisite: AM 150.* The experimental analysis of typical problems involving vibrations in mechanical systems, such as a study of the characteristics of a vibration isolation system, or a determination of the transient strains in a machine member subjected to impact loads. The measurements 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, Crede, Hudson.

AM 174 abc. Advanced Dynamics I. *6 units (3-0-3). Prerequisites: AM 125 abc and AM 150 abc or equivalents.* The first two terms will cover topics in advanced linear vibration theory with special emphasis on approximate methods of analysis of complex systems and topics in non-linear vibration theory with special emphasis on systems with strong non-linearities. The third term will be devoted to noise and stochastic processes applied to vibration problems. This course will be given every other year to alternate with AM 176. Given 1960-61. Instructor: Caughey.

AM 176 abc. Advanced Dynamics II. *6 units (3-0-3). Prerequisites: AM 125 abc and AM 150 abc or equivalents.* The first term will be devoted to topics in engineering applications of acoustics. The second and third terms will cover topics in stability of dynamic mechanical systems and in control of mechanical-electrical systems. This course will be given every other year to alternate with AM 174. Instructor: Caughey.

AM 180. Matrix Algebra. *9 units (3-0-6); first term. Prerequisite: AM 95 ab 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: *Principles of Numerical Analysis*, Householder. Instructor: Franklin.

AM 181 ab. Linear Programming. *9 units (3-0-6); second and third terms. Prerequisite: AM 180 or Ma 5.* 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. Instructor: Franklin.

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 201 abc. Advanced Reactor Theory. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 101 abc, AM 102 abc, or equivalent.* The neutron transport equation. Slowing-down problems; resonance escape and thermalization problems. Mono-energetic diffusion; the Milne problem. Non steady state problems; pulsed neutrons and reactor kinetics. Numerical solutions; digital computer codes for diffusion problems. Instructor: Cohen.

AM 204 abc. Hydrodynamics of Free Surface Flows. *9 units (3-0-6); each term. Prerequisites: Hy 101 abc, AM 125 ab and AM 116, or equivalent.* Theory of surface waves in a liquid; initial value problems and boundary value problems. Wave pattern due to moving disturbances. Wave resistance of a floating or submerged body. Theory of thin ships. Lifting surfaces in flows having a free surface: planing surfaces, hydrofoils. Theory of tidal waves. The mathematical method of characteristics will be applied to the problems of the flow in open channels, river waves and flood waves. Free boundary theory; theories of physical cavity flows. Dynamics and stability of vapor bubbles in a liquid. Water entry problems. Given in alternate years. Instructor: Wu.

AM 205 abc. Theory of Solids. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 112 abc or equivalent.* Theory of specific heats. Free electron theory of metals and semiconductors, Thomas-Fermi and Hartee-Fock approximations. Theory of cohesion, conductivity, and optical properties. Not given in 1962-63. Instructor: Willens.

AM 225 abc. Advanced Topics in Applied Mathematics. *9 units (3-0-6). Prerequisite: AM 125 or equivalent.* Advanced mathematical techniques used in Engineering and Physics. Special emphasis on a systematic theory of partial differential equations. This will include theory of characteristics, Green's functions, tensor analysis, perturbation methods, similarity, Wiener-Hopf method. Selected advanced topics, such as Calculus of Variation, Integral Equations, will be included. The connections between physical and mathematical problems will be emphasized. Instructors: Cole, Lagerstrom, Kaplun.

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 is intended to give the student sufficient familiarity with general astronomy to enable him to read with profit all but the more technical books and articles dealing with this subject. Reading in a text is supplemented by lectures on current astrophysical topics. Instructor: Greenstein.

Ay 2 abc. General Astronomy. *9 units (3-3-3); first, second, and third terms. Prerequisites: Ph 2 abc, Ma 2 abc.* The planets, the sun and solar-terrestrial relations. Physical properties of the stars and the spectral sequence. Binary and variable stars. Dynamics of the galaxy, extragalactic nebulae. Introduction to astrophysics of stellar interiors and atmospheres. Instructors: Münch, Eggen, Schmidt.

ADVANCED SUBJECTS

Ay 108 abc. Astronomical Instruments and Radiation Measurement. *9 units (3-1-5), (3-2-4); first and second terms.* 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, amplifiers. Photometric systems and their applications. Open to qualified undergraduates. Instructor: Oke.

Ay 112 abc. General Astronomy. *6 units (3-2-1); first, second, and third terms.* This subject is the same as Ay 2, with reduced credit for graduate students. Instructors: Münch, Eggen, Schmidt.

Ay 131 ab. Stellar Atmospheres. *9 units (3-0-6); first and second terms. Prerequisites: Ay 2 abc, Ph 112 abc.* Atomic spectroscopy. Stellar spectra. The theory of radiative equilibrium in stellar atmospheres. The continuous absorption by atoms and the production of the continuous spectrum of the stars; the line absorption coefficient and the formation of spectral lines. The solar atmosphere. Analysis of stellar spectra. Abundances of the elements. Nucleo-synthesis. Instructors: Greenstein, Münch.

Ay 132 ab. Stellar Interiors. *9 units (3-0-6); second and third terms. Prerequisites: Ay 2 abc, Ph 112 abc, or their equivalents.* Introduction to the study of stellar interiors; polytropes; opacity and energy generation. Stellar models. Red giants and white dwarfs. Stellar evolution. Pulsating stars. Not given in 1962-63.

Ay 133 ab. Radio Astronomy. *9 units (3-0-6); second and third terms.* 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 non-thermal emission, cosmic rays. Discrete sources and their identification. The 21-cm hydrogen line in absorption and emission and galactic structure. Given in alternate years. Instructor: Schmidt and Staff. Not given in 1962-63.

Ay 135. Topics in Modern Astronomy. *9 units (3-0-6); third term.* Lectures on recent developments and trends in current research. Instructor: Struve.

Ay 136. Planetary Physics. *9 units (3-0-6); third term.* Introduction to planetary dynamics. Physical properties of the planets and satellites, their atmospheres and interiors. Interplanetary matter and fields. Comets. Given in alternate years. Instructor: Münch.

Ay 140 abc. Seminar in Astrophysics. *4-12 units; first, second, third terms.* Discussions on the large-scale distribution of matter in the universe, statistics of the distribution of nebulae and clusters of nebulae. Morphology of nebulae. Theory and discussion of observational data on stars of special interest, such as supernovae, white dwarfs, variable stars, and emission line stars. Practical work of reduction of data obtained with the Schmidt telescopes on Palomar Mountain. Students and visiting research personnel are admitted to the seminar who have the time, inclination and ability to engage in active, constructive work on problems that will be formulated in this seminar. Meetings throughout the year according to agreement. Instructor: Zwicky.

Ay 141 abc. Research Conference in Astronomy. *2 units; first, second and third terms.* Meets weekly to discuss work in progress in connection with the staff of the Mount Wilson and Palomar observatories.

Ay 142. Research in Astronomy, Radio Astronomy, and Astrophysics. *Units in accordance with the work accomplished.* The student should consult a member of the department and have a definite program of research outlined with him before registering. Eighteen units required for candidacy.

Ay 202. The Solar Atmosphere. *9 units (3-0-6); third term.* The photosphere and the outer layers of the sun; the chromosphere and corona. Magnetic fields; spots and the general field; their motion and variations. Instructor: Howard.

Ay 206. Variable Stars. *9 units (3-0-6); first term.* Observations. Eclipsing stars and the physical properties of the stars. Intrinsic variables, cepheids, long-period and others. Galactic distribution, luminosities. Instructor: Eggen.

Ay 208. Laboratory in Stellar Astronomy. *10 units (2-6-2); third term.* Use of astronomical observational and laboratory equipment. Measurement and reduction of research materials. Projects undertaken by the group will involve research on star positions, motions, brightness, color, variability and spectra. Given in alternate years. Instructor: Eggen.

Ay 210. Interstellar Matter. *9 units (3-0-6); third term.* 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 1962-63.

Ay 211. Stellar Dynamics and Galactic Structure. *9 units (3-0-6); first term.* 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 1962-63.

Ay 212. Content and Evolution of Our Own and Other Galaxies. *6 units (2-0-4); first term.* Analysis of stellar content of galaxies.Photometry and color-magnitude diagrams. Study of star clusters. Age-dating. Chemical composition. Comparison of extragalactic nebulae and our galaxy. Evolutionary considerations. Distance scale, masses, ages; choice of model universes. Not given in 1962-63.

Ay 215. Seminar in Astrophysics. *4 units (1-0-3); second term. Prerequisites: Ay 131 and/or Ay 132.* Seminar on recent developments for advanced students. The current observational and theoretical literature will be discussed by the students. Instructor: Münch. Not given in 1962-63.

Ay 234. Seminar in Radio Astronomy. *8 units (2-0-6); second term. Prerequisite: Ay 133.* Recent developments in radio astronomy for the advanced student. Current publications and research in progress will be discussed by students and staff. Instructor: Schmidt and Staff.

The following courses will be offered from time to time by members of the Mount Wilson Observatory and Institute staffs:

Ay 203. Stellar Electromagnetism.

Ay 204. Advanced Stellar Spectroscopy.

Ay 207. Stellar Luminosities and Colors.

Ay 209. Planetary and Diffuse Nebulae.

Ay 213. Selected Topics in Observational Cosmology.

Ay 214. Theoretical Cosmology.

Ay 216. Advanced Stellar Interiors.

BIOLOGY

UNDERGRADUATE SUBJECTS

Bi 1. Elementary Biology. *9 units (3-3-3); second term.* A study of the organism as a structural and functional entity, and of the relation of biological problems to human affairs. Instructors: Bonner, Staff.

Bi 3. Plant Biology. *12 units (3-6-3); first term. Prerequisite: Bi 1, Bi 9, or consent of instructor.* Principles of plant structure, plant diversity, and plant function. Instructors: Lang, Bonner, 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: Hodge, Staff.

Bi 10. Animal Biology. *12 units (3-6-3); second term.* Principles of animal structure, function, and diversity. Instructor: Brokaw.

Bi 20. Mammalian Anatomy and Histology. *12 units (2-6-4); third term.* Macroscopic and microscopic structure of a mammal, including elementary instruction in preparation of tissue for microscopic inspection. Instructors: Van Harreveld, Keighley.

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: The 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. Embryology. *12 units (2-6-4); third term. Prerequisite: Bi 10.* The subject deals mainly with vertebrate embryology and includes some invertebrate, experimental and cytological material. Instructor: Tyler.

Bi 107 abc. Biochemistry. *10 units (3-0-7; 3-3-4; 3-5-2); first, second, and third terms. Prerequisite: Ch 41.* A lecture course on the chemical constitution of living matter and the chemical changes in animals, with laboratory work illustrating principles and methods in current use. In the third quarter emphasis is placed upon the application of physical methods to biochemical problems. Instructors: Borsook, Mitchell, Sinsheimer.

Bi 109. Advanced Genetics Laboratory. *Units to be arranged; second term.* An advanced laboratory course in the genetics of Drosophila. Instructor: Lewis.

Bi 110. General Microbiology. *12 units (3-4-5); third term. Prerequisites: Bi 122, Bi 107 a.* A course dealing with the various aspects of microorganisms, including cytology, antigenic properties of bacteria; nutritional requirements, with particular emphasis on autotrophic bacteria; the influence of environment; growth; spontaneous death and artificial killing; microbial variation; sexuality in microorganisms; taxonomical problems. Instructor: Dulbecco. Not offered in 1962-63.

Bi 114. Immunology. *9 units (2-4-3); first term. Prerequisite: Ch 41 abc.* A course on the principles and methods of immunology and their application to various biological problems. Instructor: Owen.

Bi 117. Psychobiology I. *9 units (3-3-3); third term. Prerequisite: Bi 1.* An introduction to the biology of behavior with correlated laboratory study of the vertebrate nervous system. Instructor: Sperry.

Bi 118. General Physiology. *10 units (3-3-4); first term.* A lecture and laboratory course on selected topics like nervous excitation and conduction, synaptic transmission, inhibition, muscle contraction, sense organ physiology, etc. Instructors: Van Harreveld, Wiersma.

Bi 120. Mammalian Anatomy and Histology. *9 units; third term.* This subject is the same as Bi 20 but with reduced credit for graduate students. Graduate students majoring in Biology receive no credit for this subject. Instructors: Keighley, Van Harreveld.

Bi 122 Genetics. *10 units (3-3-4); first term. Prerequisite: Bi 1 or Bi 9.* A course presenting the fundamentals of genetics in relation to general biological problems. (This course was previously listed as Bi 2.) Instructor: Lewis.

Bi 126. Genetics of Microorganisms. *10 units (2-4-4); second term. Prerequisite: Bi 122.* The genetics of algae, fungi, protozoa, and bacteriophage with laboratory work to illustrate the suitability of different microorganisms to particular kinds of genetic analysis. Instructors: Emerson, Edgar, Staff.

Bi 127. Biochemical Genetics. *10 units (2-4-4); third term. Prerequisites: Bi 122 and Bi 126.* A course dealing with gene action at the molecular and cellular levels. Topics to be reviewed include genetic determination of protein structure, gene-enzyme relationships, genetic control of metabolism and biosynthetic pathways, and genes and development. May be taken without the laboratory, for reduced credit, with permission of instructor. Instructor: Horowitz.

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 ab. Biophysics. *6 units (2-0-4); first and second terms.* The subject matter to be covered will be repeated approximately in a three-year cycle. During the first term 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. During the second term the subject matter will be organized according to methods of research. This course together with Ch 132 constitutes an integrated program covering the physical and physico-chemical approaches to biology. Instructor: Sinsheimer. (Bi 129a will not be offered in 1961-62.)

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: Emerson, Dulbecco, Wiersma.

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 206. Immunology Seminar. *1 unit; all terms.* Reports and discussions; meets twice monthly. In charge: Owen, 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: Sinsheimer.

Bi 214 abc. Chemistry of Bio-Organic Substances. *3 units (1-0-2); first, second, and third terms. Prerequisite: Ch 41 ab.* A series of lectures on selected topics of organic chemistry that have special interest from a biological viewpoint. Instructor: Haagen-Smit.

Bi 217. Quantitative Organic Microanalysis. *Units to be arranged; second term.* Laboratory practice in the methods of quantitative organic microanalysis required for structure determination of organic compounds. Students must obtain permission from the instructor before registering for this subject as the enrollment is necessarily limited. Instructor: Haagen-Smit.

Bi 218. Virology. *9 units (2-3-4); second term. Prerequisites: Bi 1 or Bi 9, and permission of instructor.* The multiplication of viruses, the origin of their chemical constituents, and the determination and transmission of their genetic properties. Instructor: Dulbecco.

Bi 220 abc. Experimental Embryology. *6 units (2-0-4); first, second, and third terms.* Lectures and discussion of the problems of embryonic development, including such topics as growth of the ovary, breeding habits of animals, fertilization, cleavage, organ formation, metamorphosis, regeneration, tissue culture, embryonic metabolism, etc. The subject may be taken for two consecutive years since the subject matter will be duplicated only in alternate years. Instructor: Tyler.

Bi 221. Experimental Embryology Laboratory. *Units to be arranged; all terms.* The work will include certain classical experiments and instruction in the methods of studying embryonic metabolism, transplantation, vital staining, cytochemistry, etc. Instructor: Tyler.

Bi 230. Psychobiology 2. *Units to be arranged. First, second, and third terms. Prerequisite: consent of instructor.* An advanced course on the neural organization of behavior. Instructor: Sperry.

Bi 240 abc. Plant Physiology. *6 units (2-0-4); first, second, and third terms.* Reading and discussion of the problems of plant physiology. Instructors: Bonner, Lang.

Bi 241 abc. Advanced Biochemistry. *6 units (2-0-4); first, second, and third terms.* Detailed discussions of biochemical topics on an advanced level. Instructor: Bonner.

Bi 260. Advanced Physiology. *Units to be arranged. Second term.* A course in the methods of physiology, with special reference to nerve and muscle, with opportunity for research. Instructors: 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), virology (290).

Chemical Engineering

UNDERGRADUATE SUBJECTS

ChE 50. Applications of Chemistry. *9 units (3-0-6); second term.* Consideration of the most recent developments in the field of chemical engineering viewed from the quantitative backgrounds of physics, mathematics, chemistry, and economics. Instructor: Corcoran.

ChE 61 ab. Industrial Chemistry. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 abc.* A study of the more important industrial chemical processes, from the point of view not only of the chemical reactions, but of the conditions and equipment necessary to carry on these reactions. Instructor: Manning.

ChE 63 abc. Chemical Engineering Thermodynamics. *9 units (3-0-6) first, third terms; 6 units (2-0-4) second term.* Class exercises and problems in engineering thermodynamics studied from the point of view of the chemical engineer. Text: *Thermodynamics of One-Component Systems,* Lacey and Sage. Instructor: Pings.

ChE 65. Economics of Chemical Technology. *9 units (1-0-8); second term.* Detailed studies of the technology and its relation to the economic feasibility of exemplary chemical processes. Offered to seniors in the chemical engineering option as an elective. Instructor: Manning.

ChE 66 abc. Chemical Engineering Operations. *12 units (3-0-9); first, second, third terms. Prerequisite: ChE 63 abc.* Calculations and discussions on the quantitative problems encountered in carrying out chemical processes efficiently on a commercial scale. The unit operations of chemical engineering are studied both as to principle and practice. Texts: *Transport Phenomena,* Bird, Stewart, and Lightfoot; *Principles of Unit Operations,* Foust. Instructor: Pings.

ChE 67 ab. Chemical Engineering Laboratory. *9 units (0-7-2); second, third terms. Prerequisites: Ch 21 abc, ChE 63 abc.* Instruction and practice in making engineering measurements, and illustration of some of the principles encountered in engineering courses. Instructor: Richter.

ChE 68. Introductory Chemical Engineering Kinetics. *9 units (3-0-6); first term. Prerequisite: Ch 21 abc.* A quantitative treatment of the engineering design of chemical reactors. Instructor: Corcoran.

ChE 80. Undergraduate Research. Research in chemical engineering and industrial chemistry offered as an elective in each of three terms. If ChE 80 units are to be used as electives in the Chemical Engineering Option a thesis must be submitted in duplicate before May 10 of the year of graduation and be approved by the research director. 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 may cover only a portion of the research.

ChE 81. Special Topics in Chemical Engineering. 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 as electives in the Chemical Engineering Option.

ADVANCED SUBJECTS

ChE 163 abc. Chemical Engineering Thermodynamics. *6 units (3-0-3) first, third terms; 4 units (2-0-2) second term.* This subject is the same as ChE 63 abc for third-year students, but with reduced credit for graduate students. No graduate credit is given for this subject to students in chemical engineering.

ChE 166 abc. Chemical Engineering Operations. *8 units (3-0-5); first, second, third terms. Prerequisite: ChE 63 abc.* This subject is the same as ChE 66 abc, but with reduced credit for graduate students. No graduate credit is given for this subject to students in chemical engineering.

ChE 167 abc. Chemical Engineering Laboratory. *15 units (0-15-0); first, second, third terms. Prerequisites: Ch 21 abc, ChE 61 ab, ChE 63 abc.* A laboratory course providing fundamental training in the methods and techniques of engineering measurements and in research encountered by the chemical engineer. Instructors: Sage, Richter.

ChE 168 ab. Mechanics of Fluid Flow. *9 units (2-0-7); second, third terms. Prerequisites: ChE 66 a, AM 95 ab, or taking AM 113 ab concurrently.* A study of the flow of fluids in situations of interest to chemical engineers, with emphasis on estimation of velocity and pressure distribution. Subjects include the conservation of momentum and the Navier-Stokes equations, boundary layer theory, turbulence, non-Newtonian fluids, and flow in porous media. Instructor: Longwell.

ChE 169. Advanced Industrial Chemistry. *9 units (2-0-7); first term. Prerequisites: ChE 61 ab, ChE 63 abc.* An extension of ChE 61 with emphasis on quantitative approaches to industrial chemical problems. Consideration is given to the more important chemical reactions of industrial interest. Chemical kinetics and material and energy balances are treated. Instructor: Corcoran.

ChE 170. Chemical Process Dynamics. *9 units (2-0-7); third term. Prerequisite: Ma 2 abc.* A treatment of automatic control of chemical processes with emphasis on theory and dynamic response. Instructor: Richter.

ChE 171 ab. Chemical Engineering Applied Mathematics. *9 units (2-0-7); first, second terms. Prerequisite: AM 95 ab.* Handling and interpretation of data including elementary statistical treatment, Laplace transforms and other methods of solution of linear partial differential equations, numerical solution of ordinary and partial differential equations, calculus of finite differences. Instructor: Longwell.

ChE 172. Heat Transfer. *9 units (2-0-7); third term. Prerequisite: ChE 66 abc.* Detailed consideration of problems in thermal transfer. Instructor: Sage or Corcoran.

ChE 175 ab. Chemical Process Development. *9 units (0-0-9); two terms, by arrangement with instructor. Prerequisites: ChE 61 ab, ChE 66 abc.* Application of chemical engineering and related economic principles involved in process development, equipment selection and plant design. Through regular consultation with the instructor, the student will select a chemical compound or product and carry out a comprehensive investigation leading to a detailed report which will include the elements of a technical business problem in the chemical industry. Instructor: Manning.

ChE 262 abc. Thermodynamics of Multi-Component Systems. *9 units (2-0-7); first, second, third terms. Prerequisites: ChE 61 ab, ChE 63 abc, AM 95 ab, or taking AM 113 ab concurrently.* A presentation of the background necessary for a working knowledge of multi-component open systems from the engineering viewpoint. A discussion of the volumetric and phase behavior of pure substances, and of binary, ternary, and multi-component fluid systems at physical and chemical equilibrium is included as a part of this thermodynamic treatment. The solution of numerous problems relating to the application of these principles to industrial practice constitutes a part of this course. Texts: *Volumetric and Phase Behavior of Hydrocarbons,* Sage and Lacey; *Thermodynamics and Multi-Component Systems,* Sage and Lacey. Instructor: Sage.

ChE 263 abc. Transfers in Fluid Systems. *12 units (2-0-10); first, second, third terms. Prerequisites: ChE 66 abc, ChE 168 ab, AM 95 ab, or taking AM 113 ab concurrently.* A consideration of thermal and material transfers in fluid systems under conditions encountered in practice. Emphasis is placed upon point conditions and upon the analogies between momentum, thermal, and material transfers in turbulent flow. The greater part of the effort in the course is devoted to the solution of transfer problems, many of which require the use of graphical or numerical methods for solution of the differential equations involved. Given in alternate years. Offered in 1961-62. Instructor: Sage.

ChE 266 abc. Applied Chemical Kinetics. *9 units (2-0-7); first, second, third terms. Prerequisite: ChE 66 abc.* Both homogeneous and heterogeneous kinetics are studied. Design of various types of reactors is treated on the basis of the associated phenomena of material, energy and momentum transfer. In the third term an extended problem in the design of a chemical reactor wherein there is simultaneous energy, material and momentum transfer is considered, and the Datatron 220 digital computer is used in the solution of the problem. Given in alternate years. Offered in 1962-63. Instructor: Corcoran.

ChE 280. Chemical Engineering Research. Offered to Ph.D. candidates in Chemical Engineering. The main lines of research now in progress are:

Influence of turbulence upon heat transfer in fluids.
Influence of turbulence on the transfer of material through fluids.
Phase and thermodynamic behavior of hydrocarbons and others fluids.
Studies of non-equilibrium behavior of fluid systems at elevated pressure.
Reaction kinetics in flow and non-flow systems.
Study of gas chromatography in analytical chemistry and mass transfer.
Application of mathematics to complex chemical engineering problems.
Liquid state physics.
Chemical thermodynamics.
Thermodynamics of irreversible processes.

ChE 291 abc. Chemical Engineering Conference. *2 units (1-0-1); first, second, third terms.* Oral presentations on industrial chemistry and chemical engineering problems of current interest. Instructor: Corcoran.

CHEMISTRY

UNDERGRADUATE SUBJECTS

Ch 1 abc. General and Quantitative Chemistry. *12 units (3-6-3); first, second, third terms.* Lectures, recitations, and laboratory exercises dealing with the general principles of chemistry. Fundamental laws and theories of chemistry are discussed and illustrated by factual material. In the first and second terms of the laboratory analytical experiments involving quantitative gravimetric, volumetric, optical, and electrical measurements are provided; in the third term use is made of a system of qualitative and semiquantitative analysis for selected elements representative of the periodic system. The stress in the course is on quantitative reasoning and on accurate and intelligent work in the laboratory. Texts: *General Chemistry,* Pauling; *Quantitative Chemistry,* Waser; and *Qualitative Elemental Analysis,* Swift and Schaefer. Instructors: Waser, Schaefer, other staff members, and assistants.

Ch 13 abc. Inorganic Chemistry. *6 units (2-0-4); first, second, third terms. Prerequisites: Ch 1 abc, Ch 21 ab.* The chemical and physical properties of the elements are discussed with reference to the periodic system and from the viewpoints of atomic structure and radiation effects. Such topics as coordination compounds, the liquid ammonia system, the compounds of nitrogen, the halides, and selected groups of metals are taken up in some detail. The class work is supplemented by problems which require a study of current literature. Instructor: Yost.

Ch 14. Quantitative Analysis. *10 units (2-6-2); first term. Prerequisite: Ch 1 abc or equivalent.* Laboratory instruction in advanced analytical chemical measurements, supplemented by lectures in which the principles involved in the laboratory work are emphasized. Text: *Chemical Analysis,* Laitinen. Instructors: Anson, Swift.

Ch 16. Instrumental Analysis. *8 units (0-6-2); first term. Prerequisite: Ch 1 abc.* Laboratory practice designed to familiarize the student with special analytical apparatus and methods, used both for process and control and for research. Instructor: Sturdivant.

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 the principles of thermodynamics, statistical mechanics, and atomic theory, and their application to the quantitative interpretation of the properties of matter. Instructor: Robinson.

Ch 24 ab. Physical Chemistry for Geologists. *10 units (4-0-6); first, second terms. Prerequisites: Ch 1 abc; Ma 2 abc; Ph 2 abc.* A discussion of selected topics in physical chemistry, adapted to the needs of Science Course students in the Geology Option. Instructor: Hughes.

Ch 26 ab. Physical Chemistry Laboratory. *8 units (0-6-2); second, third terms. Prerequisites: Ch 1 abc; Ch 21 a.* Text: *Experiments in Physical Chemistry,* Badger. Instructor: Badger.

Ch 41 abc. Basic Organic Chemistry. *4 units (2-0-2); first, second, third terms. Prerequisite: Ch 1 abc.* Lectures and recitations relating to the classification of carbon compounds, development of fundamental theories, and preparation and characteristic properties of the principal classes of carbon compounds. Text: *Basic Principles of Organic Chemistry,* Roberts and Caserio. Instructor: Roberts.

Ch 46 abc. Basic Organic Chemistry Laboratory. *6 units (1-5-0); first, second, third terms. Prerequisite: Ch 1 abc.* Laboratory exercises to accompany Ch 41 abc. The preparation and purification of carbon compounds and the study of their characteristic properties. Qualified students may pursue research work. Instructors: Richards 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 must be submitted in duplicate before May 10 of the year of graduation and be approved by the research director. The thesis must contain a statement of the problems, appropriate background material, a description of the research work, a discussion of the results, conclusions, and an abstract. The thesis may cover only a portion of the research.

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. Instructors: Corey, Booth.

ADVANCED SUBJECTS

Ch 113 abc. Inorganic Chemistry. *4 units (2-0-2); first, second, third terms.* Selected groups of inorganic compounds will be considered from modern physicochemical viewpoints; thus with reference to their physical properties, their thermodynamic constants (their heat-contents, free-energies, and entropies), their rates of conversion into one another (including effects of catalysis and energy radiations), and their molecular structure and valence relations. Instructor: Yost.

Ch 117. Electroanalytical Chemistry. *4 units (2-0-2); second term.* The theory and practice of selected electroanalytical techniques are presented. Topics covered include potentiometry, diffusion currents, polarography, amperometry, coulometry, chronopotentiometry, and other electrochemical methods. Text: *Electroanalytical Chemistry,* Lingane. Instructor: Anson.

Ch 118 ab. Electroanalytical Chemistry Laboratory. *6 units (0-6-0); second, third terms.* Laboratory experiments involving the use of electroanalytical instruments. Instructor: Anson.

Ch 120. Electric and Magnetic Properties of Molecules. *6 units (2-0-4); third term.* Topics discussed are index of refraction and birefringence of substances, electronic polarizability of molecules, dielectric constant, diamagnetism, paramagnetism, ferromagnetism, ferrimagnetism, antiferromagnetism, Kerr effect, electric dipole moments, magnetic moments, and other molecular properties, especially in relation to the structure of molecules and crystals and the nature of the chemical bond. Offered in 1962-63. Instructor: Pauling.

Ch 121 ab. The Nature of the Chemical Bond. *6 units (2-0-4); second, third terms.* This subject comprises the detailed non-mathematical discussion of the electronic structure of molecules and its correlation with the chemical and physical properties of substances. Text: *The Nature of the Chemical Bond,* Pauling. Instructors: Pauling and others.

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: *The Nature of the Chemical Bond,* Pauling. Given in alternate years. Offered in 1962-63. Instructor: Marsh.

Ch 124 ab. Physical Chemistry for Geologists. *6 units (4-0-2); first, second terms.* This course is the same as Ch 24 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 brief but quantitative introduction to quantum mechanics, and is otherwise devoted primarily to both theoretical and experimental aspects of the electronic wave functions of molecules and solids. Illustrative topics are: molecular orbital and valence bond theories of molecules, Bloch states in solids, and applications of electron and nuclear magnetic resonance to electronic structure problems. Instructor: McConnell.

Ch 127 abc. Radioactivity and Isotopes. *6 units (2-0-4); first, second, third terms.* The fundamental particles and isotopes. Nuclear structure. Natural and artificial radioactivity. Instrumentation in nuclear studies. Techniques of radiochemistry. The applications of stable and radioactive isotopes to various chemical studies. Instructor: Yost.

Ch 128 ab. Electronic Structure of Molecules. *6 units (2-0-4); second, third terms. Prerequisite: Ch 21 abc.* Molecular electronic structure is treated with particular reference to chemical and geometric properties of molecules and the variation of these properties with electronic excitation. An elementary introduction to group theoretical methods in molecular problems is presented. A generally descriptive treatment follows of the electronic structure of organic and inorganic prototype molecules, free radicals, and ions, starting from the molecular orbital and valence bond approximations. The nature and chemical importance of the coupling of electronic motions with other kinds of molecular motions are stressed, and a discussion of inter-molecular interactions is given. Given in alternate years. Not offered in 1961-62. Instructor: Robinson.

Ch 129. Surface and Colloid Chemistry. *8 units (3-0-5); first term. Prerequisite: Ch 21 abc or equivalent.* Classroom exercises with outside reading and problems, devoted to the properties of surfaces and interfaces, and the general principles relating to disperse systems with particular reference to the colloidal state. Instructor: Badger.

Ch 130. Photochemistry. *6 units (2-0-4); first term. Prerequisite: Ch 21 abc.* Lectures and discussions on photochemical processes, especially in their relation to quantum phenomena. The following topics are included: the photochemical absorption law; the processes—excitation, dissociation, ionization—accompanying the absorption of radiation; subsequent processes including fluorescence and collisions of the second kind; photosensitization; quantum yield and its relation to photochemical mechanism; kinetics of homogeneous thermal and photochemical reactions; catalysis and inhibition; temperature coefficients of photochemical reactions. Instructor: Wulf.

Ch 132 a. Biophysical Chemistry. *6 units (2-0-4); third term.* This course considers the physical chemistry of macromolecules of biological interest. Together with Bi 129 ab it constitutes an integrated program covering the physical and physico-chemical approaches to biology. The subject matter to be repeated, approximately in a three-year cycle, will consist of a discussion of the principles and methods employed in the determination of size, shape, charge, and thermodynamic properties of biological macromolecules. Not offered in 1962-63. Instructor: Vinograd.

Ch 135. Chemical Kinetics. *6 units (2-0-4); third term.* The mechanics of chemical reactions as revealed by various methods, especially rate measurements and photochemical experiments, are discussed. Both theoretical and experimental aspects of the subject are studied. Topics include the transition state theory and the collision theory, unimolecular reactions, ionic reactions, modern experimental approaches to the nature of transient intermediates and elementary reactions, molecular structure and reactivity, catalysis, tracer studies, hydrodynamics and kinetics, combustion and detonation. Not offered in 1962-63. Instructor: Davidson.

Ch 144 abc. Advanced Organic Chemistry. *9 units (3-0-6); first, second, third terms.* A survey of synthetic and theoretical organic chemistry at an advanced level with emphasis on stereochemistry. Applications of fundamental principles to the chemistry of naturally occurring substances. Instructor: Hammond.

Ch 148 abc. Characterization of Organic Compounds. *4 units (2-0-2); first, second, third terms. Prerequisites: Ch 41 abc, Ch 46 abc.* Lectures and recitations emphasizing the analytical methods of organic chemistry. Consideration of the general problem of the characterization of organic compounds by qualitative and quantitative procedures. Instructor: Niemann.

Ch 149 abc. Laboratory in Characterization of Organic Compounds. *6 units (0-6-0); first, second, third terms. Prerequisites: Ch 41 abc, Ch 46 abc, and consent of instructor.* Laboratory exercises to accompany Ch 148. The isolation, purification, and identification of organic compounds with special reference to the manipulation of milligram and decigram quantities. Qualified students may pursue research work. Instructors: Niemann and assistant.

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. Instructors: Waser, Corey, Booth.

Ch 223 abc. Statistical Mechanics. *9 units (3-0-6); first, second, third terms.* After a survey of the principles of classical and quantum mechanics and of the theory of probability, the equilibrium theory of statistical mechanics is developed and used to interpret the laws of thermodynamics from the molecular standpoint. A detailed study of the relationships between the thermodynamic functions of gases, liquids, and solids and their structure on the molecular scale follows. Given in alternate years. Not offered in 1962-63. Instructor: Davidson.

Ch 225 abc. Advanced Chemical Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or the 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.

Ch 226 abc. Introduction to Quantum Mechanics, with Chemical Applications. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 125 abc, or Ph 112 abc, or the equivalent.* A review of the physical and historical background of the quantum theory is followed by a treatment of the mathematical formalism. Some exactly soluble problems are discussed and approximate methods for more complicated problems are developed. The structure of atoms and molecules, the theory of spectra, and if time permits other special topics will be treated.

Ch 227 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. Offered in 1961-62. Instructor: Sturdivant.

Ch 229 ab. X-Ray Diffraction Methods. *6 units (2-0-4); second, third terms. Prerequisite: Ch 227 abc or equivalent.* An advanced discussion of the techniques of structure analysis by X-ray diffraction. Given in alternate years. Offered in 1962-63. Instructors: Hughes, Marsh.

Ch 233 ab. The Metallic State. *6 units (2-0-4); first, second terms.* The physical, electrical, and magnetic as well as the structural, chemical, and thermodynamic properties of metals and alloys considered from modern viewpoints. Instructor: Yost.

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. Instructor: Badger.

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. The course is given as a continuing cycle such that each of the major areas is presented once every three years. Instructor: Richards.

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 1962-63. Instructor: Roberts.

Ch 247 ab. Organic Reaction Mechanisms. *6 units (2-0-4); first, second terms. Prerequisite: Ch 144 or equivalent.* Various tools for the study of organic reaction mechanisms will be discussed with major emphasis on kinetic methods. Given in alternate years. Offered in 1962-63. 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. Offered in 1962-63. Instructor: Niemann.

Ch 254 ab. The Chemistry of Amino Acids and Proteins. *3 units (1-0-2); first, second terms. Prerequisites: Ch 41 abc, Ch 46 abc.* A consideration of the physical and chemical properties of the amino acids, peptides, and proteins. Given in alternate years. Offered in 1961-62. Instructor: Niemann.

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. Instructor: Haagen-Smit.

Ch 258. Immunochemistry. *8 units (2-3-3); second term. Prerequisite: Ch 129 and Bi 114, or consent of instructor.* Lectures cover the following material: fundamental physical and biochemical factors of importance in immunochemistry; nature of antigens and antibodies; physical and biological manifestations of antigen-antibody reactions; basis of immunological specificity; and practical aspects of immunology. The laboratory consists of a variety of experiments designed essentially to familiarize the student with the preparation of antigens and antibodies and the nature of antigen-antibody interactions. Particular emphasis is given to quantitative aspects of the precipitin reaction and its significance. Texts: *Principles of Immunology,* Cushing and Campbell; *Experimental Immunochemistry,* Kabat and Mayer; *Fundamentals of Immunology,* Boyd. Instructors: Campbell and associates.

Ch 280. Chemical Research. *Offered to Ph.D. candidates in Chemistry.* The main lines of research now in progress are:

In physical and inorganic chemistry—
- Free energies, equilibria, and electrode potentials of reactions.
- Distribution of chemical compounds between immiscible phases.
- Kinetics and mechanisms of electrode reactions. Inorganic analytical methods.
- Kinetics of chemical reactions including photochemical reactions.
- 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.
- Electronic structures of simple molecules and molecular fragments.
- Spectroscopic studies of the chemistry of free radicals trapped at low temperatures.

In organic chemistry—
- Mechanism of organic reactions in relation to electronic theory.
- Isolation of alkaloids and determination of their structure.
- Structural elucidation and biosynthesis of natural products.
- Chemistry and reaction mechanisms of metallocenes.
- Isotope effects in organic and biochemical reactions.
- Synthesis of substances related to cyclobutadiene.
- Chemistry of amino acids and peptides.
- Chemistry of small-ring carbon compounds.
- Application of isotopic tracer and nuclear magnetic resonance techniques to problems in organic chemistry.
- 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.
- Enzymatic cleavage and formation of amide bonds.
- Chemical analysis of proteins and determination of the order of amino-acid residues in polypeptide chains.
- 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.
Nature of sickle cell anemia and other hemolytic diseases.
Behavior of biological macromolecules in the ultracentrifuge.
Chemistry in relation to mental disease.

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, physical chemistry, organic 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 8 and AM 9 (may be taken concurrently).* 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. Instructor: McCormick.

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. Instructor: Staff.

ADVANCED SUBJECTS

CE 105. Introduction to Soil Mechanics. *9 units (2-3-4); first term. Prerequisites: AM 8, AM 9.* 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. Instructor: Scott.

CE 120 ab. Advanced Structural Analysis. *9 units (3-0-6); first and second terms. Prerequisite: CE 10 or equivalent.* Advanced methods of structural analysis, including the solution of differential equations, energy methods, moment distribution and relaxation methods, finite difference and numerical methods, applied to special structures such as elastic and plastic frames, unstable columns and frames, suspension bridges, arches, prismatic shells. Instructors: Housner, McCormick.

CE 121. Analysis and Design of Structural Systems. *9 units (0-9-0); third term. Prerequisite: CE 120 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: Housner, McCormick.

CE 123. Dynamics of Structures. *9 units (3-0-6); third term. Prerequisites: AM 150 ab, CE 120.* Analysis of structures and their response to dynamic loads such as blast and earthquakes. Consideration will be given to both elastic and plastic deformations. Instructor: Housner.

CE 124. Special Problems in Structures. *9 units (3-0-6); any term.* Selected topics in the field of structures to meet the needs of first-year graduate students. Instructors: Housner, McCormick.

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 137 abc. Water Supply and Waste Water Disposal. *9 units (3-0-6), first term; 9 units (3-0-6), second term; 9 units (1-6-2), third term. Prerequisites: ME 17 ab, ME 19 ab or equivalent, CE 155 (may be taken concurrently).* A study of the principles involved in the collection, storage, treatment, and distribution of water for municipal, industrial, and irrigation use, and the removal of storm waters, municipal sewage, and excess irrigation waters; water rights and stream administration; water quality criteria; the economic aspects of projects; the theory of unit operations as applied to the treatment of water and waste water; and the design of works for the collection, treatment, and disposal of water and liquid wastes. Instructors: McKee, Samples.

CE 138 abc. Sanitary Sciences. *9 units (2-3-4); first, second and third terms. Prerequisites: Ch 1 abc, Ph 2 abc.* A review of chemical, physical, and biological phenomena and their application to the analysis and treatment of water, waste waters, and polluted atmospheres; laboratory exercises and problems in water and air analysis. Instructors: Johansson, Samples.

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 151 abc. Air Resources Engineering. *9 units (2-3-4); first, second, and third terms. Prerequisites: Ch 1 abc, Ph 2 abc, Ma 2 abc, ME 17 ab, ME 19 ab.* The application of engineering analysis and scientific phenomena to problems of atmospheric pollution; evaluations of source emissions, meteorologic and climatologic factors, air quality measurements, aerosol properties and behavior, photochemical reactions, effects on animate and inanimate receptors; and principles of engineering control. Study of hazardous conditions in work places. The advanced courses comprise aerosol technology, special methods of air analysis, air and gas cleaning, field survey techniques, administrative and legal aspects, public health implications, and studies of selected occupational exposures. Instructor: Rossano and visiting lecturers.

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: Rossano.

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. Instructor: Rossano and visiting lecturers.

CE 155. Hydrology. *9 units (3-0-6); first term. Prerequisites. Ma 2 abc, Ph 2 abc.* An introductory study of the occurrence and movement of water on the earth's surface, including such topics as precipitation, evaporation, transpiration, infiltration, ground water, runoff, and flood flows; applications to various phases of hydraulic engineering such as water supply, irrigation, water power, and flood control; the use of statistical methods in analyzing hydrologic data. Instructor: Brooks.

CE 156. Industrial Wastes. *9 units (3-0-6); third term. Prerequisites: CE 137 ab, CE 138 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. Instructors: McKee, Samples.

CE 160. Advanced Hydrology. *6 or more units as arranged; any term. Prerequisite: CE 155.* 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 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.

CE 204. Advanced Work in Water Resources.

Hy 200. Advanced Work in Hydrodynamics or Hydraulic Engineering.

CE 300. Civil Engineering Research.

Computers and Machine Methods of Computation

The following courses in computers and their application to applied mathematics and engineering analysis are offered under the various options indicated.

EE 180. Digital Computer Design. See Electrical Engineering Section for description.

EE 181 ab. Principles of Analog Computation. See Electrical Engineering Section.

EE 280 abc. Advanced Course in Machine Computing Methods for Engineering Analysis. See Electrical Engineering Section.

AM 180. Matrix Algebra. See Applied Mechanics Section.

Ma 105 ab. Introduction to Numerical Analysis. See Mathematics Section.

Ma 205. Advanced Topics in Numerical Analysis. See Mathematics Section.

Economics

UNDERGRADUATE SUBJECTS

Ec 4 ab. Economic Principles and Problems. *6 units (3-0-3); first term, and either second or third term.* A course in economic life, institutions, and problems, stressing the national income approach. Subjects studied parallel those of Ec 2 ab, with such difference in emphasis as is necessary to make this shorter course complete in itself. Instructors: Sweezy, Brockie, Untereiner, Sherman.

Ec 13. Reading in Economics. *Units to be determined for the individual by the department.*

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 25. Business Law. *7 units (3-0-4); third term.* A survey of the law governing business activities and relationships. Contracts, agency, sales, insurance, negotiable instruments, employment, property rights, trusts and estates, and forms of business organization are studied. Instructor: Untereiner.

Ec 48. Introduction to Industrial Relations.* *9 units (3-0-6). Senior Elective.* 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.

ADVANCED SUBJECTS**

Ec 100 abc. Business Economics. *10 units (4-0-6); 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 fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**Advanced students in Economics should be aware that AM 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.

the courses are: 1) business organization, 2) industrial promotion and finance, 3) factory management, 4) industrial sales, 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.

Ec 104. Government Regulation. *9 units (3-0-6); third term.* A study of government's growing role in the functioning of the private business system. Conditions leading to, and objectives sought by regulation of competition, quality and price. The evolution and functioning of a "mixed" economy. Emphasis on public utilities: methods and objectives of their regulation and problems of determining rate base, reasonable return and spread of rates. Instructor: Untereiner.

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); first 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. May be taken as a senior elective. Instructor: Brockie.

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: Brockie.

Ec 113. Reading in Economics. *Same as Ec 13 but for graduate credit.*

Ec 120. International Economic Relations. *9 units (3-0-6); second term; Senior elective.* An investigation of the factors influencing the flow of goods and services between markets. Particular attention is paid to the techniques of exporting and importing, foreign investments, the balance of international payments, foreign exchange rates and controls, international monetary and commodity agreements, and the international inter-relationships of politics and economics. Open to all students who have taken Ec 4 ab or the equivalent. Instructor: Oliver.

Ec 124. Economic Problems of Underdeveloped Areas.* *9 units (3-0-6); third term. Senior elective.* An examination of economic conditions in low income countries. Modern

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

techniques of promoting development are studied, including international assistance programs and national economic planning. Instructor: Sweezy.

Ec 125 abc. Technical Cooperation (Seminar). *9 units (3-0-6). Senior elective.* This special seminar will be conducted experimentally during the year 1961-1962 as a part of the Carnegie Science and Public Affairs program. The primary objectives of the seminar are to prepare students for participation in technical cooperation programs, both in the United States and overseas, and to provide an opportunity for an intensive examination of the technical problems of raising living standards in newly developing countries. Guest lecturers and faculty from other divisions will participate in the seminar. Research projects will be undertaken by the students. Instructor: Oliver.

Ec 126 abc. Economic Analysis and Policy* (Seminar). *9 units (3-0-6); first, second, third term. Senior elective.* Open to students who have taken Ec 2 ab or Ec 4 ab and to other qualified students with the consent of the instructor: Instructors: Sweezy, Sherman.

Electrical Engineering

Undergraduate Subjects

EE 1 abc. Basic Electrical Engineering. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc; Ph 1 abc.* An introductory course in circuit analysis, energy conversion, electromechanical devices, vacuum and solid-state devices and circuits. Instructor: Nicolet.

EE 2 ab. Basic Electrical Engineering Laboratory.

EE 2 a. Laboratory in Electrical Circuits. *3 units (0-3-0); second term. Prerequisite: EE 1 a.* This course is the laboratory for EE 1 a. The experiments are designed to acquaint the student with techniques of electrical measurements and to provide experimental verification of the behavior of passive electrical circuits. Instructors: Staff.

EE 2 b. Laboratory in Electronics. *3 units (0-3-0); third term. Prerequisites: EE 1 ab, EE 2 a.* This course is the laboratory for EE 1 b. The experiments are designed to acquaint the student with techniques of electrical measurements and to provide experimental verification of the properties of electron devices and simple electronic circuits. Instructor: Nicolet.

EE 5. Introductory Electronics. *9 units (3-0-6); third term. Prerequisite: Ph 1 abc.* 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 amplifiers and switching circuits. Instructor: Langmuir.

EE 7 abc. Experimental Techniques in Electrical Engineering. *5 units (0-3-2); first, second, third terms.* A general laboratory program developing experimental techniques, and verifying the theory of the five senior engineering courses (EE 101, EE 106, EE 107, EE 115 and EE 162). Text: Laboratory notes. Instructors: Electrical Engineering Faculty.

Advanced Subjects

EE 101 abc. Electric Circuit Theory. *9 units (3-0-6); first, second and third terms. Prerequisites: EE 1 abc; AM 116.* Steady state and transient analysis of linear electric

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

circuits. Application of transform methods. Elementary principles of circuit synthesis, filter theory, classical transmission line theory. Instructor: Mason.

EE 106 ab. Electronic Circuits. *9 units (3-0-6); first and second terms. Prerequisite: EE 1 abc.* A course covering the general areas of nonlinear electronics. Diode circuits, rectifiers, clippers, clamps, mixers. Transistor and vacuum tube amplifiers treated from the equivalent circuit point of view; biasing, gain, frequency response, class A, B and C power output and limitations. Transistor switching, saturation, power converters, transistor choppers, direct coupled transistor logic. Oscillators; relaxation and harmonic, using 3 terminal and negative resistance devices. Modulation (AM and FM) methods. Texts: *Transistor Circuit Analysis,* Joyce and Clarke; *Electronic and Radio Engineering,* Terman. Instructor: Mead.

EE 107. Principles of Feedback. *9 units (3-0-6); third term. Prerequisite: EE 101 ab.* Basic principles of linear feedback theory. Automatic control systems, feedback amplifiers, oscillators. Instructor: Wilts.

EE 115 abc. Electromagnetism. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc; Ma 2 abc; AM 95 a, b.* A course in theoretical electricity and magnetism, primarily for electrical engineering students. Topics covered include electrostatics, magnetostatics, Maxwell's equations, wave-guides, cavity resonators, and antennas. EE 115 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 132 abc. Network Synthesis. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 101 ab.* The analysis and synthesis of lumped and distributed parameter circuits. Mathematical properties of network functions. Realization theory for driving-point and transfer functions, including the synthesis techniques of Bode, Brune, Cauer, Darlington, Foster, Guillemin and others. The approximation problem, the scattering matrix, the Deschamps chart, and selected topics of research importance. Text: *Synthesis of Passive Networks,* Guillemin; *Principles of Microwave Circuits,* Montgomery et al. Instructor: George.

EE 140 abc. Communication Theory. *9 units (3-0-6); first, second, third terms. Prerequisites: EE 101 ab.* Modern basis of the theory of communication of information. Review of probability and statistical methods. Noise, its description, properties and effects; random time series; autocorrelation and cross-correlation functions; spectral density; physical origins and mathematical models of noise; effects of linear and non-linear circuits. Information theory; entropy of a source and channel capacity; equivocation and redundancy; coding theorems; error detecting and correcting codes; continuous information; modulation methods–AM, FM, PM, PCM. Optimum linear circuits (Wiener filters) for smoothing or prediction of statistical signals in noise. Text: *Random Signals & Noise,* Davenport and Root. Instructor: H. Martel.

EE 150 abc. Electromagnetic Fields. *9 units (3-0-6); first, second, third terms. Prerequisites: EE 115 ab or Ph 107.* 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 abc. Physics of Electronic Devices. *6 units (2-0-4); first, second, third terms. Prerequisite: EE 1 ab.* A course in the physical principles of electron devices and an introduction to atomic and molecular physics. Motion of charged particles in electric and magnetic fields and applications. Electronic phenomena in metals; conduction, emission, contact potential. Electrical conduction in gases; breakdown, plasmas, gas tubes. Electronic phenomena in semiconductors; transistors. Instructor: Gould.

EE 164 abc. Microwave Electronics and Magnetics. *9 units (3-0-6); first, second, third terms. Prerequisites: EE 115 ab or Ph 107 and EE 162 abc.* Principles of interaction between the electronic charge and spin with microwave electromagnetic fields. Generation and focusing of high-current electron beams with electric and magnetic fields. Velocity modulation, transit time effects, plasma oscillation and space charge wave propagation, and traveling wave interaction with electron beams with application to microwave amplifiers and oscillators. The electromagnetic theory of slow-wave circuits and noise in electron beams will also be considered. Electron spin resonance and relaxation phenomena will be discussed. The interaction of electromagnetic fields with magnetic materials with application to the behavior of quantum amplifiers such as Masers and Lasers, microwave ferrite devices, and thin magnetic films will be treated in detail. Instructor: Soohoo.

EE 165. Microwave Laboratory. *6 units (1-3-2); second term. Prerequisite: EE 132 or EE 150 or may be taken concurrently.* Covering experiments on microwave generation, bridges, precise impedance measurement, nodal shift methods, and the properties of microwave circuit elements such as matched T's, directional couplers and antennas. Instructor: George.

EE 170 abc. Feedback Control Systems. *9 units (3-0-6); first term; 12 units (3-3-6); second and third terms. Prerequisites: EE 101 ab, EE 107.* A study of automatic feedback control systems. Basic theory and methods of analysis and synthesis; root locus methods, the Nyquist criterion, and analog computer techniques. Multiple loop systems. Non-linear systems with emphasis on phase plane and describing function techniques. Sampled-data systems. The laboratory experiments are designed to acquaint the student with characteristics of practical components, but emphasis is placed on a correlation of observed response with predictions based on the various theoretical methods.

EE 171 abc. Sampled-Data Systems. *6 units (2-0-4). Prerequisites: EE 170, AM 116.* A study of feedback systems which operate on pulsed-data. The analysis of sampled-data systems using the z-transform and the modified z-transform; root locus techniques and frequency response of sampled-data systems; difference equations applied to sampled-data systems. Compensation by discrete and continuous networks. The synthesis of optimum discrete systems using statistical techniques. Selected topics on non-linear sampled-data systems. Text: *Sampled-Data Control Systems,* Jury. To be offered in alternate years. Not offered in 1962-63.

EE 180 abc. Data Processing Systems and Switching Theory. *EE 180 a, 9 units (3-3-3); EE 180 bc, 9 units (3-0-6).* The first term is concerned with the basic principles of logical design and instrumentation of digital computers with an introduction to modern switching theory, pulse circuitry, and electronic instrumentation principles. The laboratory permits a study of the design and operating characteristics of the actual computers. The second and third terms are a more detailed treatment of switching theory and switching circuit synthesis as applied to modern concepts of instrumenting complex data processing systems, together with more advanced concepts of machine organization for data processing. Text: *Logical Design of Digital Computers,* Phister (first term); course notes (second and third terms). Instructor: Miller.

EE 181 ab. Principles of Analog Computation. *12 units (3-3-6); second, third terms. Prerequisite: AM 180.* General survey of the basic principles of electric analog computing techniques. Development and application of electronic differential analyzer and direct analogy principles. Synthesis of passive analogies—lumped parameter systems. Synthesis of passive analogies—distributed systems. Synthesis of active circuit analogies. Applications to solid mechanics, aeroelasticity, heat transfer, fluid mechanics, servomechanisms. Text: Course notes. Instructor: McCann.

EE 190 abc. Advanced Electronics. *9 units (3-0-6); first, second, third terms.* An integrated treatment of the theory and application of vacuum and solid-state electronic devices. 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 vacuum and semiconductor triodes, and their static and incremental models. Design of bias networks. Practical design of feedback and d-c amplifiers. Instructor: Middlebrook.

EE 191 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 filter, band theory of crystal electrons, holes, semiconductors, theory of p-n junctions and p-n junction transistors. Instructor: Nicolet. (Second or third term only in 1962-63.)

EE 200. 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. The Institute is equipped to an unusual degree for the following lines of work: electronic devices and their application, physical electronics, microwave tubes, transistor applications, electromechanical devices, control systems, communications and information theory, electromagnetic wave propagation and antennas, analog and digital computers, engineering analysis requiring large scale computing techniques.

EE 220. Research Seminar in Electrical Engineering. *2 units.* Meets once a week for discussion of work appearing in the literature and in industry. All advanced students in electrical engineering and members of the electrical engineering staff are expected to take part. In charge: Staff.

EE 240 abc. Advanced Communication Theory. *9 units (3-0-6). Prerequisite: EE 140 abc.* A continuation of EE 140 with a more detailed treatment of stochastic processes, random time series, information theory and optimum linear filters. Emphasis will be on recent developments in the field. Course content will vary. Instructor: H. Martel.

EE 250 abc. Boundary-Value Problems of Electromagnetic Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 150 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 260 abc. Topics in Physical Electronics. *4 units (1-0-3); first, second, and third terms. Prerequisite: EE 164 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. Instructor: Gould.

EE 280 abc. Advanced Course in Machine Computing Methods for Engineering Analysis. *9 units (2-3-4); first, second, third terms.* The application of analog and digital methods to problems in engineering analysis. Specific system and design analysis problems in such fields as electricity and magnetism, solid mechanics, fluid mechanics, aeroelasticity and thermal conductivity will be solved by both analog and digital methods with the comparison of various machine computing techniques. Course open only to advanced graduate students and by permission of instructor. Instructors: Franklin, McCann.

EE 281 Seminar in Electronic Computers. *4 units (1-0-3); first, second, third terms.* Special topics on new developments in digital and analog computers and their applications to engineering analysis. Instructor: McCann.

EE 290. Topics in Solid State Devices and Circuits. *5 units (1-0-4); third term. Prerequisite: EE 190 ab.* Advanced seminar in solid-state devices and circuits. A term paper will be required. Instructors: Middlebrook, Nicolet.

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 7 ab. EE 7 ab must be taken concurrently with E 11 ab. Instructors: Staff.

E 150 abc. Engineering Seminar. *2 units (1-0-1); each term.* All candidates for the M.S. degree in 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, Kiceniuk.

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. Instructor: Welch.

Gr 7. Advanced Graphics. *Maximum of 6 units. Elective; second and third terms. Prerequisite: Gr 1.* Further study in the field of graphics as applied to engineering problem analysis and in design for production. Through a coordinated series of discussions, laboratory problems and field trips the student is introduced to work in various branches of engineering as well as to some of the broad aspects of human engineering, aesthetics and various economic factors as they affect design. Instructor: Welch.

ENGLISH

UNDERGRADUATE SUBJECTS

En 1 abc. Literature. *6 units (3-0-3); first, second, third terms.* A study of literary documents illustrating Rationalism, Romanticism and the Modern Reaction with frequent analytical and critical papers assigned. Instructors: Bowerman, Clark, Eagleson, Langston, Mandel, Stanton, D. Smith.

En 7 abc. Advanced Literature. *8 units (3-0-5); first, second, third terms. Prerequisite: En 1 abc.* Advanced study of major literary works in various forms. The reading of the first term is focused on tragedy and epic, the second term on Shakespeare and the third term on the novel. Instructors: Bowerman, Clark, Eagleson, Eaton, Langston, Mandel, Miller, D. Smith, Stanton.

En 8. Contemporary English and European Literature.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* A survey of English and Continental literature from 1859 to the present time. Emphasis is placed on the influence of science, particularly biological and psychological theory, on content and techniques. Instructor: Eagleson.

En 9. American Literature.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* A study of major literary figures in the United States from Whitman and Mark Twain to those of the present time. The larger part of the course is concerned with contemporary writers. An emphasis is placed on national characteristics and trends as reflected in novel and short story, biography, poetry, and drama. Instructor: Langston.

En 10. Modern Drama.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* A study of leading European, British, and American dramatists from Ibsen to writers of the present time. Special attention is given to dramatic technique, and to the plays both as types and as critical comments upon life in the late nineteenth and twentieth centuries. Instructor: Stanton.

En 11. Literature of the Bible.* *9 units (3-0-6). Senior Elective. 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. Instructor: Stanton.

En 12 abc. Debating. *4 units (2-0-2).* A study of the principles of argumentation; systematic practice in debating; preparation for intercollegiate debates.

En 13. Reading in English and History. *Units to be determined for the individual by the department.* 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.

En 14. Special Composition. *2 units (1-0-1).* This subject may be prescribed for any student whose work in composition, general or technical, is unsatisfactory.

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.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

En 16. Spelling. *No credit.* This subject may be prescribed for any student whose spelling is unsatisfactory.

En 17. Technical Report Writing.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* Practice in writing reports and articles in engineering, science, or business administration. The course includes some study of current technical and scientific periodicals. The major project is the preparation of a full-length report.

En 18. Modern Poetry.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* An 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 19. Seminar in Literature.* *9 units (3-0-6); second term. Senior Elective. Prerequisite: En 7.* The subject matter of this course arises from the interest of the students registered in any given term. Each student is required to give a long oral report to the class on some humanistic subject selected by himself with the approval of the instructor. The number registered for the course in any term is strictly limited and is by permission of the instructor. Hours by arrangement. Instructor: Eagleson.

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.

En 21. Literature an Art in 18th Century England.* *9 units (3-0-6). Senior Elective. Prerequisite, En 7.* Studies in the literature of the eighteenth century in the context of English creative activity in other arts, particularly architecture and painting. Reading, discussion, lectures with slides, and visits to the Huntington Library and Art Gallery. Instructor: Wark.

ADVANCED SUBJECTS

En 100 abc. Seminar in Literature. *9 units (2-0-7); first, second, third terms.* A survey of recent critical methods, from I. A. Richards to the present time, and the application of these methods to the work of such major writers as Joyce, Yeats, Eliot and Mann. The influence of modern psychology and anthropology on creative writing and criticism. Instructor: H. Smith.

FRENCH

(See under Languages)

GEOLOGICAL SCIENCES

UNDERGRADUATE SUBJECTS

Ge 1. Physical Geology. *9 units (4-2-3); first term. Prerequisites: Ch 1 abc, Ph 1 abc.* 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's crust. 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: Allen, Sharp, and Teaching Fellows.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

Ge 2. Geophysics. *9 units (3-0-6); second term. Prerequisites: Ge 1, Ma 2 ab, Ph 2 ab.* 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 3. Mineralogy. *9 units (3-3-3); second term. Prerequisites: Ge 1, Ch 1, Ph 1.* A study of the fundamental structure of minerals, rocks, and other earth materials and their behavior under the varying physical conditions of the earth's crust. Topics discussed include crystallography, stability relations of minerals, solid-state transformations, and mechanisms of material transfer with strong emphasis on the basic atomistic relations. This course is intended to provide fundamental information needed for subsequent studies in mineralogy, petrology, and structural geology. Instructor: Wasserburg.

Ge 5. Geobiology. *9 units (3-0-6); third term. Prerequisites: Ge 1, Ch 1, Bi 1.* 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. Instructors: Lowenstam, Brown.

Ge 30 ab. Introduction to Geochemistry. *6 units (2-0-4); first and second terms. Prerequisites: Ch 14, 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. Instructors: Epstein (Ge 30a); Brown (Ge 30b).

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.

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: Allen.

Ge 102. Oral Presentation. *1 unit (1-0-0); 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 the bachelor's, master's, and doctor's degrees in the Division. The number of terms taken will be determined by the proficiency shown in the first term's work. Offered in 1962-63. In charge: Sharp (first term).

Ge 103. Historical Geology. *9 units (2-2-5); second term. Prerequisite: Ge 1.* Distribution in time and space of stratified rocks; development of the biota since the beginning of the Cambrian; distribution of orogenies in time and space since the Precambrian; relation of major stratified rock types and orogenic areas to the Precambrian shields of the world. Instructor: Boucot.

Ge 104 a. Igneous Petrology. *8 units (3-3-2); first term. Prerequisite: Ge 3.* A study of the origin, occurrence, and classification of the igneous rocks, with training in the megascopic identification, description and interpretation of these rocks and their constituent minerals. Problems of genesis are considered mainly in the light of chemical equilibria and features of geologic occurrence. Instructor: Silver.

Ge 104 b. Sedimentary Petrology. *10 units (3-4-3); second term. Prerequisites: Ge 1, Ge 3.* A study of the origin, occurrence, and classification of the sedimentary rocks, training in the identification, description, and interpretation of these rocks, using megascopic methods and the binocular microscope; consideration of the chemical, physical, and biologic processes involved in the origin, transport, and deposition of sediments, and their subsequent diagenesis. Field trips supplement the laboratory study. Texts: *Sedimentary Rocks,* Pettijohn; *Principles of Geochemistry,* Mason. Instructor: Degens.

Ge 104 c. Metamorphic Petrology. *7 units (2-3-2); third term. Prerequisites: Ge 3, Ch 24 ab.* A study of the origin, occurrence, and classification of the principal metamorphic rocks, with training in the megascopic identification, description, and interpretation of these rocks. Emphasis is placed upon problems of genesis, which are viewed mainly in the light of chemical equilibria and features of geologic occurrence. Text: *Igneous and Metamorphic Petrology,* Turner and Verhoogen. Instructor: Taylor.

Ge 105. Optical Mineralogy. *12 units (2-8-2); first term. Prerequisite: Ge 3.* The principles of optical crystallography; training in the use of the petrographic microscope in identification of crystalline substances, especially natural minerals, both in thin section and as unmounted grains. Text: *Optical Crystallography,* Wahlstrom. Instructor: Kamb.

Ge 106 ab. Petrography. *9 units (2-6-1) second and third terms. Prerequisites: Ge 105, Ch 24 ab.* A systematic study of rocks and rock-forming minerals; training in the use of the petrographic microscope in the study of rocks; interpretation of mineral assemblages and textures; problems of genesis. Text: *Optical Mineralogy,* Kerr. Instructor: Albee.

Ge 108. Mathematical Techniques for Geologists. *6 units (3-0-3); first term.* A review of some of the mathematical methods used in formulating and solving geologic problems. The purpose of this course is to give new graduate students a reasonable proficiency with those mathematical techniques which will be used in advanced courses in the earth sciences. Instructor: Phinney.

Ge 109. Structural Geology. *6 units (1-3-2); first term. Prerequisites: Ge 1, Ge 2, Ge 3.* A problem course in the interpretation and description of geologic structures. Includes use of descriptive geometry and stereographic projection in solution of geologic problems; mechanical properties of rocks; geologic scale models. Instructor: Allen.

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 invertebrates groups; preparation of fossils and problems of invertebrate paleontology. Instructors: Lowenstam, Boucot.

Ge 120 abc. Field Geology. *10 units (4-5-1), first term; 10 units (0-8-2), second term; 10 units (0-6-4), third term. Prerequisites: Ge 1, Ge 3.* An introduction of the interpretation of geologic features in the field, and to the fundamental principles and techniques of geologic mapping. Classroom and field studies include the interpretation of geologic maps, megascopic investigation of rock types, the solution of field problems in structure and stratigraphy, geologic computations, and an introduction to the use of aerial photographs for field mapping. To these ends, small areas are mapped in great detail and reports are prepared in professional form. Text: *Field Geology,* Lahee. Instructors: Allen (120 a); Taylor (120 b); Degens (120 c).

Ge 121 abc. Advanced Field Geology. *14 units (4-8-2), first term; 10 units (0-8-2), second term; 11 units (0-5-6), third term. Prerequisites: Ge 3, Ge 120 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: Silver (121 a); Albee (121 b); Kamb (121 c).

Ge 123. Summer Field Geology. *30 units. Prerequisite: Ge 120 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 20 and Ge 121. The course begins the Monday following commencement (about June 12) and lasts for six weeks. It is required at the end of the junior year of candidates for the bachelor's degree in the geology and geochemistry options; of candidates for the Master of Science degree; 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,* Wood and Lane. 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. *Offered in 1963-64. Instructor: Sharp.*

Ge 130 ab. Introduction to Geochemistry. *4 units (2-0-2); first and second terms.* This subject is the same as Ge 30 ab, but with reduced credit for graduate students.

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.

Ge 150 g. 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. The lectures are given by members of the staff of the Division of the Geological Sciences. Staff members from other divisions and visiting lecturers from the outside also participate in the instruction. Students may enroll for any or all terms of this course without regard to sequence. Instructors: The staff and visitors.

Ge 151 a. 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 emission spectrograph, spectrophotometer, X-ray 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. In charge: Epstein.

Ge 151 b. Geophysical Investigations of Geological Field Relationships. *5 units (0-5-0); third term.* This course is designed to familiarize the student with various geophysical techniques and instruments that can be brought to bear on the investigation of diverse geological field problems. The course consists essentially of a series of field exercises, and should be of interest to both geologists and geophysicists. Instructors: Phinney and Smith.

Ge 165. General Geophysics. *6 units (3-0-3); third term.* A survey course in the physics of the earth. Among topics included are Seismology, Gravity, Terrestrial Magnetism, Thermal History of the Earth and Submarine Geophysics. Suitable for students in geology and as an elective in physics and engineering. Instructor: Press.

Ge 171. Applied Geophysics I. *10 units (4-2-4); second term.* The use of gravity, magnetic and seismic methods applied to geological field problems. Theoretical background and field practice. 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.

GEOLOGY

Ge 209. Sedimentary Petrology. *10 units (2-4-4); third term. Prerequisite: Ge 105.* A study of the processes and products of sedimentation in relation to their geologic environment. Emphasis is given to major lithologic facies and their interpretation. The laboratory work affords an introduction to techniques of sedimentary analysis. Occasional field trips. Instructor: Degens.

Ge 211 abc. Topics in Advanced Petrology. *15 units each term (4-4-7).* Integrated lecture, laboratory and seminar treatments of topics in igneous and metamorphic petrology and the mechanics of rock deformation at an advanced level. Laboratory and field studies will be pursued in close association with the classwork. Consideration of petrologic problems in terms of basic principles and modern investigative approaches will be emphasized.

211 a. Problems in igneous petrology: the origin, nature, distribution, and behavior of magmas and analogous chemical systems. Critical comparison of theoretical predictions and natural systems. *Prerequisites: Ge 106 ab, Ch 124 ab.* Instructor: Wasserburg.

211 b. Topics in metamorphic petrology, including the facies principle and the thermodynamic equilibrium of metamorphic mineral assemblages. These problems are attacked using the tools of thermodynamics, chemical kinetics and isotope geology, and are evaluated in terms of field evidence. *Prerequisites: Ge 211 a.* Instructor: Epstein.

Ge 211 c. Rock Deformation. Tensor analysis of stress and strain; deformation of single crystals; rock plasticity and creep; recrystallization; structural petrology and petrofabrics; theory of fracture; stress distribution and fault patterns; tectonic models. *Prerequisites: Ge 211 b and Ge 108 or Ph 108 abc.* Not offered in 1962-63. Instructors: Kamb and Allen.

Ge 213. Mineralogy-Petrology (Seminar). *5 units; second term. Prerequisite: Ge 211 ab.* Discussion of special problems and current literature related to the general provinces of mineralogy and petrology. Topics in such broad fields as crystal structure, mechanics of crystallization, geochemistry, techniques of mineral identification, and the origin of rocks and mineral deposits are selected for critical attention during the term, largely on the basis of trends of interests among members of the group.

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. Offered in 1962-63. Instructor: Sharp.

Ge 230. Geomorphology (Seminar). *5 units; third term.* Discussion of research and current literature in geomorphology. In charge: Sharp.

Ge 237. Tectonics. *8 units (3-0-5); third term.* Advanced structural and tectonic geology. Structure of some of the great mountain ranges; theories of origin of mountains; mechanics of crustal deformation; isotasy, continental drift, convection; fault-plane solutions. Offered in 1962-63. Instructors: Allen and Kamb.

Paleontology

Ge 244 ab. Paleoecology (Seminar). *5 units; second and third terms.* Critical review of classic investigations and current research in paleoecology and biogeochemistry. In charge: Lowenstam.

Ge 245. Biostratigraphy (Seminar). *5 units; first term.* 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. Instructor: Boucot.

Geophysics

Ge 261. Advanced Seismology: Theoretical. *6 units (3-0-3); first term. Prerequisite: Ph 108 abc.* Discusses essential material not covered in Ge 264 (Elastic Waves), including equations of electromagnetic seismographs and paths of seismic rays within the earth. Instructor: Richter.

Ge 264 ab. Elastic Waves. *8 units (4-0-4); first and second terms. Prerequisite: Ph 106 abc.* Experimental and theoretical aspects of elastic wave propagation in a layered half space, in plates, cylinders, and spheres, with application to seismic waves and underwater acoustics. Instructor: Press.

Ge 265 ab. Advanced General Geophysics. *9 units (3-0-6); second and third terms. Prerequisites: Ph 107 abc; Ph 108 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. Not offered in 1962-63. Instructors: Press and Knopoff.

Ge 268 ab. Selected Topics in Theoretical Geophysics. *6 units (3-0-3); second and third terms. Prerequisite: Ph 129 abc or equivalent.* Discussion of seismic wave propagation, gravitational and magnetic fields, stress systems, and general thermodynamics as applied to earth processes. Content of course is altered somewhat from year to year depending mainly upon student needs. Instructor: Dix.

Ge 282 abc. Geophysics-Geochemistry (Seminar). *1 unit; first, second, third terms. Prerequisite: At least two subjects in geophysics or geochemistry.* Discussion of papers in geochemistry, general and applied geophysics. In charge: Epstein, Phinney, Smith.

General

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 8 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
- (P) Space Science

Geophysics:

- (Q) Applied Geophysics
- (R) General Geophysics
- (S) Geophysical Instruments
- (T) Seismology
- (U) Theoretical Geophysics

GERMAN

(See under Languages)

HISTORY AND GOVERNMENT

UNDERGRADUATE SUBJECTS

H 1 abc. History of European Civilization. *5 units (2-0-3); first, second, third terms.* An introduction to the history of Europe from 1648 to the present. The course will include discussions of political, social, and economic problems, and of the more important theoretical concepts of the period. Instructors: Ellersieck, Elliot, Fay, Huttenback, Conhaim, Searle.

H 2 abc. History and Government of the United States. *6 units (2-0-4); first, second, third terms.* The United States since the Revolution. Particular attention will be given to the great questions of domestic and foreign policy which the United States has faced in recent times. The course will include a study of the Constitution and form of government of the United States and the State of California, and will trace the evolution of national and local political institutions and ideas. Instructors: J. Davies, Paul, Piper, Strout, Baker.

H 4. The British Empire and the Commonwealth.* *9 units (3-0-6). Senior Elective.* 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 5 abc. Public Affairs. *2 units (1-0-1); first, second, third terms.* In this course a selection of important contemporary problems connected with American political and constitutional development, economic policies, and foreign affairs will be considered. Instructors: Elliot, Sweezy; occasional lectures by other members of the department.

H 7. Modern and Contemporary Germany.* *9 units (3-0-6). Senior Elective.* A study of what is sometimes called "The German Problem." Attention will be focused on the rise of Prussia, on Prussian leadership in the unification and direction of Germany, and on the place of Germany in the economy of Europe. Particular stress will be placed upon the German experience since the first World War.

H 8. Modern and Contemporary Russia.* *9 units (3-0-6). Senior Elective.* 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 15. Europe since 1914.* *9 units (3-0-6). Senior Elective.* Since 1914 the world has felt the impact of two great wars and powerful revolutionary ideas. This course will analyze these upheavals of the twentieth century and their effect on domestic and international organization. Instructor: Fay.

H 16. American Foreign Relations.* *9 units (3-0-6). Senior Elective.* 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 17. The Far West and the Great Plains.* *9 units (3-0-6). Senior Elective.* A study of the development of the great regions that compose the western half of the United States. Especial attention will be paid to the influence of the natural environment

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

on the men who settled the West, from pioneer days to the present time, and the exploitation of natural resources, through such industries as mining, ranching, oil and farming. Instructor: Paul.

H 19. Modern America.* *9 units (3-0-6). Senior Elective.* An experimental course in which the main theme will be the conflict between government regulation and private enterprise in Twentieth-Century America. Classes will be conducted as discussions under the joint leadership of an historian and an economist. Instructors: Paul, Sweezy.

H 20. Modern and Contemporary France.* *9 units (3-0-6). Senior Elective.* A study of modern France in the light of her revolutionary tradition. A consideration of the French Revolution followed by an examination of selected episodes between 1815 and 1944 (the June Days, the Paris Commune, the Dreyfus affair, the Stavisky riots, the Vichy regime) which reflect continuing revolutionary strain. Instructor: Fay.

H 21. Medieval England.* *9 units (3-0-6).* Feudalism as a political system, and its part in the early development of parliamentary democracy, approached principally through the study of selected political episodes in English history, 1066-1485. Instructor: Searle.

H 22. Modern Britain.* *9 units (3-0-6). Senior Elective.* A study of Britain's recent past with particular emphasis upon the development of the working class movement. Instructor: Elliot.

H 23. Modern War.* *9 units (3-0-6). Senior Elective.* The course will trace the major developments within the military establishment, such as the growth of the general staff and mass armies. It will discuss the major strategic concepts of the nineteenth and twentieth centuries and the problems of modern war, with some consideration of the political, economic, and social aspects of waging war. Instructor: Ellersieck.

H 24 a. Political Behavior.* *9 units (3-0-6). Senior Elective.* An examination of general behavior patterns and tendencies of individuals as related to their political behavior and to appropriate types of political institutions. Relevant psychological and sociological theory and research will be discussed in an effort to find the kinds of government suitable to people living in modern technological and industrial society. Instructor: J. Davies.

H 24 b. Political Revolution. *9 units (3-0-6). Senior Elective.* An analysis of various revolutions in light of the basic psychic and social forces which impel individuals to fight for and support a drastic, sudden change in the political power structure of their society. Instructor: J. Davies.

H 25. Political Parties and Pressure Groups.* *9 units (3-0-6). Senior Elective.* A study of those institutions through which individuals and groups seek to control governmental policy and administration. Particular attention will be focused on parties as formulators of individuals' political wants, fears, and expectations and as transmitters of these programs to government. Instructor: J. Davies.

H 26. The Political Novel.* *9 units (3-0-6). Senior Elective.* A political and literary appraisal of modern novels that attempt to explain and to judge relationships between the individual and the state in both free and totalitarian societies. The

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

class will meet under the joint supervision of a professor of English and a political scientist. Instructors: J. Davies, Stanton.

H 28. American Political Ideas.* *9 units (3-0-6).* Historical and analytical examination of liberal, conservative and radical thought with an emphasis on reading in original sources. Instructor: Strout.

H 29. American Philosophical Ideas. *9 units (3-0-6).* A survey of American intellectual history in the 19th and 20th centuries, with particular emphasis on philosophical, literary, religious, artistic, and historical thought. Instructor: Baker.

H 30. The Individual and Society in America.* *9 units (3-0-6).* Readings in some "classics" of American history, centered about the relation of the individual to the larger community at different periods. Problems such as status and social mobility, personal and group values and tensions, nonconformity and social criticism, and the development of the American character will be discussed. Instructor: Baker.

H 35. Modern India and Pakistan.* *9 units (3-0-6).* The course will deal with 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 40. Reading in History. *Units to be determined for the individual by the department. Elective, in any term. Approval of the Registration Committee is required where excess units are involved.* 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.

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.

ADVANCED SUBJECTS

H 100 abc. Seminar in History and Government. *9 units (2-0-7).* Studies in English and American civilization. The reading will be chiefly in biographies of great men and women, famous novels, and suggestive essays in historical and political interpretation. Instructor: Fay.

H 123. The Growth of Industrial Civilization.* *9 units (3-0-6). Senior Elective.* An analysis and study of some of the major factors affecting the past, present and future development of industrial civilization with emphasis on projections into the next century. Among the factors to be considered are population changes, material, food and energy resources and technical manpower. Lectures and discussions will be given by staff members from various Institute divisions. Instructors in charge: Weir, Bonner, Brown.

H 124. Seminar in Foreign Area Problems.* *9 units (3-0-6); second term. Senior Elective.* 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

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

year to year. Instruction will be given mainly by area specialists of the American Universities Field Staff. Instructors: Elliot and members of AUFS.

H 125 abc. Seminar on National Security. *9 units (2-0-7). Senior Elective.* 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 defence policy, and the role of international organizations in the development of an orderly world society. Instructor: Elliot.

H 140. Reading and Research in History and Government. *Units to be determined for the individual by the department.*

H 150 abc. African Studies. *9 units (2-0-7). Senior Elective.* Problems of transition from colonial status to independence in countries south of the Sahara. Racial and cultural tensions in the Union of South Africa. Instructor: Munger.

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 fifth-year students or qualified undergraduate students.

Hy 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: ME 19 ab and Hy 111 or equivalent.* Continuity, momentum, and energy equations for viscous, compressible fluids; circulation and the production of vorticity; potential flow and applications to flow around bodies; gravity waves; laminar flow; laminar boundary layers; turbulence and turbulent shear flow; transport of sediment; topics from gas dynamics and introduction to mechanics of compressible flow. Instructor: Marble.

Hy 103 abc. Advanced Hydraulics and Hydraulic Structures. *9 units (3-0-6); first, second, third terms. Prerequisites: ME 19 ab and Hy 111 or equivalent.* Ideal fluid flow, turbulence and diffusion, boundary layers, dimensional analysis, hydraulic models, steady flow in open channels, hydraulic jump, high-velocity flow in open channels, sedimentation, surface waves and coastal engineering, and unsteady flow in pipes and channels. Theory and design of hydraulic structures such as inlets, chutes, energy dissipators, canals, transitions and the like. Instructors: Vanoni, Harleman, 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, Raichlen.

Hy 111. Fluid Mechanics Laboratory. *6 units (0-6-0); 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 course is primarily for seniors, it is also open to first-year graduate students who have not had an equivalent course. Instructor: Raichlen.

Hy 121. Advanced Hydraulics Laboratory. *6 or more units as arranged; any term. Prerequisite: Consent of instructor.* A laboratory course primarily for fifth-year 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 134. Flow in Porous Media. *9 units (3-0-6); third term. Prerequisite: AM 95 ab or equivalent. AM 116 is also recommended. (AM 95 b may be taken concurrently.)* A study of the hydrodynamics of flow through porous media, with applications primarily in the field of ground water flow, including seepage through earth dams and levees, uplift pressures on dams and foundations, flow toward wells, ground water recharge, drainage, dewatering for excavations, dispersion, and salinity intrusion. Emphasis is placed on flow-net analysis and mathematical methods. Instructor: Harleman.

Hy 200. Advanced Work in Hydrodynamics or Hydraulic Engineering. *Units to be based upon work done; any term.* Special courses on problems to meet the needs of students beyond the fifth year.

Hy 201 abc. Hydraulic Machinery. *6 units (2-0-4); first, second, third terms. No prerequisite.* A study of such rotating machinery as turbines, pumps, and blowers and their design to meet specific operating conditions. This course will be given in seminar form led by members of the Hydrodynamics and Mechanical Engineering staffs. Not given every year. Check with your instructor.

Hy 203. Cavitation Phenomena. *6 units (2-0-4). Prerequisite: Graduate standing.* Study of the experimental and analytical aspects of cavitation and allied phenomena. Problems will be considered in the field of hydraulic machinery and also for bodies moving in a stationary fluid. Instructor: Ellis.

Hy 210 ab. Hydrodynamics of Sediment Transportation. *9 units (3-0-6). Prerequisites: AM 95 ab and Hy 103 abc or Hy 101 abc.* A study of the mechanics of the entrainment, transportation, and deposition of solid particles by flowing fluids. This will include problems of water and wind erosion, and density currents. 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 Engineering Division. 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: Harleman.

Hy 300. Thesis.

JET PROPULSION

ADVANCED SUBJECTS

JP 120 abc. Chemistry Problems in Propulsion. *9 units (3-0-6); each term. Open to all graduate students and to seniors by permission of instructor.* Propellant chemistry; descriptive discussions of atomic and molecular structure, standard heats of formation, normal vibrations, chemistry of propellants. Combustion thermodynamics; chemical equilibrium, quantitative evaluation of rocket propellants, thermodynamic functions for atoms and molecules. Introduction to flame theory; phenomenological chemical kinetics, transport properties, introduction to laminar and diffusion flames, detonation, combustion of solid propellants, heterogeneous combustion, turbulent flames. Text: *Chemistry Problems in Jet Propulsion,* Penner. Instructor: Penner.

JP 121 abc. Rockets and Air Breathing Engines. *9 units (3-0-6); each term. Prerequisites: AM 95 ab, AM 116 or equivalent (may be taken concurrently with permission of instructor).* Basic performance and comparison of rocket and air breathing engines. Nozzle flow, under- and over-expansion, particle flow in nozzles, heat transfer and cooling of components. Cycle analysis of air-breathing engines; component performance; diffusers, combustion chambers, compressors, turbines, ducted fans; component matching and overall performance. Properties and burning characteristics of solid propellants, solid propellant rocket motors; properties and burning characteristics of liquid propellants, propellant feed systems, liquid rocket motors, low frequency and high frequency instability; weight estimates, optimization of vehicle performance. Instructors: Rannie, 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. Not offered every year. Instructor: Penner.

JP 202 abc. Quantitative Spectroscopy and Gas Emissivities. *9 units (3-0-6); each term. Prerequisite: Ph 112 or Ch 226 or JP 201 or equivalent.* This course will consist of the following subjects, with one term being devoted to each subject: (1) Black-body radiation laws, Einstein coefficients, integrated intensities and f-numbers. Spectral line widths and shapes; the curves of growth. Theoretical calculation of absolute intensities for atoms and molecules. (2) Theoretical calculation of equilibrium gas emissivities and absorptivities; infrared emissivities for diatomic molecules at low pressures; pressure-induced transitions. Infrared emissivities of polyatomic molecules. Emissivity calculations for heated air. Emissivity calculations for a hydrogen plasma. Relation between gas absorptivities and emissivities. Spectroscopic techniques for temperature measurements. (3) Radiative transfer problems in ionized gases; emission of radiation behind shock fronts; the influence of radiative transfer on the flow equations; radiant heat transfer to hypersonic vehicles during re-entry of the atmosphere. Approximate emissivity calculations for polyelectronic atoms. Line broadening in ionized gases. Not offered every year. Text: *Quantitative Molecular Spectroscopy and Gas Emissivity,* Penner. Instructor: Penner.

JP 203 abcd. Ionized Gas Theory. *6 units (2-0-4); any term. Prerequisite: Ph 112 or Ch 226 a or JP 201 a or equivalent.* The course will consist of the following subjects with one term being devoted to each subject: (1) Particle interactions: elastic, inelastic and recombination collisions involving neutral atoms, electrons and + ions studied in sufficient detail for accurate evaluation of bulk kinetic and thermodynamic properties of ionized gases. (2) Bulk properties: Application of kinetic theory, statistical thermodynamics and collision parameters developed in (1) above to bulk properties of ionized gases such as equilibrium composition, electrical conductivity, ambipolar diffusion rate and others. (3) Surface phenomena: Particle and bulk interactions between an ionized gas and a bounding surface, surface emission processes, electrical and thermal conduction between a hot ionized gas and a cold surface. (4) Discharges: Ionization in strong electric fields, electron and ion mobilities, glow discharges, arc discharges, engineering applications. Not offered every year. Instructor: Staff.

JP 211 ab. Gas Dynamics of Propulsion System Components. *6 units (2-0-4); any term. Prerequisites: JP 121 abc, Ae 101 abc or Hy 101 abc or equivalent.* This course will consist of the following subjects with one term being devoted to each subject: (1) Inlet diffusers: theory of diffusers for air breathing engines in supersonic and hypersonic flow, real fluid effects and losses, stability, diffuser problems in rarefied gases. (2) Nozzles: theory of three-dimensional flow in nozzles, separation and over-expansion, plug nozzles; chemical reactions and phase condensation; particle flow in nozzles. Not offered every year. Instructors: Marble, Zukoski.

JP 212 ab. Flame Theory and Combustion Technology. *6 units (2-0-4); any term. Prerequisites: JP 120 abc, Ae 101 abc or Hy 101 abc or equivalent.* This course will consist of the following subjects with one term being devoted to each subject: (1) Stationary flames: review of laminar flame and diffusion flame theory; combustion of solid propellants, spray burning; combustion in boundary layers, wakes, and laminar mixing regions; principles of ignition; turbulence and turbulent flames. (2) Unsteady flames: gas dynamic flow fields with flame discontinuities, structure of non-steady flames, stability of laminar flames; unsteady combustion of particles and droplets; flame holding, flame spreading; combustion chambers. Not offered every year. Instructors: Marble, Penner.

JP 221 abc. Rocket Trajectories and Orbital Mechanics. *6 units (2-0-4); any term. Prerequisite: AM 95 ab. (Students who have taken or are intending to take Ae 103 and Ae 203 should consult the instructor.)* This course will consist of the following subjects with one term being devoted to each subject: (1) Ballistic trajectories: impulsive launching, optimization with finite burning time, gravity turn; re-entry, non-lifting and gliding. (2) Satellite orbits: motion in an inverse square law field; perturbations due to oblateness of the earth, radiation pressure, moon, sun, and aerodynamic drag. (3) Space vehicle trajectories: transfer ellipses, minimum energy estimates, motion in the Earth-Moon system, powered flight. Not offered every year. Instructor: Rannie.

JP 230 abcd. Power Generation and Propulsion in Space. *6 units (3-0-3); any term. Prerequisite: JP 121 abc (some previous knowledge of Electromagnetic Theory and Modern Physics is advisable).* (The aim of this course is to provide the background for understanding the current status and problems of space propulsion systems. The emphasis will change from year to year and the various terms are independent.) This course will consist of the following subjects with one term being devoted to each subject: (1) Power generation for space systems: general power requirements for space systems, turbogenerator systems with solar or nuclear power sources, radioisotope power supply, silicon solar cell, and thermoelectric systems; heat rejection and condensation processes. (2) Plasma propulsion and power extraction: plasma properties and magnetohydrodynamic flow fundamentals; steady, wave guide, and pulsed types of plasma accelerators, limitations on performance. (3) Ion propulsion: ion sources, ion accelerators, and beam neutralization; limitations on performance. (4) Nuclear propulsion: principles of the nuclear heat transfer rocket, propellant feed systems, cooling, and materials limitations; the gaseous fission rocket. Not offered every year. Instructor: Marble.

JP 240 a. 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. Not offered every year. Instructor: Penner.

JP 240 b. Heat Transfer in Propulsion Systems—Conductive and Convective Heat Transfer. *9 units (3-0-6); any term. Prerequisite: Hy 101 abc or ME 118 abc or equivalent.* Exact and approximate integral solutions of unsteady heat conduction problems, applications to solid propellant rocket motors; convective heat transfer to rocket chambers and nozzles, regenerative cooling of liquid propellant motors. Not offered every year. Instructor: Rannie.

JP 250 abc. Fluid Mechanics of Axial Turbomachines. *6 units (2-0-4); any term. Prerequisite: Hy 101 abc or equivalent.* This course will consist of the following subjects with one term being devoted to each subject: (1) Cascade theory: potential flow through two-dimensional cascades, real fluid effects, and evaluation of performance. (2) Axisymmetrical flow: flow through an actuator disc in an annular duct, linearized perturbations of strong vorticity fields, single and multiple blade rows of finite axial length, effect of varying duct height, and compressibility effects. (3) Three-dimensional real fluid effects: secondary flow, propagating stall, blade tip clearance flow. Not offered every year. Instructors: Marble, Rannie.

JP 270. Special Topics in Propulsion. *6 units (2-0-4).* The topics covered will vary from year to year. Instructors: Staff Members.

JP 280 abc. Research in Jet Propulsion. *Units to be arranged.* Theoretical and experimental investigations of problems associated with propulsion and related fields. Instructors: Staff Members.

JP 290 abc. Advanced Seminar in Jet Propulsion. *2 units (1-0-1); each term.* Seminar on current research problems in propulsion and related fields. Instructors: Staff Members.

LANGUAGES

UNDERGRADUATE SUBJECTS

L 1 abc. Elementary French. *10 units (3-1-6); first, second, third terms.* A subject 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 the department of languages. Instructor: Stern.

L 5. French Literature.* *9 units (3-0-6); second term. Senior elective. Prerequisite: L 1 ab, or the equivalent.* The reading of selected classical and modern literature, accompanied by lectures on the development of French literature. Elective and offered when there is sufficient demand. Instructors: Bowerman, Stern.

L 32 abc. Elementary German. *10 units (3-1-6); first, second, third terms.* This subject is presented in the same manner as the Elementary French. Students who have had German in the secondary school or junior college should not register for this subject without consulting the department of languages. One session in the language laboratory will be scheduled each week. Instructors: Bowerman, Wayne.

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.

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.

L 40. German Literature.* *9 units (3-0-6): third term. Senior Elective. Prerequisite: L 35, or L 32 abc with above average grades.* The reading of selected classical and modern literature, accompanied by lectures on the development of German literature. Instructor: Stern.

L 50 abc. Elementary Russian. *10 units (4-0-6); first, second, third terms.* A subject 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. Instructor: Kosloff.

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 105. Same as L 5. For graduate students.

L 140. Same as L 40. For graduate students.

MATHEMATICS

UNDERGRADUATE SUBJECTS

Ma 1 abc. Freshman Mathematics. *12 units (4-0-8); first, second, third terms. Prerequisites: High school algebra and trigonometry.* An introduction to the calculus; vector algebra; analytic geometry; the infinite series. Professors in charge: Bohnenblust, De Prima.

Ma 1.5 abc. Advanced Placement Course. *12 units (4-0-8); three terms.* This course is restricted to entering freshmen who are given advanced placement in mathematics. The concepts of the calculus are reviewed and the course covers the material of Ma 1 abc and Ma 2 ab. Students who complete this course take Ma 2 c either in the first or in the last quarter of their sophomore year.

Ma 2 abc. Sophomore Mathematics. *12 units (4-0-8); first, second, third terms.* A continuation of the freshman mathematics course including: an extension of the calculus to functions of several variables; introduction to probability; vector analysis; differential equations; numerical analysis. Professor in charge: Lees.

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. Their subsystems, factor systems and direct products are studied. The algebraic techniques of decom-

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

position and extension are presented. A large portion of the course is devoted to linear algebra and matrix theory with applications to geometry. Included are determinants, characteristic roots, Hermitian matrices and canonical forms. Professor in charge: Hall. Instructors: Block, Dade, Dixon.

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. Markoff's theorems. Classical orthogonal polynomials. Applications to interpolation and approximation integration. Instructor: Sharples.

Ma 91. Special Course. *9 units (3-0-6); third term.* Each year, during the third term, a course will be given in one of the following topics:

(a) Some field of number theory. (Given in 1959-60.)
(b) Some field of algebra or logic. (Given in 1961-62.)
(c) Theory of elasticity. (Given in 1962-63.) Knowles.
(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:

Ma 102. Differential Geometry. *9 units (3-0-6); third term.* Selected topics in metrical differential geometry. Instructor: Erdélyi.

Ma 104. Projective and Algebraic Geometry. *9 units (3-0-6); first term.* Homogeneous coordinates, projective group. Duality principle. Singular points of curves. Birational transformation. Given in 1963-64 and alternate years.

Ma 105 ab. Introduction to Numerical Analysis. *11 units (3-2-6); second and third terms. Prerequisites: Ma 108 or AM 15 or equivalent, Ma 5, Ma 31 or AM 180 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: Franklin.

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 calculus are treated. Point set topology is the point of departure for the theory of convergence, and applications are made to implicit functions, partial differentiations, infinite series and infinite products of real and complex numbers. Other topics treated include: uniform convergence of sequences of functions; functions defined by integrals; Fourier series and integrals; analytic functions of a complex variable. Instructors: Apostol, Chakerian, Fuller, Garsia, Sharples.

Ma 109. Operational Calculus. *9 units (3-0-6); third term.* Introduction to operational calculus and to delta functions. Applications to ordinary and partial differential equations. Given in 1963-64 and alternate years.

Ma 112. Elementary Statistics. *9 units (3-0-6); first and repeated in second 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. Instructors: Knowles, Ward.

Ma 116 ab. Mathematical Logic and Axiomatic Set Theory. *9 units (3-0-6); first and second terms. Prerequisite: Ma 5 abc or equivalent.* The predicate calculus and functional calculi of first order are presented and problems in the foundations of mathematics are studied. Included are Boolean algebra, theorems of Gödel, axiomatic set theory, and theory of cardinal and ordinal numbers. Instructor: Halpern.

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: Chakerian.

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. Instructors: Block, Ward.

Ma 121 ab. Combinatorial Analysis. *9 units (3-0-6); first and second 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 geometries. Instructor: Hall.

Ma 137. Introduction to Lebesgue Integrals. *9 units (3-0-6); first term. Prerequisite: Ma 108 or equivalent.* Sets, topology, metric spaces. Functions of bounded variation. Lebesgue integrals of functions of one or two real variables. Fourier integrals. L^2 spaces. Linear functionals on Hilbert spaces and Banach spaces. This is an introductory course designed as a preparation for graduate courses in analysis and probability theory. Instructor: Erdélyi.

Ma 142 ab. Introduction to Partial Differential Equations. *9 units (3-0-6); second and third terms. Prerequisite: Ma 137 or equivalent.* Topics will include the following: Equations of the first order. Linear equations of the second order. Boundary value and eigenvalue problems for elliptic equations. Initial value and initial boundary value problems for parabolic and hyperbolic equations. Applications to problems of mathematical physics. Not given in 1962-63.

Ma 143 ab. Functional Analysis and Integral Equations. *9 units (3-0-6); second and third terms. Prerequisites: Ma 108 and Ma 137 or equivalent.* This course is a continuation of Ma 137 and 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: Erdélyi.

Ma 144 ab. Probability. *9 units (3-0-6); second and third terms. Prerequisite: Ma 137 or equivalent.* Basic concepts of probability, limit theorems, random walks, Markow chains, stochastic processes with applications. Instructor: Garsia.

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. Instructor: Apostol.

Ma 165 a. 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. Not given in 1962-63.

Ma 180 abc. Methods of Applied Mathematics. *9 units (3-0-6); each term. Prerequisites: Ma 108, or AM 95, AM 116 or equivalent.* Basic theory and methods of solution of partial differential equations. Classification of equations and general properties of solutions. Green's functions, eigen-function expansions, integral transforms. Other topics such as parts of the theory of ordinary differential equations, asymptotic expansions and generalized functions will be introduced as required. Instructor: Whitham.

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. In charge: J. Todd, O. Todd.

[B] The following courses are open primarily to graduate students.

Ma 205 abc. Numerical Analysis. *9 units (3-0-6); three terms. Prerequisite: Ma 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, 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, Knuth.

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 1963-64 and alternate years.

Ma 223. Matrix Theory. *9 units (3-0-6); second term. Prerequisites: Ma 108, 1220 or equivalent.* Algebraic, arithmetic and analytic aspects of matrix theory. Not offered in 1962-63.

Ma 224 abc. Lattice Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 120 or permission of instructor.* Systematic development of the theory of Boolean algebras, distributive, modular, and semi-modular lattices. Includes the study of lattice congruences, decomposition theory, and the structure of free lattices. Instructor: Dilworth.

Ma 237 abc. Real Variable Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 137 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. Given in 1963-64 and alternate years.

Ma 238 abc. Advanced Complex Variable Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 108, Ma 118 a or equivalent.* In this course the knowledge of basic parts of the classical theory of analytic functions is assumed, and special topics are presented introducing topological and group-theoretical considerations, and relations to functional analysis. The topics will be selected from: linear spaces of analytic functions, conformal mapping, algebraic functions, Riemann surfaces, functions of several complex variables, singular integral equations. Not given in 1962-63.

Ma 244 ab. Advanced Probability. *9 units (3-0-6); first and second terms. Prerequisites: Ma 137 and 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). Instructor: Konheim.

Ma 280 abc. Applied Mathematics. *9 units (3-0-6); three terms. Prerequisites: Ma 137 and Ma 143 or equivalent.* Special theory of self-adjoint operators in Hilbert spaces with applications to boundary value problems and to functional equations. Nonlinear problems in functional analysis applied to the theory of partial differential equations and to approximation processes. Not offered in 1962-63.

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 abc Special topics in Algebra. 9 units. Three terms.

Ma 325 abc Seminar in Algebra. 6 units. Three terms.

Ma 340 abc Special topics in Analysis. 9 units. Three terms. Instructor: Luxemburg.

Ma 345 abc Seminar in Analysis. 6 units. Three terms.

Ma 350 ab Special topics in Geometry. 9 units. First and second terms. Instructor: Garsia.

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 380 abc Special topics in Applied Mathematics. 9 units. Three terms.

Ma 385 abc Seminar in Applied Mathematics. 6 units. Three terms.

Ma 390 Research. Units by arrangement.

Ma 392 Research Conference. 2 units.

APPLIED MATHEMATICS COURSES OFFERED BY OTHER DEPARTMENTS

AM 95 Engineering Mathematics. *See Applied Mechanics section, for description.*

AM 116 Complex Variables and Applications. *See Applied Mechanics section, for description.*

AM 125 Engineering Mathematical Principles. *See Applied Mechanics section, for description.*

AM 180 Matrix Algebra. *See Applied Mechanics section, for description.*

AM 181 Linear Programming. *See Applied Mechanics section, for description.*

AM 225 Advanced Topics in Applied Mathematics. *See Applied Mechanics section, for description.*

Ph 107 Electricity and Magnetism. *See Physics section, for description.*

Ph 108 Theoretical Mechanics. *See Physics section, for description.*

Ph 129 Methods of Mathematical Physics. *See Physics section, for description.*

EE 280 Advanced Course in Mechanical Computing Methods. *See Electrical Engineering section, for description.*

MECHANICAL ENGINEERING

UNDERGRADUATE SUBJECTS

ME 1. Introduction to Design. *9 units (0-9-0); second, or third term. Prerequisite: Gr 1.* This course supplements first-year graphics with more advanced applications of graphical methods to spatial delineation and design. The following subjects are introduced through a series of coordinated lecture discussions and laboratory problems: descriptive geometry in analysis and design; useful mechanisms; displacement, velocity and acceleration in machines and systems; creative synthesis; human and economic factors as they affect design. Emphasis is placed on an imaginative yet rational approach to new problems and upon the development of the individual student's ability to recognize fundamental principles and logically plan his development work. Instructors: Welch, Morelli.

ME 3. Materials and Processes. *9 units (3-3-3); first, second or third 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. Prerequisites: ME 1, ME 3, ME 17 ab, AM 8 abc, AM 95 ab.* The purpose of this course is to develop creative ability and engineering judgment through work in design and engineering analysis. Existing devices are analyzed to determine their characteristics and the possibilities for improving their performance or economy and to evaluate them in comparison with competitive devices. Practice in the creation or synthesis of new devices is given by problems in the design of machines to perform specified functions. The fundamental principles of scientific and engineering knowledge and appropriate mathematical techniques are employed to accomplish the analysis and designs. Text: *Design and Production,* Kent. Instructors: Morelli, Welch.

ME 17 ab. Thermodynamics. *9 units (3-0-6); first and second terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Basic laws of thermodynamics, fundamental properties and interrelationships between properties. Maxwell relations, Joule-Thomson effect, Clapeyron-Clausius equation. Application to gases as well as to other systems. Elements of kinetic theory. Analyses of energy conversion cycles and propulsion devices. One-dimensional flow in a duct, normal and oblique shocks, expansion through nozzles. Basic chemical thermodynamics and theory of equilibrium of a reacting mixture. Text: *Elements of Engineering Thermodynamics*, Sabersky. Instructor: Sabersky.

ME 17 c. Heat Transfer. *9 units (3-0-6); third term. Prerequisites: Ma 2 ab, ME 17 ab or equivalent.* Conduction in solids. Solution of problems by analytical, graphical, and numerical methods. Basic equations governing convective heat transfer. Similarity requirements. Special problems in laminar and turbulent flow. Free convection. Heat transfer in condensing and boiling fluids. Energy exchange by radiation. Instructor: Sabersky.

ME 19 ab. Fluid Mechanics and Gas Dynamics. *9 units (3-0-6); first and second 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 tubulent flow. Flow and wave phenomena in open conduits. Instructor: Acosta.

ME 19 c. Principles of Energy Conversion. *9 units (3-0-6); third term. Prerequisites: Ma 2 abc, ME 17 ab and ME 19 ab or equivalent.* Availability of chemical, nuclear, and solar energy. Systems for the conversion into mechanical or electrical power. Analysis of principal system components such as fans, compressors, pumps and turbines. To include topics from two- and three-dimensional design theories of turbomachines. Instructor: Acosta.

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 fifth-year students 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 is developed at an advanced level. Laboratory problems are given in terms of the need for accomplishing specified end results in the presence of broadly defined environments. Investigations are made of environmental conditions to develop quantitative specifications for the required designs. Searches are made for the possible alternate designs and these are compared and evaluated. Preferred designs are developed in sufficient detail to determine operational characteristics, material specifications, general manufacturing requirements and costs. Instructors: Morelli, Welch.

ME 118 abc. Advanced Thermodynamics and Energy Transfer. *9 units (3-0-6); first, second, and third terms. Prerequisites: ME 18, ME 19 ab.* 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: Sabersky.

ME 126. Fluid Mechanics and Heat Transfer Laboratory. *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.* Introduction to some of the basic measurements and phenomena in fluid mechanics and heat transfer. The students will become acquainted with the use of hot wire equipment, thermocouples, thermistors, velocity probes, as well as with electrical and hydraulic analogues. The experiments in which these instruments will be used will include, for example, the flow over a flat plate, free and forced convention heat transfer, boiling heat transfer, solid state energy conversion phenomena, free surface and supersonic flows. Instructors: Sabersky, Zukoski.

ME 127. High Frequency Measurements in Fluids and Solids. *9 units (2-6-1); second term. Prerequisites: AM 8 abc, AM 95 ab.* The course will treat the theory and application of modern instrumentation to dynamic problems in fluid mechanics and elasticity which will be selected to provide familiarity with a wide range of electronic devices, transducers, and high-speed photoelastic and schlieren photographic techniques. Instructor: Ellis.

ME 200. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses on problems to meet the needs of students beyond the fifth year.

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 255.
Hydraulics, page 295.
Jet Propulsion, pages 296, 297.
Physical Metallurgy, pages 310-312.

Music

Mu 1 abc. Music History and Analysis. *5 units (2-0-3).* The development of Western music studied through the analysis of historically significant compositions. Musical notation, melodic techniques, harmonic and polyphonic forms will be studied in relation to stylistic use during the principal periods of music history. An understanding of the musical score will be emphasized by means of correlated studies in analysis and record listening. Instructor: Ochse.

Paleontology

(See under Geological Sciences)

PHILOSOPHY AND PSYCHOLOGY

UNDERGRADUATE SUBJECTS

Pl 1. Introduction to Philosophy.* *9 units (3-0-6). Senior Elective.* A study of the major problems of philosophy in terms of the most influential contemporary world views, including naturalism, idealism, theism, pragmatism, and positivism. Instructor: Bures.

Pl. 2. Logic* *9 units (3-0-6). Senior Elective.* A study of modern and traditional logic. An analysis of knowledge into basic symbolic forms. Detailed consideration of such logical concepts as: proposition, truth, variable, definition, implication, inference, class, syllogism, logical law, deductive system. Emphasis on the fundamental role of logical methods in the rational approach to knowledge. Instructor: Bures.

Pl 3. Contemporary European Philosophy.* *9 units (3-0-6). Senior Elective.* 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. Instructor: Stern.

Pl 4. Ethics.* *9 units (3-0-6). Senior Elective.* A study of ethical values in relation to human nature and culture. Among the major topics considered are: the moral systems of some representative cultures; the development of personality and values in these cultures; the possibility of a rational basis for ethics; competing views of human nature; ethical conflicts in American culture. Instructor: Bures.

Pl 6 a. Introduction to Personality and Culture.* *9 units (3-0-6). Senior Elective; first term.* A study of selected aspects of contemporary psychology and anthropology, aimed at introducing the student to the wide diversity of approaches currently being employed in seeking a scientific understanding of man and his behavior. The complementary character of the various concepts and methods will be indicated. Recommended as preparation for Pl 6 b and Pl 6 c. Instructor: Atkins.

Pl 6 b. The Psychology of Behaviorial Processes.* *9 units (3-0-6). Senior Elective; second 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. Pl 6 a and Pl 6 b are recommended as preparation for this course. Instructor: Weir.

Pl 6 c. The Psychology of Personality Development.* *9 units (3-0-6). Senior Elective; third 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. Recommended as preparation for Pl 6 c. Instructor: Bures.

Pl 7. Human Relations. *7 units (3-0-4); third term.* An introduction to the principles of human relations with major emphasis on the development of groups. Psychological and emotional factors influencing group behavior, group leadership and group co-operation will be explored. Instructors: Ferguson, Weir.

Pl 8 a. Classical Social Theories.* *9 units (3-0-6); first term.* Reading, analysis, and interpretation of major political philosophies, Greek and post-Renaissance, as related to the philosophical task and to the relevant political, economic, and social issues. Instructor: Morris.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

Pl 8 b. Modern Social Theories.* *9 units (3-0-6); second term.* A study of contemporary social issues, their alternative formulation by communist, fascist, and democratic thinkers, with special attention to the myths that obfuscate their thought. Instructor: Morris.

Pl 9. Philosophy of Culture.* *9 units (3-0-6); third term.* Theories of culture and their significance for understanding basic issues and controversies in contemporary society as manifested in science and technology, the arts, education, religion, and ethics. Instructor: Morris.

Pl 13. Reading in Philosophy. *Units to be determined for the individual by the department. Elective, with the approval of the Undergraduate Academic Standards and Honors Committee, in any term.* Reading in philosophy, supplementary to, but not substituted for, courses listed; supervised by members of the department.

ADVANCED SUBJECTS

Pl 100 abc. Philosophy of Science. *9 units (2-0-7).* A full-year sequence. The relation between science and philosophy. The functions of logical analysis in knowledge and the analysis of the language of science. A study of the nature of formal science (logic and mathematics) and of factual science, their methods and interrelationships. Concept formation in the sciences. Analysis of some basic problems in the philosophy of science: measurement, casuality, probability, induction, space, time, reality. Scientific method and social problems. 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: Morris.

Pl 102 abc. Philosophy and Literature. *9 units (2-0-7). A full-year sequence.* A philosophical analysis and interpretation of literature as an art and as a vehicle of philosophical thought, exemplified in great works of world literature, beginning with Homer and the pre-Socratic poems on nature and ending with the literature of Existentialism and Surrealism. The course includes a study of the main philosophical theories of the different forms of literary expression (tragedy, comedy, poetry, the novel) and the reading of original works or translations. Instructor: Stern.

Pl 113. Reading in Philosophy. Same as Pl 13 but for graduate credit.

PHYSICAL METALLURGY

UNDERGRADUATE SUBJECTS

PM 5 abc. Principles of Engineering Materials. *9 units (3-0-6); first, second and third terms. Prerequisites: Ch 1 abc, Ph 2 abc, AM 8 c, (AM 8 c may be taken concurrently with PM 5 c).* The purpose of this course is to acquaint the student with the principles underlying the properties of solid materials. Elementary principles of quantum mechanics are employed to discuss the electronic structure of atoms, the types of bonds between atoms in molecules and crystals, and to develop the band theory of solids. An introduction to the principles of statistical thermodynamics also is given. These principles are employed as the basis for discussion of the electrical, magnetic, and thermal properties of solids. Rate processes such

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

as diffusion and phase transformation also are considered. The concepts and theory of dislocations in crystals are introduced and are employed in the discussion of the processes of deformation and fracture of solids. Instructors: Buffington, Wood.

PM 10. Engineering Physical Metallurgy. *9 units (2-1-6); first term. Prerequisite: PM 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.

PM 11. Metallography Laboratory. *9 units (0-6-3); second term. Prerequisite: PM 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.

PM 15. Behavior of Solids Laboratory. *9 units (0-6-3); third term. Prerequisite: PM 5 abc, or concurrent registration.* Experimental studies of the physical and mechanical behavior of solid materials which may be correlated with the fundamental principles of material behavior. A few examples of investigations which the student may elect to undertake are: The thermal and electrical conductivities of a metal and a semi-conductor as functions of temperature. The influence of temperature on the stress-strain behavior of rubber-like polymers and temperature changes produced by deformation of such materials. The influence of grain size on the brittle fracture stress of mild steel at low temperatures and observations of microcracks. The generation and direct observation of dislocations in lithium fluoride crystals under applied stress. Instructor: Wood.

ADVANCED SUBJECTS

PM 100. Advanced Work in Physical Metallurgy. The staff in physical metallurgy will arrange special courses or problems to meet the needs of fifth-year students or qualified undergraduate students.

PM 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. Instructor: Staff.

PM 103 ab. Physical Metallurgy Laboratory. *9 units (0-9-0); first term. 6 units (0-6-0); second term. Prerequisite: PM 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.

PM 104. Photography. *9 units (1-6-2). first term. Prerequisite: Ph 2 abc.* Study and synthesis of optical systems in the use of photographic methods in research. Experiments will be conducted with various systems to illustrate the effectiveness of photographic methods as research tools. Instructors: Staff.

PM 105. Mechanical Behavior of Metals. *6 units (2-0-4); first term. Prerequisites: AM 9 abc, PM 5 abc.* A study of the various types of behavior of metals under applied load which are of significance for engineering applications. Properties under simple tension and compression loading, hysteresis and damping capacity, the influence of temperature, behavior under rapidly applied and impact loads, fatigue, mechanical wear, behavior under combined stress, and selection of working stresses. Instructor: Wood.

PM 112 ab. Advanced Physical Metallurgy. *9 units (3-0-6); second and third terms. Prerequisites: PM 5 ab or PM 120, PM 115 a.* Ternary phase diagrams; order-disorder transformations; solid-state diffusion; theory of gas-metal reactions; advanced consideration of magnetic properties; effects of radiation on materials. Instructor: Buffington.

PM 115 ab. Crystal Structure and Properties of Metals and Alloys. *9 units (3-0-6); second and third terms. Prerequisite: PM 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.

PM 116. X-Ray Metallography Laboratory I. *9 units (0-6-3); third term. Prerequisite: PM 115 a.* Experiments on X-ray emission spectra and absorption edges. Determination of crystal structures by the Von Laue and Debye-Scherrer methods. Use of the X-ray spectrometer. Study of preferred orientation in cold worked metals. Application of X-ray diffraction methods to the study of phase diagrams. Instructor: Duwez.

PM 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 PM 5 ab cannot receive credit for PM 120, since there exists some duplication of material. Additional study in physics of solids can be arranged under PM 100. Instructor: Buffington.

PM 135. Radioisotopes Laboratory. *9 units (0-9-0); third term. Prerequisites: AM 103, PM 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.

PM 200. Advanced Work in Physical Metallurgy. The staff in physical metallurgy will arrange special courses or problems to meet the needs of students beyond the fifth year.

PM 205. Theory of the Mechanical Behavior of Metals. *9 units (3-0-6); third term. Prerequisites: AM 110 a, PM 115.* A study of the nature and physical theory of the deformation of metals under the influence of applied stress. Elasticity of single crystals, plastic flow in crystals by slip and twinning, the concept of dislocations, stress fields of dislocations, dislocation interactions, generation of dislocations, dislocations in crystal lattices, arrays of dislocations, application of dislocation theory. Text: *Dislocations in Crystals,* Read. Instructor Vreeland.

PM 217. X-Ray Metallography Laboratory II. *9 units (0-6-3); any term. Prerequisite: PM 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.

PM 225. Industrial Physical Metallurgy. *9 units (0-6-3); any term. Prerequisites: PM 103, PM 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.

PM 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. Instructor: Staff.

PM 300. Thesis Research.

Physics

UNDERGRADUATE SUBJECTS

Ph 1 abc. Kinematics, Particle Mechanics, and Electric Forces. *12 units (4-3-5); 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. A weekly three-hour laboratory provides working familiarity with physical principles and measurement techniques. 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: Sutton, Leighton, Feynman, Vogt, and Graduate Assistants.

Ph 2 abc. Electricity, Fields, and Atomic Structure. *12 units (4-3-5); 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; elasticity; fluid flow; atomic structure. Instructors: Neher, Feynman, Sands, Neugebauer, Caughey, Plesset, Wilts, and Graduate Assistants.

Ph 77. Experimental Physics Laboratory. *6-9 units (subject to arrangement with instructor). Either first or second term.* A one-term laboratory course open to 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, van Putten, Hellwarth.

ADVANCED SUBJECTS

Ph 107 abc. Electricity and Magnetism. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 2 abc, Ma 2 abc.* A course in classical electromagnetism that starts with the fundamental law of electromagnetic force and Maxwell's Equations. Topics include electromagnetic energy and momentum, electromagnetic induction and radiation, and solutions to various boundary-value problems involving static fields and traveling waves. The emphasis is upon the more general aspects of the subject, and upon physical principles. Graduate students majoring in physics or astronomy will be given only 6 units credit for this course. Instructors: Cowan, Boehm, Kobrak, Tollestrup.

Ph 108 abc. Theoretical Mechanics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 1 abc, Ph 2 abc, and preferably Ph 107 abc.* An intermediate course in the application of mathematical methods to problems in mechanics. Topics include particle mechanics, Lagrange and Hamilton equations, damped vibrations, coupled vibratory systems, rigid body dynamics. Graduate students majoring in physics or astronomy will receive only 6 units credit for this course. Text: *Classical Mechanics,* Goldstein. Instructors: Anderson, Knopoff, Pellam.

Ph 111 abc. Structure of Matter. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 1 abc; Ph 2 abc.* A course dealing with those properties of matter which can be treated from a relatively simple, largely classical, point of view. The connection between the properties of matter and the properties of the atoms of which it is composed is stressed. Topics include: atomic structure, atomic spectra, magnetic properties of matter; molecular binding, spectra of diatomic molecules, dielectric and optical properties; kinetic theory of gases, ionized gases, plasmas; free electron theory of solids, metals, semi-conductors; structure of solids, electrical and mechanical properties, specific heats. Quantum concepts are introduced but no formal development of quantum mechanics is included. Graduate students majoring in physics or astronomy will receive only 6 units credit for this course. Instructor: Ward Whaling.

Ph 112 abc. Atomic and Nuclear Physics. *12 units (4-0-8); first, second, and third terms. Prerequisites: Ph 107 abc and Ph 111 abc, or equivalent.* A problem and lecture course in the experimental and theoretical foundations of modern atomic and nuclear physics. Topics include the special theory of relativity with applications to kinematics and electrodynamics, and an introduction to quantum mechanics with applications to the harmonic oscillator, the free particle, the one-electron atom and selection rules. Also treated, on a less analytical basis, are the exclusion principle and atomic shell structure; optical spectroscopy; molecular binding and molecular spectra; quantum statistics; the band theory of solids; X-rays; radioactivity and nuclear structure; nuclear reactions; elementary particles; high energy physics. Text: *Principles of Modern Physics,* Leighton. Instructor: T. Lauritsen.

Ph 115 ab. Geometrical and Physical Optics. *9 units (3-0-6); first and second terms. Prerequisite: Ph 2 abc.* An intermediate lecture and problem course dealing with the fundamental principles and applications of geometrical optics, interference, diffraction and other topics of physical optics. Given in alternate years. Offered in 1962-63. Instructor: King.

Ph 129 abc. Methods of Mathematical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 107 abc and Ph 108 abc or the equivalents (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: Walker.

Ph 131 abc. Electricity and Magnetism. *9 units (3-0-6); first, second, and third terms. Prerequisite: An average grade of C in Ph 107 abc.* A problem course in electricity, magnetism and electromagnetic waves for students who are doing or plan to do graduate work. The first two terms cover potential theory as applied to electrostatics, magnetostatics and current flow in extended mediums; eddy currents; and the laws of electromagnetic induction as applied to linear circuits. The third term covers electromagnetic waves and the motion of charged particles in electromagnetic fields. Text: *Static and Dynamic Electricity*, Smythe. Instructor: Smythe.

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.

Ph 201 abc. Analytical Mechanics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 108 abc; Ph 129 ab is desirable.* A problem and lecture course dealing with the various formulations of the laws of motion of systems of particles and rigid bodies, and with both exact and approximate solutions of the resulting equations. Topics considered include Lagrange's and Hamilton's equations, canonical transformations, the dynamics of axially symmetric rigid bodies, and vibrations about equilibrium and steady motion. Additional topics will be selected from such subjects as elasticity, hydrodynamics, non-linear vibrations, dynamics of particles in accelerators, potential theory, and hydromagnetics. Given in alternate years. Offered in 1962-63. Instructor: Davis.

Ph 203 abc. Nuclear Physics. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 112 abc or equivalent.* A problem and lecture course in nuclear physics. Subjects include fundamental properties and structure of nuclei, including the liquid drop, shell, and collective models, nuclear forces, modes of nuclear decay, nuclear reactions, interaction of particles and radiation with matter, and particle acceleration and detection. The third term is usually devoted to such specialized topics as nuclear processes in stars including energy generation and element synthesis. Text: *The Atomic Nucleus*, Evans. Instructor: Fowler.

Ph 204 abc. Low Temperature Physics. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 112 abc. Recommended: Ph 205 abc, Ph 227 abc.* First and second terms: 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. Third term: Advanced topics on specific aspects of low temperature physics to be covered by special reading assignments. Given in alternate years. Not offered in 1962-63. Instructor: Pellam.

Ph 205 abc. Principles of Quantum Mechanics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 112 abc or equivalent; Ph 129 abc concurrently.* A fundamental treatment of quantum mechanics including stationary states of one and many particle systems; exclusion principle; approximation methods; transition problems; scattering theory; angular momentum; introduction to the quantum theory of radiation; application of these methods to atomic, molecular, and nuclear problems. Instructor: Christy.

Ph 207 abc. X- and Gamma-rays. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 112 abc, or equivalent.* Covers the generation of X-rays and gamma-rays and the various interactions of these with matter both in practical applications to research physics and in theory. The first term is devoted to a descriptive general survey of the subject. The second term deals with nuclear gamma-ray and X-ray emission spectra, the mean lives of excited states, elementary theory of multipole radiation, theories of the generation and intensities of characteristic X-ray line spectra and also of the continuous X-ray spectrum covering briefly under the latter topic the theories of Sommerfield and of Heitler and their experimental verifications. The third term covers in considerable detail the scattering of these radiations by matter, both coherent and incoherent processes being considered, and presents the resulting physical conclusions regarding the structure of atoms, molecules, liquids, solids and the Compton effect with its manifold implications. Other interactions between radiation and matter are also treated. Solution of a moderate number of illustrative problems required in all three terms. Instructor: DuMond.

Ph 209 abc. Electromagnetism and Electron Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 107 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: Jon Mathews.

Ph 217. Spectroscopy. *9 units (3-0-6); third term. Prerequisite: Ph 112 ab or the equivalent.* Atomic line spectra. Experimental techniques of excitation and observation of the spectra of atoms and ions. A discussion of observed spectra, including complex spectra, in terms of atomic structure theory. Given in alternate years. Offered in 1962-63. Instructor: King.

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 1962-63. Instructor: Tollestrup.

Ph 220 abc. Introduction to Solid State Physics. *6 units (2-0-4); first, second and third terms. Prerequisite: Ph 112 abc. Recommended: Ph 205 concurrently.* An introduction to the experimental and theoretical foundations of solid state physics and its relation to other domains of physics. Topics presented will include: The dynamics of lattices and their association with physical properties of solids; crystal structures; the electric and magnetic properties of bulk matter, including ferromagnetism; band theory of solids; theory of conductors and semiconductors; optical spectra of crystals; nuclear hyperfine interactions in solids; scattering of slow neutrons from crystals; lattice defects. Instructor: Moessbauer.

Ph 227 abc. Thermodynamics, Statistical Mechanics, and Kinetic Theory. *9 units (3-0-6); first, second and third terms. Prerequisites: Ph 108 abc, 205 ab (may be taken concurrently) 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. Given in alternate years. Not offered in 1962-63. Instructor: Davis.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 205 or equivalent.* Relativistic quantum mechanics, Feynman diagrams, quantum electrodynamics, field theory formalism, dispersion relations, theories of strong and weak interactions. Instructors: Gell-Mann, Zachariasen.

Ph 231 abc. High Energy Physics. *9 units (3-0-6); first, second and third terms.* 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. Given in alternate years. Offered in 1962-63. Instructor: Frautschi.

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.

Ph 236 ab. Relativity Theory. *9 units (3-0-6); first and second terms.* The incompatibility of Newtonian relativity and Maxwell's electromagnetism; survey of the classic ether experiments, and the transformation equations of Lorentz. Einstein's derivation of these, based on the Postulates of Relativity. Minkowski's discovery of the Riemannian geometry of space-time. Tensor analysis applied to the differential geometry of space-time, and the covariant expression of relativistic physics. The relativistic generalization of the law of inertia to include gravitation. Offered in 1962-63. Instructor: Estabrook.

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: Christy, Feynman, Frautschi, Gell-Mann, Mathews, Zachariasen.

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. In charge: Anderson, Christy.

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.

PSYCHOLOGY

(See under Philosophy)

RUSSIAN

(See under Languages)

Section VII

DEGREES CONFERRED JUNE 8, 1962

Doctor of Philosophy

Frank Addison Albini (Mechanical Engineering and Philosophy). *B.S., California Institute of Technology, 1958; M.S., 1959.* Thesis: I. Relaxation Time of One-Dimensional, Lamina-Deflagration for First Order Reactions. II. Reflection and Transmission of Electromagnetic Waves at Electron Density Gradients.

Ethan Davidson Alyea, Jr., (Physics and Mathematics). *A.B., Princeton University, 1953.* Thesis: Photoproduction of K^{o} Mesons from Carbon—A Freon Bubble Chamber Experiment.

Don Lynn Anderson (Geophysics and Mathematics). *B.S., Rensselaer Polytechnic Institute, 1955; M.S., California Institute of Technology, 1959.* Thesis: Surface Wave Propagation in Layered Anistropic Media.

Charles Dwight Babcock, Jr. (Aeronautics and Mathematics). *B.S., Purdue University, 1957; M.S., California Institute of Technology, 1958.* Thesis: The Buckling of Cylindrical Shells with an Initial Imperfection under Axial Compression Loading.

William Frederick Beach (Chemistry). *B.S., Rutgers University, 1957.* Thesis: The Structure and Biogenesis of Nidulin.

Ronald David Bercov (Mathematics). *B.Sc. (Hons), University of Alberta, 1959.* Thesis: The Double Transitivity of a Class of Permutation Groups.

Ronald Edmund Brown (Physics). *B.S., University of Washington, 1956.* Thesis: A Study of the 0^{17}(p,alpha)N^{14} Reaction.

Wilbur Parker Brown, Jr. (Electrical Engineering and Physics). *B.S.E., University of Michigan, 1957; M.S.E., 1958.* Thesis: A Theoretical Study of the Scattering of Electromagnetic Impulses by Finite Obstacles.

Robert Everett Carter (Chemistry, Biology). *A.B., Columbia College (New York), 1958.* Thesis: I. The Biogenesis of Phenazine Pigments. II. Beta-Ferrocenyl Carbonium Ions. III. Chemical Shift and pi-Electron Densities.

David Bing Jue Chang (Physics). *B.S., University of Washington, 1956.* Thesis: Synchrotron Radiation as the Source of the Polarized Decimeter Radiation from Jupiter.

Tseng-Hsu Chang (Physics). *B.S., Columbia University, 1955.* Thesis: The Ratio of pi^{0} Photoproductions from Neutrons and Protons in Deuterium in the Energy range of 700 to 1100 mev.

Hung Cheng (Physics). *B.S., California Institute of Technology, 1959.* Thesis: Spin Absorption of Solids.

Donald Delbert Clayton (Physics). *B.S., Southern Methodist University, 1956; M.S., California Institute of Technology, 1959.* Thesis: Studies of Certain Nuclear Processes in Stars. I. Neutron Capture Chains in Heavy Element Synthesis. II. A Search for Excited States in N^{14} Pertaining to the Synthesis of C^{13}.

Richard Lewis Cohen (Physics). *B.S., Haverford College, 1957; M.S., California Institute of Technology, 1959.* Thesis: Mössbauer Effect in $Thulium^{169}$.

Sidney Richard Coleman (Physics). *B.S., Illinois Institute of Technology, 1957.* Thesis: The Structure of Strong Interaction Symmetries.

James Ekstedt Conel (Geology). *B.A., Occidental College, 1955; M.S., California Institute of Technology, 1957.* Thesis: Studies on the Development of Fabrics in Some Naturally Deformed Limestones.

Benjamin Edgar Cummings (Aeronautics). *B.S., California Institute of Technology, 1955; M.S., 1956; Ae.E., 1957.* Thesis: Some Nonlinear Vibration and Response Problems of Cylindrical Panels and Shells.

Melvin Drew Daybell (Physics). *B.S., New Mexico State University, 1956.* Thesis: The Photoproduction of Positive K Mesons in Hydrogen at Large Center of Mass Angles.

Aldo Gene Di Loreto (Electrical Engineering and Physics). *B.S., California Institute of Technology, 1956; M.S., 1957.* Thesis: Noise Optimization Techniques for Linear Transistor Amplifiers.

William Franklin Dove, Jr. (Chemistry). *A.B., Amherst College, 1958.* Thesis: The Helix-Coil Transition in DNA: Effects of Small-ion Interactions and DNA Composition.

Everett Truman Eiselen (Mechanical Engineering and Physics). *B.S., California Institute of Technology, 1956; M.S., 1957.* Thesis: Sound Propagation in Small Diameter Tubes.

Christian Albertus Engelbrecht (Physics). *B.Sc., University of Pretoria, 1955.* Thesis: Photoproduction of Neutral Pions in Complex Nuclei.

James Lawrence Collier Ford, Jr. (Physics). *B.A., Montana State University, 1955; M.S., California Institute of Technology, 1959.* Thesis: The Elastic Scattering of Deutrons by Li^7.

Donald Charles Garwood (Chemistry). *B.A., Kalamazoo College, 1957.* Thesis: Electrophilic Aromatic Substitution of Metallocenes, Stereochemistry of Halogen Addition to 4-1-Butylcyclohexene, Lithium Aluminum Hydride Reduction of CIS-2, 6-Dimethylcyclohexanone.

Richard Morris Goldstein (Electrical Engineering and Physics). *B.S., Purdue University, 1947; M.S., California Institute of Technology, 1959.* Thesis: Radar Exploration of Venus.

R. Clive Greenough (Chemistry). *S.B., Massachusetts Institute of Technology, 1953.* Thesis: I. The Distribution of Antimony (III) between Hydrochloric Acid and Isopropyl Ether. II. The Infrared Spectra and Probable Structures of Some Nitrogen-Sulfur Compounds.

George Drake Guthrie (Biophysics). *A.B., Wabash College, 1954.* Thesis: Studies on the Interaction of Subviral Particles of the Bacteriophage phi X 174 with Protoplasts of *Escherichia coli.*

Andrew Guttman (Mechanical Engineering and Physics). *B.S., College of the City of New York, 1957; M.S., California Institute of Technology, 1958.* Thesis: I. Quantitative Studies of the NO_2–N_2O_4 System in the Infrared. II. Emission of Diffuse Bands of Sodium Behind Shock Fronts.

Alfred Washington Hales (Mathematics). *B.S., California Institute of Technology, 1960.* Thesis: On the Nonexistence of Free Complete Boolean Algebras.

Peter Edgar Hare (Geochemistry). *B.S., Pacific Union College, 1954; M.S., University of California, 1955.* Thesis: The Amino Acid Composition of the Organic Matrix of Some Recent and Fossil Shells of Some West Coast Species of *Mytilus.*

William David Hobey (Chemistry and Physics). *B.S., Tufts University, 1957.* Thesis: Vibronic Interactions in Conjugated Systems.

David Parks Hoult (Aeronautics, Physics). *S.B., Massachusetts Institute of Technology, 1957; M.S., California Institute of Technology, 1958.* Thesis: Magnetohydrodynamic Surface Waves.

Merlin E. H. Howden (Chemistry and Physics). *B.Sc. (Hons), University of Sydney, 1958.* Thesis: I. Carbonion and Free Radical-Type Rearrangements in Homoallylic Systems. II. Nuclear Magnetic Resonance in Cyclopropanes.

Elisha Rhodes Huggins (Physics). *S.B., Massachusetts Institute of Technology, 1955.* Thesis: Quantum Mechanics of the Interaction of Gravity and Electrons: Theory of a Spin-two Field Coupled to Energy.

James Brown Ifft (Chemistry). *B.S., Pennsylvania State University, 1957.* Thesis: A Quantitative Examination of the Buoyant Behavior of Macromolecules of Known Molecular Weight in a Density Gradient at Equilibrium in the Ultracentrifuge.

Philip Ray Kennicott (Chemistry and Physics). *B.S., University of Utah, 1953.* Thesis: Studies in Infrared Spectroscopy.

Kenneth Robert King (Materials Science and Physics). *B.S., California Institute of Technology, 1953; M.S., 1954.* Thesis: Dynamic Shear Deformation in Zinc Crystals.

William Klement, Jr. (Engineering Science). *B.S., California Institute of Technology, 1958.* Thesis: Metastable Structures in Alloys Rapidly Cooled from the Melt.

Joseph Kohler (Mathematics). *B.Sc., Ohio State University, 1957.* Thesis: Finite Groups with All Maximal Subgroups of Prime or Prime Square Index.

Robert Louis Kovach (Geophysics). *Gp.Engr., Colorado School of Mines, 1955; M.A., Columbia University, 1959.* Thesis: Geophysical Investigations in the Colorado Delta Region.

William Kozicki (Chemical Engineering and Chemistry). *B.A.Sc., University of Toronto, 1953; M.A.Sc., 1957.* Thesis: I. Enthalpy Change upon Vaporization of the Hydrocarbons n-Pentane, Cyclohexane and 1-Butane. II. Evaluations of Diffusion Coefficients for the Methane-n-Butane System Based on Gradients in Thermodynamic State Properties.

Marvin Alder Lanphere (Geology). *B.S., Montana School of Mines, 1955; M.S., California Institute of Technology, 1956.* Thesis: I. Geology of the Wildrose Area, Panamint Range, California. II. Geochronologic Studies in the Death Valley-Mojave Desert Region.

Kaye Don Lathrop (Mechanical Engineering and Physics). *B.S., United States Military Academy, 1955; M.S., California Institute of Technology, 1959.* Thesis: Neutron Thermalization in Solids.

Peter Anthony Leermakers (Chemistry). *B.A., Wesleyan University, 1958.* Thesis: I. Chemistry of Low Energy pi-pi* Triplet States. The Photoproduction of 1-Naphthaldehyde and 2-Acetonaphthone. II. Triplet-Triplet Energy Transfer in Solution.

Chung-Yen Liu (Aeronautics). *B.S., Taiwan College of Engineering, 1955; M.S., Brown University, 1958.* Thesis: I. Kinetic Theory Description of Plane, Compressible Couette Flow. II. Kinetic Theory Description of Conductive Heat Transfer from a Fine Wire.

James Reily Lloyd (Mechanical Engineering). *B.S., California Institute of Technology, 1956; M.S., 1957.* Thesis: Wave Propagation in an Elastic Plate Resting on an Elastic Foundation.

Kenneth Lock (Electrical Engineering and Physics). *B.Sc., Battersea Polytechnic Institute (London), 1955; M.Sc., Imperial College of London, 1957.* Thesis: A Digital-Computer-Programmed Topological Method of Coordinate Selection for Numerical Computations in an Electrical Network.

Raymond Paul Lutz (Chemistry). *B.A., University of Florida, 1953; M.S., 1955.* Thesis: I. Mechanism of the Rearrangement of Fenchone. II. Mechanism of the Diels-Alder Reaction.

Norman David Malmuth (Aeronautics). *B.A.E., University of Cincinnati, 1950; M.A.E., Polytechnic Institute of Brooklyn, 1956.* Thesis: Perturbations on Hypersonic Wedge Flow.

Gary Lynn Marlotte (Aeronautics and Physics). *B.S.A.E., Purdue University, 1958; M.S., California Institute of Technology, 1959.* Thesis: An Experimental Investigation of the Effect of a Transverse Flow Velocity upon a Low-Density D.C. Electrical Discharge in Air.

Gerald A. Marxman (Mechanical Engineering and Physics). *B.A., Case Institute of Technology, 1956.* Thesis. Heat Transfer in Reacting Gas Mixtures with Large Pressure Gradients.

Peter Vroman Mason (Electrical Engineering and Physics). *B.S., California Institute of Technology, 1951; M.S., 1952.* Thesis: Surface Impedance of Thin Superconducting Films.

John Francis McCarthy, Jr. (Aeronautics and Physics). *S.B., Massachusetts Institute of Technology, 1950; S.M., 1951.* Thesis: Hypersonic Wakes.

James Arthur McCray (Physics). *A.B., Millikin University, 1954; M.S., Agricultural and Mechanical College of Texas, 1955.* Thesis: The Elastic Scattering of Protons from Li^6 Nuclei.

Martin Mendelson (Animal Physiology and Geobiology). *A.B., Cornell University, 1958.* Thesis: Studies on the Activation of Crustacean Mechanoreceptors. The Movement Receptors of the Crab *Pachygrapsus crassipes* Randall and the Movement and Stretch Receptors of the Crayfish *Procambarus clarkii* (Girard).

Roger Edwin Messick (Engineering Science). *B.S., University of Illinois, 1951; M.S., 1952.* Thesis: Applications of an Edge-and Corner Layer Technique to Elastic Plates and Shells.

F. Curtis Michel (Physics). *B.S., California Institute of Technology, 1955.* Thesis: The Beta Spectra of the Mass 12 Nuclei.

Hugh Thompson Millard, Jr. (Chemistry). *B.A., Coe College, 1957.* Thesis: I. A Procedure for the Analysis of Polonium-210 and Lead-210 in Rocks. II. A Characterization of the Meteorite Flux at the Earth's Orbit.

Charles Robert Miller (Physics and Mathematics). *B.S., California Institute of Technology, 1953.* Thesis: The Orientation of Dust Grains in Interstellar Space.

Richard Stephen Muller (Electrical Engineering and Physics). *M.E., Stevens Institute of Technology, 1955; M.S., California Institute of Technology, 1957.* Thesis: Electronic Processes in Au-CdS-In Diodes.

Gerald Leslie Pollack (Physics and Mathematics). *B.S., Brooklyn College, 1954; M.S., California Institute of Technology, 1957.* Thesis: Heat Flow in Liquid Helium with Clamped Normal Fluid.

R. Darden Powers (Physics). *B.S., University of Oklahoma, 1955; M.S., California Institute of Technology, 1957.* Thesis: The Range of Heavy Ions in Solid Materials.

Richard Bradley Read (Physics). *B.S., California Institute of Technology, 1955.* Thesis: Accurate Declination Measurements of Radio Sources.

Robert Leopold Rosenfeld (Applied Mechanics). *S.B., Massachusetts Institute of Technology, 1959.* Thesis: Analysis of Long Compressional Elastic Waves in Rods of Arbitrary Cross Section and Elastic Wave Fronts in Plates and Circular Rods.

Henry Ruderman (Physics). *B.S., Rensselaer Polytechnic Institute, 1956.* Thesis: Photoproduction of Neutral Pions from Complex Nuclei: An Indirect Measurement of the pi^o Lifetime.

Richard Allan Schapery (Aeronautics). *B.S., Wayne State University, 1957; M.S., California Institute of Technology, 1958.* Thesis: Irreversible Thermodynamics and Variational Principles with Applications to Viscoelasticity.

Edward Joseph Seppi (Physics). *B.S., Brigham Young University, 1952; M.S., University of Idaho, 1956.* Thesis: Nuclear-Resonance Excitation in F^{19} and Mn^{55} with a Germanium Bent-Crystal Monochromator.

Fred Ichiro Shimabukuro (Electrical Engineering and Physics). *S.B., Massachusetts Institute of Technology, 1956; S.M., 1956.* Thesis: A Study of Dispersion in Plasmas.

Donald Cecil Shreffler (Genetics and Chemistry). *B.S., University of Illinois, 1954; M.S., 1958.* Thesis: I. Genetic Studies of Mouse Serum Protein Types. II. Molecular Hybridization of Sheep Hemoglobins.

John Richard Stevens (Physics). *B.A., Pomona College, 1956; M.S., California Institute of Technology, 1959.* Thesis: A Study of the Alpha-Particle Decay from certain Excited Levels in C^{12}, O^{16}, and Ne^{20} Following Population of the Levels by Beta-Decay.

Jack Justin Stiffler (Electrical Engineering). *B.A., Harvard College, 1956; M.S., California Institute of Technology, 1957.* Thesis: Self-Synchronizing Binary Telemetry Codes.

Edwin Jule Stofel (Mechanical Engineering and Physics). *B.S., California Institute of Technology, 1953; M.S., 1954.* Thesis: Plastic Flow and Fracture of Zinc Single Crystals.

Millard Susman (Genetics and Biochemistry). *A.B., Washington University, 1956.* Thesis: The Size of the Mating Group in Bacteriophage T4.

Colwyn Boyd Trevarthen (Psychobiology). *B.Sc., University of New Zealand, 1952; M.Sc., 1954.* Thesis: Studies on Visual Learning in Split-Brain Monkeys.

Emilio Cesare Venezian (Chemical Engineering). *B.Eng., McGill University, 1958; M.S., California Institute of Technology, 1959.* Thesis: I. Temperature Gradients in Turbulent Gas Streams, Effects of Viscous Dissipation on the Evaluation of Total Conductivity. II. Thermal Transfer from Small Wires in the Boundary Flow about a Cylinder.

William Gerard Wagner (Physics). *B.S., California Institute of Technology, 1958.* Thesis: Production and Decay Processes Involving Vector Mesons.

Duen-pao Wang (Engineering Science). *B.S., National Taiwan University, 1956; M.S., Virginia Polytechnic Institute, 1958.* Thesis: A Perturbation Theory for Unsteady Cavity Flows.

Neng-Ming Wang (Engineering Science). *B.S., National Taiwan University, 1955; M.S., University of Texas, 1958.* Thesis: Bending of Thin Elastic Plates Containing Line Discontinuities.

Robert LeRoy Wildey (Astronomy). *B.S., California Institute of Technology, 1957; M.S., 1958.* Thesis: The Stellar Content of the Perseus Galactic Arm in the Region of h and Chi Persei.

Robert Woodrow Wilson (Physics). *B.A., Rice University, 1957.* Thesis: Observations of the Galactic Plane at 960 Megacycles per Second.

Daniel Lewis Wulff (Chemistry). *B.S., California Institute of Technology, 1958.* Thesis: On Nucleic Acid Photochemistry.

Cavour Wei-Hou Yeh (Electrical Engineering). *B.S., California Institute of Technology, 1957; M.S., 1958.* Thesis: Electromagnetic Surface-wave Propagation along a Dielectric Cylinder of Elliptical Cross Section.

Harold Thomas Yura (Physics). *B.S., California Institute of Technology, 1959.* Thesis: The Quantum Electrodynamics of a Medium.

Abraham Zukerman (Aeronautics and Mathematics). *B.S., St. Louis University, 1954; M.S., University of Southern California, 1956; M.S., California Institute of Technology, 1958.* Thesis: Analytical Approximations to the Solutions of the Equations of Motion in the Earth Moon Space.

Engineer's Degree

AERONAUTICAL ENGINEER

John Carl Casey, Major, U.S.A.F. *B.S., Purdue University, 1955; M.S., California Institute of Technology, 1961.*

Douglas Stoddard Johnson, Capt., U.S.A.F. *B.S., United States Military Academy, 1956; M.S., California Institute of Technology, 1961.*

Grant Reed Johnson, Lt., U.S.N. *B.S., University of Utah, 1955; B.S., United States Naval Postgraduate School, 1961.*

Werner Preukschat. *Dipl. Ing., Technische Hochschule (Aachen), 1959.*

Kendrick Radey. *B.S.Ae.,E., University of Texas, 1947; M.S., California Institute of Technology, 1951.*

Marc L. Renard. *I.C.M.E., Faculte Polytechnique de Hons (Belgium), 1959; I.Co.Ae., Universite Libre de Bruxelles, 1960.*

Stuart Blackton Savage. *B.Eng. (Hons), McGill University, 1960; M.S., California Institute of Technology, 1961.*

Ernest Richard Seymour, Lt., U.S.N. *B.S., United States Naval Academy, 1953; B.S., United States Naval Postgraduate School, 1961.*

Jerry Lee Simmons. *B.S., University of Kansas, 1959; M.S., 1960.*

George Arthur Watts. *M.A. Sc., University of Toronto, 1956.*

Master of Science in Science

ASTRONOMY

Glenn LeRoy Berge. *B.A., Luther College, 1960.*

Manuel E. Mendez. *B.S., University of Mexico, 1960.*

CHEMISTRY

Bernard Foran. *B.Sc. (General), London University, 1951; B.Sc. (Special), 1952.*

Seymour Alvin Rapaport. *B.S.,California Institute of Technology, 1957; M.D., The Johns Hopkins University School of Medicine, 1961.*

Masaaki Takahashi. *B.S., Tohoku University, 1955.*

CHEMICAL ENGINEERING

Thomas Elöd Berty. *Dipl. M.E., Polytechnical University of Budapest, 1954.*

Shiou-Shan Chen. *Dipl., Taipei Institute of Technology, 1958.*

Dennis Jerome Graue. *B.S., University of Colorado, 1961.*

Johannes Huisman. *Associateship Dipl. in Applied Chemistry, Royal Melbourne Technical College, 1956; Associateship Dipl. in Chemical Engineering, 1959.*

John James Kennedy. *B.S., California Institute of Technology, 1961.*

Roy Nathan Levitch. *B.Ch.E., Rensselaer Polytechnic Institute, 1961.*

Chung-Chiun Liu. *B.S., Cheng-Kung University, 1959.*

William Joseph Moore. *S.B., Massachusetts Institute of Technology, 1958.*

Milton Edward Morrison. *B.S., Iowa State University, 1961.*

Wei-yu Francis Wang. *B.S., California Institute of Technology, 1961.*

GEOLOGY

Stewart Douglas McDowell. *B.S., Pennsylvania State University, 1960.*

David Lawrence Schleicher. *B.S., Pennsylvania State University, 1959.*

GEOCHEMISTRY

Dennis Roland Wik. *B.S., Beloit College, 1960.*

GEOPHYSICS

Alexander Franklin Hermann Goetz. *B.S., California Institute of Technology, 1961.*

Jean Marie Noël. *Dipl., Université de Strasbourg, 1961.*

Robert James Quigley. *B.S., California Institute of Technology, 1961.*

MATHEMATICS

James Secord Howland. *B.S., University of Florida, 1959.*

Robert Leroy Kruse. *B.A., Pomona College, 1960.*

PHYSICS

David George Agresti. *B.S., The Ohio State University, 1959.*

Norman Webster Albright. *B.S., California Institute of Technology, 1956.*

Donald Milford Baker. *B.S., University of Colorado, 1960.*

Larry Dean Fitzgerald. *B.S., United States Military Academy, 1956.*

Paul Walton Purdom, Jr. *B.S., California Institute of Technology, 1961.*

Harvey Kenneth Shepard. *B.S., University of Illinois, 1960.*
Henry Archer Thiessen. *B.S., California Institute of Technology, 1961.*

Master of Science in Engineering

AERONAUTICS

Nazeer Ahmed. *B.E., University of Mysore, 1961.*

Anthony Bedford. *B.S., University of Texas, 1961.*

Jean-Pierre Dorlhac. *Dipl. d'Ing. de l'Aéronautique, Ecole Nationale Supérieure de l'Aéronautique, 1961.*

Joseph Paul Giesing. *B.S., University of Colorado, 1961.*

Scott Edwin Gilles. *B.S., University of Kansas, 1961.*

J. Stuart Keith. *B.S, The Rice Institute, 1958.*

John Michael Klineberg. *B.S.E., Princeton University, 1960.*

Joseph Carby Mendez, Jr. *B.A.E., Georgia Institute of Technology, 1961; M.S., 1962.*

John Fletcher Murphy. *B.S., University of Notre Dame, 1957.*

John Louis Porter. *B.S., University of Kansas, 1961.*

Paul Ridder Rupert. *B.S., University of Oklahoma, 1961.*

Stottler King Starr. *B.S., Purdue University, 1961.*

Charles Fleming Stebbins. *B.S., United States Air Force Academy, 1961.*

Floyd Ronald Stuart. *B.S., United States Naval Academy, 1957.*

Viviane Claude Tatin. *Dipl. d'Ing. de l'Aéronautique, Ecole Nationale Supérieure de l'Aéronautique, 1961.*

Richard R. Williams. *B.S., Purdue University, 1961.*

APPLIED MECHANICS

Clark Reid Barker. *B.S.M.E., Bradley University, 1961.*

CIVIL ENGINEERING

Clement Charles Audet. *B.Sc.A., Université Laval, 1960.*

Carlos Miguel Campuzano. *B.S., University of Kansas, 1959.*

Robert Glen Coyer. *B.S., Tufts University, 1961.*

Gidali Gutner. *Dipl. d'Ing., Ecole Nationale d'Ingénieurs des Arts et Métiers, 1961.*

ELECTRICAL ENGINEERING

Ward Calaway. *B.S., California Institute of Technology, 1961.*

Tsiu Chiu Chan. *B.Eng., McGill University, 1961.*

Robert Gorham Chapman, Jr. *B.S.E., Princeton University, 1961.*

Donald Henry Close. *B.S., University of Kansas, 1960.*

Michel M. Cousin. *Dipl. d'Ing., Ecole Nationale Supérieure Télécommunications, 1961.*

Michel d' Arbaumont. *Dipl. d'Ing., Ecole Nationale Supérieure Télécommunications, 1961.*

Kirk Montell Dawson. *A.B., Occidental College, 1961; B.S., California Institute of Technology, 1961.*

Rodney Devon Dokken. *B.S., California Institute of Technology, 1961.*

Richard Harold Drew. *B.S., California Institute of Technology, 1961.*

Jean Claude Dubois. *Dipl. d'Ing. Civil Electricien-Mécanicien, Université Catholique de Louvain, 1958.*

Richard Carl Eden. *B.S., Iowa State University, 1961.*

Claude Michel Alain Fugere. *Dipl. d'Ing., Ecole Nationale d'Ingénieurs Arts et Métiers, 1961.*

Alfred Frans Gort. *Cand., Technische Hageschool (Eindhoven), 1962.*

Clovis Roland Haden. *B.S., Arlington State College, 1961.*

Stanley Richmond Harrison. *B.S., California Institute of Technology, 1948.*

Milton Jay Kimmell. *B.S., California Institute of Technology, 1956; B.D., Fuller Theological Seminary, 1959.*

Ronald Allan Kleban. *B.S., California Institute of Technology, 1961.*

Curtis Frederick Kuebler. *B.S., California Institute of Technology, 1961.*

Bruce Thomas Kujawski. *B.S., Case Institute of Technology, 1961.*

Guy Jean Lafont. *Dipl. de Mathématiques Générales, Université de Paris, 1958; Dipl. d'Ing., Ecole Supérieure d'Electricité de Paris, 1961.*

Orval George Lorimer. *B.S., Iowa State University, 1961.*

Helmut K. V. Lotsch. *Dipl. Ing., Technische Hochschule (Karlsruhe), 1958.*

Bruce Albright Lovell. *B.E., Rensselaer Polytechnic Institute, 1961.*

Donald Edward Mack. *B.E.E., Union College, 1957.*

Osorio Chagas Meirelles. *B.Sc., Universidade do Brasil, 1960.*

Albert Watts Merrill. *B.S., California Institute of Technology, 1961.*

Padraic Declan O'Riordan. *B.E., National University of Ireland (Cork), 1959.*

Dennis Lorin Paull. *B.S., California Institute of Technology, 1959.*

Jean Claude Rivet. *Dipl. d'Ing., Ecole Supérieure d'Electricité de Paris, 1961.*

Michael Richard Ruecker. *B.S., California Institute of Technology, 1961.*

William Keith Shubert. *B.S., California Institute of Technology, 1961.*

John Robert Smith. *B.S., California Institute of Technology, 1961.*

John Paul Stenbit. *B.S., California Institute of Technology, 1961.*

Raynold Allen Svenson. *B.S., Michigan College of Mining and Technology, 1961.*

David Price Turner. *B.S., California Institute of Technology, 1961.*

Christ Orlando Velline. *B.S., California Institute of Technology, 1961.*

Gustav Nicholas Wassel. *B.S., California Institute of Technology, 1960.*

Martin Cameron Watson. *B.S.E., Princeton University, 1961.*

Maurice Vincent Whelan. *B.E., National University of Ireland (Cork), 1960.*

Jerry Doane Woods. *B.S., California Institute of Technology, 1961.*

ENGINEERING SCIENCE

Robert E. Singleton. *B.S., North Carolina State College of Agriculture and Engineering, 1960.*

MATERIALS SCIENCE

Don Paul Clausing. *B.S., Iowa State College, 1952.*

Donald Bozell Forrest. *B.S., California Institute of Technology, 1961.*

William Franklin Greenman. *B.S., California Institute of Technology, 1960.*
John Raymond Hribar. *B.S., California Institute of Technology, 1961.*
Ronald Keith Linde. *B.S., University of California, 1961.*
David Peter Pope. *B.S., University of Wisconsin, 1961.*
Om Parkash Puri. *B.Sc., Panjab University, 1950; M.Sc., 1951.*
John Burgess Trenholme. *B.S., California Institute of Technology, 1961.*

MECHANICAL ENGINEERING

Vincent George Aquino. *B.S., University of Portland, 1957.*
Robert Hugh Brown. *B.S., Bucknell University, 1961.*
Ben Graham Burke. *B.S., California Institute of Technology, 1961.*
Terrill Alan Cool. *B.S., University of California, 1961.*
John Edward Fischer. *B.M.E., Rensselaer Polytechnic Institute, 1961.*
Lawrence William Hallanger. *B.S., Harvey Mudd College, 1961.*
Paul Yu-fei Hu. *B.S., University of Maryland, 1961.*
Marlyn T. Jakub. *B.S., Carnegie Institute of Technology, 1958.*
Robert Joe Johnson. *B.M.E., Georgia Institute of Technology, 1958.*
David Walter Kendle. *B.S., California Institute of Technology, 1961.*
Hugh Kendrick. *B.Sc., University of London, 1961.*
Hans Ludewig. *B.Sc., University of Natal, 1960.*
Sami Faiz Masri. *B.S., University of Texas, 1960; M.S., 1961.*
Jackie Ross McInturff. *B.E., Vanderbilt University, 1960.*
Stanley Brun Mellsen. *B.Sc., University of Alberta, 1961.*
Edward Otto Moeck. *B.Sc., Queen's University, 1961.*
Carlos William Moreno. *B.S., Case Institute of Technology, 1961.*
Neil Ray Richardson. *B.S., California Institute of Technology, 1961.*
John Charles Stansel. *B.S., University of Utah, 1961.*

Bachelor of Science

Bruce Reggie Abell, Los Angeles, California. *Geology.*
Ahmad Khalil Abu-Shumays, Beirut, Lebanon. *Engineering.*
Lawrence Jay Altman, Chicago, Illinois. *Chemistry.*
John Theodore Armstrong, Jr., Lemoore, California. *Engineering.*
John Henry Arndt, Jr. San Rafael, California. *Chemical Engineering.*
Ray Charles Barglow, Denver, Colorado. *Physics.*
Carl Edward Baum, Syracuse, New York. *Engineering.*
Lon Edward Bell, Santa Cruz, California. *Mathematics.*
Rupert Charles Bell, Grand Rapids, Michigan. *Physics.*
David Bernard Benson, Los Alamos, New Mexico. *Engineering.*
Allen Lee Berman, Culver City, California. *Physics.*
Allen Richard Bernstein, Chicago, Illinois. *Mathematics.*
John William Berry, Jr., Corpus Christi, Texas. *Biology.*
Thomas Robert Blakeslee, Winnetaka, Illinois. *Engineering.*
Robert Louis Blinkenberg, Minneapolis. *Physics.*
Ronald David Boettcher, Buena Park, California. *Engineering.*
Richard Charles Brandt, Swarthmore, Pennsylvania. *Physics.*
Richard Craig Brosi, Janesville, Wisconsin. *Chemical Engineering.*
Stephen Whitney Bruenn, Riverdale, New York. *Physics.*
Robert Bernard Bump, Cherry Hills, Colorado. *Engineering.*
Richard Gary Burke, Pasadena, California. *Engineering.*
Robert Marvin Cadwell, Evanston, Illinois. *Engineering.*
David G. Carta, Pasadena, California. *Physics.*
Gary Craig Chamness, Santa Barbara, California. *Biology.*
Dick Mei Chang, Hong Kong, British Crown Colony. *Physics.*
Wilfred Peter Charette, Lincoln, New Hampshire. *Engineering.*
Seung Chul Choy, Seoul, Korea. *Physics.*
Joseph Carl Christensen, Manhattan Beach, California. *Engineering.*
Reginald Willis Clemens, Hollywood, California. *Physics.*
Edward Thomas Cline, Jr., Downers Grove, Illinois. *Mathematics.*
Gerald Wayne Clough, Concord, California. *Engineering.*
James Edward Cordes, Temple City, California. *Engineering.*
Matthew Miller Couch, Pasadena, California. *Chemistry.*
Thomas Edwin Creighton, St. Louis, Missouri. *Biology.*
John Dean Crossman, Squantum, Massachusetts. *Engineering.*
Steven Collins Crow, Arcadia, California. *Engineering.*
John Delafield Curtis, Washington, D.C. *Astronomy.*
Alan Bernard Dauger, Sacramento, California. *Physics.*
Ted H. Davey, Phoenix, Arizona. *Engineering.*
James I. Davis, Los Angeles, California. *Physics.*

Students whose names appear in boldface type graduated with scholastic honor in accordance with a vote of the Faculty.

Larry Ralph Dawson, Sunnymead, California. *Engineering.*
Lonnie Keith DeMent, Mt. Prospect, Illinois. *Chemical Engineering.*
Kerry Lane Donovan, Arlington, Virginia. *Biology.*
David Willis Drummond, Chicago, Illinois. *Biology.*
David Kitzmiller Edwards III, Lexington, Kentucky. *Biology.*
Lee Edward Elliott, Topeka, Kansas. *Engineering.*
Peter George Eltgroth, Tujunga, California. *Physics.*
William Richard Emerson, Los Angeles, California. *Mathematics.*
Victor Solomon Engleman, Northport, New York. *Chemical Engineering.*
William Elliston Farrell, Long Beach, California. *Physics.*
Stanley Martin Flatte, Los Angeles, California. *Physics.*
Charles Milton Flynn, Jr., Sherman Oaks, California. *Chemistry.*
Peter Campbell Ford, Porterville, California. *Chemistry.*
Gary Scott Fraley, Atascadero, California. *Physics.*
Samuel Theodore Furr, Los Angeles, California. *Engineering.*
Ronald Frank Gebhardt, Coos Bay, Oregon. *Geology.*
Porter Dean Gerber, Santa Fe, New Mexico. *Mathematics.*
Robert Gershman, Scranton, Pennsylvania. *Chemical Engineering.*
John Robert Golden, Des Moines, Iowa. *Engineering.*
Barry Alan Gordon, Los Altos, California. *Physics.*
Charles Sherman Gratch, Chicago, Illinois. *Physics.*
Donald William Green, Pasadena, California. *Physics.*
Neil Edward Gretsky, Boston, Massachusetts. *Mathematics.*
Randall Bertram Griepp, Redondo Beach, California. *Biology.*
David Cantrell Grimes, Burbank, California. *Engineering.*
John Moss Grover, Annapolis, Maryland. *Mathematics.*
Harrison Babcock Hall, Encino, California. *Engineering.*
Frederick John Hameetman, Lomita, California. *Engineering.*
Carl Wayne Hamilton, West Plains, Missouri. *Mathematics.*
Lyndon Mauriece Hardy, Los Angeles, California. *Physics.*
Vincent Charles Hascall, Jr., Longmont, Colorado. *Biology.*
William Verne Hassenzahl, Bell Gardens, California. *Physics.*
Robert Henderson Hearn, Phoenix, Arizona. *Engineering.*
Stephen Fox Heinemann, Cambridge, Massachusetts. *Biology.*
Joseph Heller, Santa Monica, California. *Mathematics.*
David Nelson Herting, Ventura, California. *Engineering.*
Richard Irwin Hess, Los Angeles, California. *Physics.*
Howard Thorndike Hilton, San Gabriel, California. *Physics.*
William John Hogan, Riverside, California. *Physics.*
Charles Henry House, Pasadena, California. *Engineering.*
Evan Eugene Hughes, Jr., Los Angeles, California. *Physics.*
Wendell Yau Git Ing., Honolulu, Hawaii. *Physics.*
Lester Ingber, Brooklyn, New York. *Physics.*
James Hayden Johnson, Oxnard, California. *Physics.*
Arnold Richard Jones, Manhattan, Kansas. *Engineering.*

Roy Scott Jordan, Clinton, Iowa. *Engineering.*
Howard Arthur Kabakow, Los Angeles, California. *Physics.*
David Kauffman, Jenkintown, Pennsylvania. *Chemical Engineering.*
William Chung King, Hong Kong, British Crown Colony. *Engineering.*
James Dean Klett, Los Angeles, California. *Physics.*
Robert Koh, Allentown, Pennsylvania. *Engineering.*
Lawrence Dean Kugler, San Jacinto, California. *Mathematics.*
Harold Charles Kurtz, Rockville Center, New York. *Mathematics.*
Michael Logan Lampton, Santa Monica, California. *Physics.*
Robert George Langsner, Sacramento, California. *Mathematics.*
Kenneth Curtis Larson, Kirkland, Washington. *Chemical Engineering.*
Peter Alan Laszlo, Beverly Hills, California. *Mathematics.*
Miguel Enrique Levy, San Salvador, El Salvador. *Engineering.*
Robert Peichung Lin, Los Angeles, California. *Physics.*
Stuart Michael Linn, Los Angeles, California. Chemistry.
Thomas James Litle IV, Grosse Point, Michigan. *Engineering.*
Gary Allen Lorden, Los Angeles, California. Mathematics.
Arthur Charles Ludwig, Sun Valley, California. *Engineering.*
Waldemar Traugott Lungershausen, Jr., Detroit, Michigan. *Astronomy.*
Alexander Newell Lyon, Huntington, New York. *Chemistry.*
Robert Jerome Manning, Dallas, Texas. *Physics.*
Etan Markowitz, Los Angeles, California. *Mathematics.*
Harold Everett Marr III, Searsport, Maine. *Chemistry.*
Franklin Lester Marshall, Burbank, California. *Engineering.*
Garland Ross Marshall, College Station, Texas. *Biology.*
Keith Matthews, Staten Island, New York. *Physics.*
Arthur Francis McGarr III, Portland, Oregon. *Physics.*
Daniel Webster McMorris, Los Angeles, California. *Physics.*
Lauren Vail Merritt, Kensington, California. *Engineering.*
Peter Lee Metcalf, Los Angeles, California. *Chemical Engineering.*
Edward Standish Miller, Berkeley, California. *Physics.*
Gary Francis Mitchell, Glen Ellyn, Illinois. *Chemistry.*
Ralph Crittenden Moore, Denver, Colorado. *Physics.*
James Marshall Moorhead, San Mateo, California. *Astronomy.*
Frank Edward Mullin, Los Gatos, California. *Mathematics.*
John Anthony Newmeyer, Los Angeles, California. *Physics.*
Donald Arthur Nisewanger, Orange Cove, California. *Physics.*
Julian Victor Noble, Roslyn Heights, New York. *Physics.*
Roger Gordon Noll, Oceanside, California. *Mathematics.*
David Justin Osias, Chevy Chase, Maryland. *Physics.*
Bunso Otani, Altadena, California. *Engineering.*
William E. Palke, St. Petersburg, Florida. *Chemistry.*
Michael Thomas Palmiter, Alhambra, California. *Mathematics.*
Julian Frederick Prince, Newton, Massachusetts. *Mathematics.*
David Edward Pritchard, Haddonfield, New Jersey. *Physics.*

Charles Howard Radoy, Los Angeles. *Engineering.*
Frank Ridolphi, Montgomery, Alabama. *Engineering.*
David Herbert Rogstad, Los Angeles, California. *Physics.*
Daniel Fredric Romm, Los Angeles, California. *Mathematics.*
George Robert Root, Jr., Arcadia, California. *Engineering.*
Robert Talman Ross, San Marino, California. *Chemistry.*
Robert Henry Rouda, Los Angeles, California. *Chemistry.*
Carl M. Rovainen, Excelsior, Minnesota. *Biology.*
Robert Charles Ruddick, Houston, Texas. *Physics.*
John Christian Russ, Philadelphia, Pennsylvania. *Engineering.*
Robert Kent Russell, Fullerton, California. *Engineering.*
Peter T. Rux, Van Nuys, California. *Physics.*
George Thomas Sallee, Nyssa, Oregon. *Mathematics.*
Lawrence Neal Sealey, Freeport, Texas. *Mathematics.*
David Lee Sellin, Milwaukee, Wisconsin. *Physics.*
Douglas Smith, St. Joseph, Missouri. *Geology.*
Gaetan Joseph St-Cyr, East Hampton, Connecticut. *Engineering.*
William Charles Straka, Phoenix, Arizona. *Astronomy.*
Nelson Peter Svegel, Phoenix, Arizona. *Engineering.*
Robert James Tait, Burbank, California. *Engineering.*
Lance Jerome Taylor, Montpelier, Idaho. *Mathematics.*
Warren Teitelman, Miami, Florida. *Mathematics.*
Joel Tenenbaum, Queens Village, New York. *Physics.*
Don Ray Thompson, Little Rock, Arkansas. *Physics.*
Kip Stephen Thorne, Logan, Utah. *Physics.*
William Frederic Tivol, San Francisco, California. *Physics.*
Michael Jellison Townsend, Sherman Oaks, California. *Engineering.*
Gary Burgess Turner, Phoenix, Arizona. *Engineering.*
William Henry Weihofen, Albuquerque, New Mexico. *Physics.*
Frederick Wesley Weingarten, Jr., Covina, California. *Engineering.*
Albert Charles Whittlesey, Portland, Oregon. *Physics.*
Robert Stephen Williams, Baton Rouge, Louisiana. *Physics.*
Hal Holcomb Wyman, Seattle, Washington. *Mathematics.*
Joel R. Yellen, Lakewood, California. *Physics.*
James Yoh, New York, New York. *Engineering.*
Geary Ralph Younce, Hillsboro, Oregon. *Engineering.*
Albert Richard Zacher, Jr., Fresno, California. *Physics.*
Alan Zame, Coral Gables, Florida. *Mathematics.*

CANDIDATES FOR COMMISSIONS
UNITED STATES AIR FORCE
RESERVE OFFICERS TRAINING CORPS

Carl Edward Baum*

Gary Craig Chamness

Reginald Willis Clemens

Victor Solomon Engleman

Roy Scott Jordan

David Kauffman*

**Distinguished Air Force Reserve Officers Training Corps Graduate*

The following candidate has completed all academic requirements, and will be commissioned 25 August, 1962, upon completion of Summer Training.

George Raynor Muenich III

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 1961-62.

CLASS OF 1963

Henry Don Abarbanel
Daniel John Alderson
Edward Anton Bender
William Lionel Burke
Robert Louis Causey
Bruce Wilcox Chesebro
Jan William Dash
Donald Robert Davis
Lawrence Kenneth Gershwin
Richard William Griffith
Roger Calvert Hill
John Michael Hosack
John Andrew Kiger
Allan Roy King
John Hathaway Lindsey, II
Barry Malcolm McCoy
James Allen Morrow
Michael David Perlman
Allen Michael Pfeffer
Raymond Herman Plaut
Stephen William Prata
Neil Paul Rosenthal
Charles Albert Ryavec
George Fredrick Soule
Willard Gibbs Spiegelman
Kenneth Barry Stolarsky
Karvel Kuhn Thornber
Ivar Harald Tombach
Warren Humphreys White
Alan Cameron Wright
Steven Joseph Yellin
Albert Yeou Yu

CLASS OF 1964

Richard Ray Burgess
John Robert Burke
Bob Li-shyng Ching
David Lem Colton
Francis Anthony Dahlen, Jr.
Duygu Mehmet Demirlioglu
Herbert Roy Flindt
Samuel Robert Gordon
Ray E. L. Green
Mark Northrop Gurnee
Richard Danforth Hake, Jr.
David Andrew Hammer
Alan Carleton Hindmarsh
David Holtz
Kwok-Chu Leung
Tommy Carl Luboeansky
Roderick Canfield McCalley
Richard Paul McGehee
Roger Leon Minear
Robert Alan Moline
George Norman Reeke, Jr.
Dennis Kent Ross
Arthur Turner
Volker Michael Vogt
Martin Eric Weiner
Joseph Herman Weis
Paul Frank Winkler, Jr.
Alvin Bau Yuen Young

CLASS OF 1965

Robert Joseph Barro
John Harden Beamer
George Conrad Brackett
I-Lok Chang
Jack Clifton Comly
Kris David Davidson
Roger Carl Davisson
Nicholas I-Tsing Djeu
Richard Charles Essenberg
Mark Joel Gingold
Donald Webb Green
Kenneth Steven Kauffmann
Kenneth Kunen
Allan Goddard Lindh
Kenneth Kiyoshi Murata
Lee Neidengard
Jerry Earl Nelson
Dimitrios Anastassios Papanastassiou
Thomas Antone Pucik
Ronald Sylvester Remmel
Hanan Rosenthal
William Franklin Satterthwaite
Edwin Paul Swatek, III
Larry Dawson Wittie

Frederic W. Hinrichs, Jr., Memorial Award

Awarded annually to the "senior who, in the opinion of the undergraduate Deans, has throughout his years at the Institute made the greatest contribution to the welfare of the student body and whose qualities of leadership, character and responsibility have been outstanding."

PORTER DEAN GERBER

Don Baxter, Inc., Prizes in Chemistry

Awarded to the undergraduate students who during the year have carried out the best original researches in chemistry.

First Prize: ROBERT L. CAUSEY

Second Prize: DONALD R. DAVIS

Conger Peace Prize Oration

Established in 1912 by Everett D. Conger, D.D.

First Prize: ROGER GORDON NOLL

Second Prize: KIP STEPHEN THORNE

Eastman Kodak Scientific Awards

Awarded to doctoral students on the basis of outstanding contributions and progress either in graduate studies and research or in teaching.

Chemistry: ALVIN L. KWIRAM

Physics: SIDNEY RICHARD COLEMAN

Institute of the Aerospace Sciences Award

Awarded to the student member of the I.A.S. attaining the best scholastic record in engineering or the physical sciences.

MRS. YING-CHU LIN WU

David Joseph Macpherson Prize

Awarded annually to the graduating senior in engineering who best exemplifies excellence in scholarship.

STEVEN COLLINS CROW

Mary A. Earle McKinney Prize in English

Established in 1946 by Samuel P. McKinney, M.D., as a memorial to his mother.

NO AWARDS MADE 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.

ROBERT D. BRUNER

RICHARD A. D'ARI

JAN W. DASH

LAWRENCE K. GERSHWIN

Society of American Military Engineers Gold Medal

Awarded annually by the National Society of American Military Engineers to each of 20 Air Force ROTC cadets selected nationwide from Air Science 3 and 4 classes for outstanding achievement as an engineering student.

CARL E. BAUM

Armed Forces Chemical Association Medal

Awarded annually by the Armed Forces Chemical Association to a junior or senior Air Force ROTC cadet who is majoring in chemistry or chemical engineering, based on leadership ability, initiative, and scholastic attainment.

VICTOR S. ENGLEMAN