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CALTECH INFORMATION FOR STUDENTS

Information for Students

1973–1974

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CONTENTS

KEY TO ABBREVIATIONS

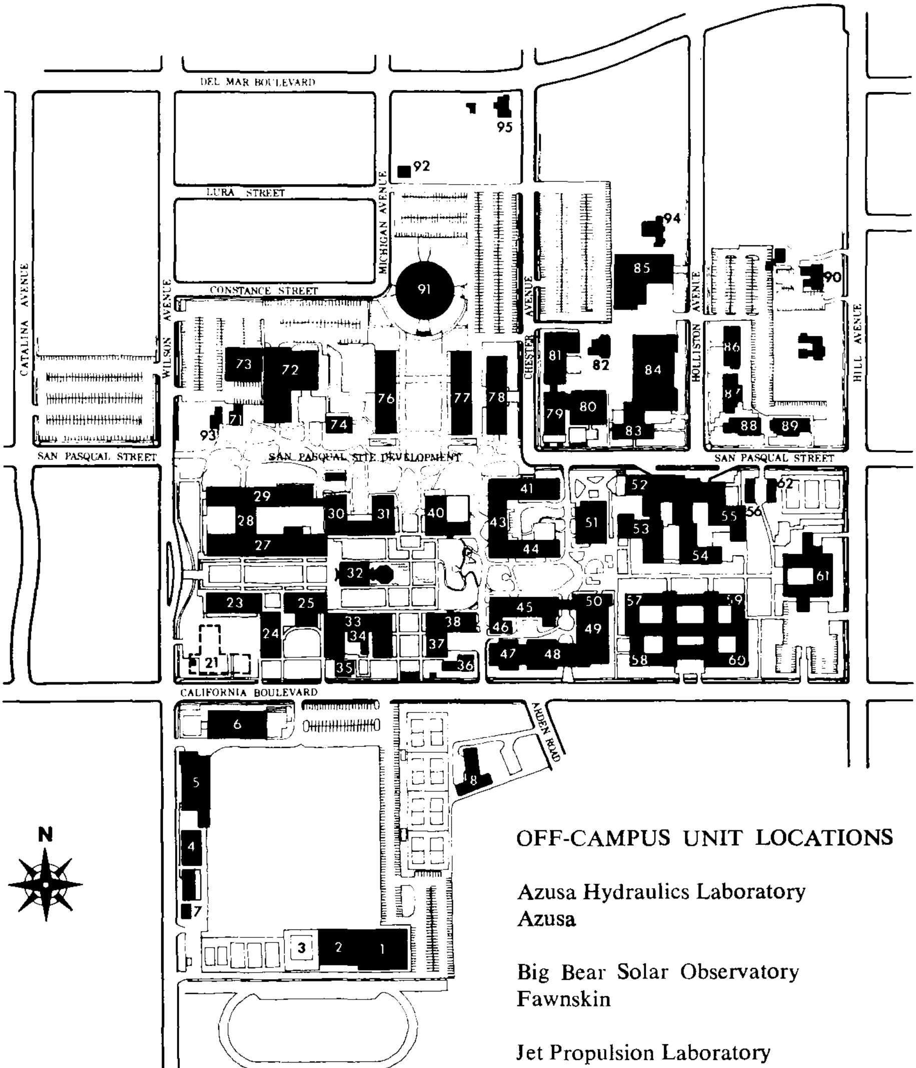
Aeronautics	Ae
Air Force Aerospace Studies	AS
Anthropology	An
Applied Mathematics	AMa
Applied Mechanics	AM
Applied Physics	APh
Astronomy	Ay
Biology	Bi
Chemical Engineering	ChE
Chemistry	Ch
Civil Engineering	CE
Economics	Ec
Electrical Engineering	EE
Engineering	E
Engineering Graphics	Gr
Engineering Science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

ACADEMIC CALENDAR 1973-74

1973	First Term
September 19	Registration of entering freshmen — 1:00 p.m.-3:00 p.m.
September 20-22	New Student Orientation
September 24	General Registration — 8:30 a.m.-3:30 p.m.
September 24	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
September 25	Beginning of instruction — 8:00 a.m.
October 12	Last day for adding courses and changing sections
October 13	Examinations for the removal of conditions and incompletes
October 29-November 2	Mid-Term week
November 2	Last day for admission to candidacy for Master's and Engineer's degrees
November 3	MID-TERM
November 5	Mid-Term deficiency notices due — 9:00 a.m.
November 12-16	Pre-registration for second term, 1973-74
November 22-25	Thanksgiving recess
November 22-23	Thanksgiving holidays for employees
November 30	Last day for dropping courses
December 8-14	Final examinations, first term 1973-74
December 15	End of first term, 1973-74
December 16-30	Christmas recess
December 17	Instructors' final grade reports due — 9:00 a.m.
December 24-25	Christmas holidays for employees
1974	**Second Term**
December 31-January 1	New Year's Day holidays for employees
January 7	General Registration — 8:30 a.m.-3:30 p.m.
January 7	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
January 8	Beginning of instruction — 8:00 a.m.
January 25	Last day for adding courses and changing sections
January 26	Examinations for the removal of conditions and incompletes
February 11-15	Mid-Term week
February 16	MID-TERM
February 18	Mid-Term deficiency notices due — 9:00 a.m.
February 25-29	Pre-registration for third term, 1973-74
March 8	Last day for dropping courses
March 16-22	Final examinations, second term 1973-74
March 22	Last day for admission to candidacy for the degree of Doctor of Philosophy
March 23	End of second term, 1973-74
March 24-31	Spring recess
March 25	Instructors' final grade reports due — 9:00 a.m.
	Third Term
April 1	General Registration — 8:30 a.m.-3:30 p.m.
April 1	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
April 2	Beginning of instruction — 8:00 a.m.

1974	Third Term (continued)
April 19	Last day for adding courses and changing sections
April 20	Examinations for the removal of conditions and incompletes
May 6-10	Mid-Term week
May 11	MID-TERM
May 13	Mid-Term deficiency notices due — 9:00 a.m.
May 17-18	Examinations for admission to upper classes, September 1974
May 20-24	Pre-registration for first term 1974-75, and registration for summer research (graduate and undergraduate)
May 24	Last day for dropping courses
May 27	Memorial Day holiday
May 31	Last day for final oral examinations and presentation of theses for the degree of Doctor of Philosophy
May 31	Last day for presenting theses for Engineer's degree
June 1-7	Final examinations for senior and graduate students, third term 1973-74
June 8-14	Final examinations for undergraduate students, third term 1973-74
June 10	Instructors' final grade reports due for seniors and graduate students — 9:00 a.m.
June 12	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
June 12	Curriculum Committee — 10:00 a.m.
June 12	Faculty Meeting — 2:00 p.m.
June 13	Class Day
June 14	Commencement
June 15	End of third term, 1973-74
June 17	Instructors' final grade reports due for undergraduate students — 9:00 a.m.
June 21	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
July 4	Independence Day holiday for employees
September 2	Labor Day holiday for employees

1974	First Term 1974-75
September 18	Registration of entering freshmen — 1:00 p.m.-3:00 p.m.
September 19-21	New Student Orientation
September 23	General registration — 8:30 a.m.-3:30 p.m.
September 24	Beginning of instruction — 8:00 a.m.



OFF-CAMPUS UNIT LOCATIONS

Azusa Hydraulics Laboratory
Azusa

Big Bear Solar Observatory
Fawnskin

Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena

Kerckhoff Marine Laboratory
Corona Del Mar

Owens Valley Radio Observatory
Big Pine

Palomar Observatory
Mayer Observatory
Palomar Mountain
San Diego County

Seismological Laboratory
295 N. San Rafael Avenue, Pasadena

CAMPUS DIRECTORY

Information — 1107 San Pasqual (Building 71)

2. Air Force ROTC — 1350 San Pasqual Street
8. Alles Laboratory (Molecular Biology)
3. Alumni Swimming Pool
3. Architect, Campus
5. Arms Laboratory (Geological and Planetary Sciences)
1. Athenaeum (Faculty Club)
7. Baxter, Donald E., M.D., Hall (Humanities and Social Sciences)
7. Baxter Lecture Hall
1. Beckman Auditorium
6. Behavioral Biology Building
0. Blacker House (Undergraduate Residence)
1. Bookstore (Student Center)
9. Booth Computing Center
8. Braun House (Graduate Residence)
3. Bridge Laboratory (Physics)
1. Brown Gymnasium
4. Campbell Laboratory (Plant Research)
5. Central Engineering Services
5. Central Plant
2. Chandler Dining Hall
3. Chemical Engineering Laboratory
3. Chemistry Laboratory, Undergraduate
9. Church Laboratory (Chemical Biology)
3. Coffeehouse, Student
4. Cooling Tower Buildings
4. Cosmic Ray Laboratory
0. Crellin Laboratory (Chemistry)
0. Dabney Hall (Administration, EQL, and Humanities)
8. Dabney House (Undergraduate Residence)
6. Development Offices
7. Downs Laboratory (Physics)
0. Firestone Laboratory (Flight Sciences and Applied Mathematics)
7. Fleming House (Undergraduate Residence)
1. Gates Building
7. Grounds Operations Office
5. Guggenheim Laboratory (Aeronautics and Applied Physics)
0. Industrial Relations Center
5. Isotope Handling Laboratory
0. Jorgensen Laboratory (Information Science)
6. Karman Laboratory (Fluid Mechanics and Jet Propulsion)
6. Keck House (Graduate Residence)

78. Keck Laboratory (Environmental Engineering and Materials Science)
38. Kellogg Radiation Laboratory
27. Kerckhoff Laboratory (Biological Scienc
48. Lauritsen Laboratory (High Energy Physic
54. Lloyd House (Undergraduate Residence)
89. Marks House (Graduate Residence)
32. Millikan (Library and Administration)
87. Mosher-Jorgensen House (Graduate Residence)
21. Mudd Building (Geophysics and Planetary Sciences)
23. Mudd Laboratory (Geology and Geochemistry)
72. Noyes Laboratory (Chemical Physics)
53. Page House (Undergraduate Residence)

7, 82,
83, 84. Physical Plant

92. Public Events Office
71. Public Relations and Publications
77. Ramo Auditorium
56. Residence and Dining Halls Office
59. Ricketts House (Undergraduate Residenc
24. Robinson Laboratory (Astrophysics)
55. Ruddock House (Undergraduate Residenc
37. Sloan Laboratory (Mathematics and Physics)
6. Spalding Building (Business Services)
41. Spalding Laboratory (Chemical Engineering)
94. Steele House (Residence, Master of Stude Houses)
81. Steele Laboratory (Applied Physics and Electrical Engineering)
44. Thomas Laboratory (Civil and Mechanic Engineering)
92. Ticket Agency
82. Transportation Building
51. Winnett Student Center
51. Caltech Y
8. Young Health Center

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RESEARCH ASSOCIATES

Eva Fifkova, M.D., Ph.D. .... *Biology*
Peter H. Lowy, Doctorandum .... *Biology*
Ken-ichi Naka, Ph.D. .... *Biology and Applied Science*
Marianne E. Olds, Ph.D. .... *Biology*
Helen R. Revel, Ph.D. .... *Biology*

ASSISTANT PROFESSORS

Henry A. Lester, Ph.D. .... *Biology*
Daniel McMahon, Ph.D. .... *Biology*
John D. Pettigrew, M.D. .... *Biology*
Richard L. Russell, Ph.D. .... *Biology*
James H. Strauss, Jr., Ph.D. .... *Biology*

SENIOR RESEARCH FELLOWS

Charles R. Hamilton, Ph.D. .... *Biology*
Barbara R. Hough, Ph.D. .... *Biology*
Harumi Kasamatsu, Ph.D. .... *Biology*
Lajos Piko, D.V.M. .... *Biology*
Ellen G. Strauss, Ph.D. .... *Biology*

GOSNEY RESEARCH FELLOWS

Bernard Croizat, Ph.D. .... *Biology*
Ilan Deak, Ph.D. .... *Biology*
Joan L. Klotz, Ph. D. .... *Biology*
Aladar Szalay, D.Sc. .... *Biology*

RESEARCH FELLOWS

Robert C. Angerer, Ph.D.[1]
Gyorgi Bagi, Ph.D.[2]
Robert J. Bishop, Ph.D.
Steven E. Brauth, Ph.D.
Reinhard Dennin, D.Sc.[3]
Angeline Douvas, Ph.D.
James M. England, Ph.D.[4]
Robert E. Enns, Ph.D.
Arturo Eslava, Ph.D.
Karl E. Espelie, Ph. D.[1]
William T. Garrard, Jr., Ph.D.
Alain Ghysen, D.Sc.[5]

Dale E. Graham, Ph.D.[1]
Karel Grohmann, Ph.D.[6]
Lawrence Grossman, Ph.D.
Richard O. Herrmann, Ph.D.[3]
Richard L. Hirsh, Ph.D.
Franz-Herbert Hubmann, Ph.D.[3]
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Rona Pettigrew, Ph.D.
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Jack Silver, Ph.D.[6]
Carlos R. Sledge, Ph.D.[7]
Michael J. Smith, Ph.D.
Mamoru Umemoto, Ph.D.
Hans-Peter Vosberg, Ph.D.[3]
Randle W. Ware, Ph.D.
H. Jurgen Weber, Dr. rer. nat.[3]
John R. Wells, Ph.D.
James Wood, Ph.D.
Paul G. Young, Ph.D.[8]
Eran Zaidel, Ph.D.

*In residence 1972-73
1Damon Runyon Memorial Fund Fellow
2UNESCO Fellow
3Deutsche Forschungsgemeinschaft Fellow
4Dernham Fellow of the American Cancer Society
5Fonds National de la Recherche Scientifique Fellow
6National Institutes of Health, Public Health Service Fellow
7American Cancer Society Fellow
8National Research Council of Canada Fellow

GRADUATE STUDENTS 1972-73

Christopher Scott Amenson
Robert Charles Anderson
David Lee Armstrong
Gerald Joseph Audesirk
Antony Clicord Bakke
Paul Arlyn Barstad
John Richard Bell
Welcome William Bender
Larry Ira Benowitz
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James William Deutsch
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William Jack Driskell
John Robinson Duguid
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Joel Melvin Gottesfeld
David Howard Hall
William Anthony Harris
Stanley Roy Hoffman
Charissa Jean Hogeboom
David Salway Holmes
Henry Vincent Huang
David Saul Isenberg
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Lily Kung Chung Jan
Algirdas Joseph Jesaitis
Carl Douglas Johnson
Amy So-Ming Shiu Lee

Elwyn Yuan Loh
Susan Leah Melvin
Ronald Leo Meyer
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Jürg Waser, Ph.D. .... *Chemistry*

RESEARCH ASSOCIATES

Justine S. Garvey, Ph.D. .... *Chemistry*
Edward W. Hughes, Ph.D. .... *Chemistry*
Joseph B. Koepfli, D.Phil. .... *Chemistry*
Richard E. Marsh, Ph.D. .... *Chemistry*
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Oliver R. Wulf, Ph.D.* .... *Physical Chemistry*

*Research Associate Emeritus

ASSOCIATE

Lyman G. Bonner, Ph.D. .... *Chemistry*

VISITING ASSOCIATES

Bernard C. Gerstein,[1] Ph.D. .... *Chemical Engineering*
Elihu Goldish,[2] Ph.D. .... *Chemistry*
Frank H. Herbstein,[3] Ph.D. .... *Chemistry*
Ting Fong Lai,[4] Ph.D. .... *Chemistry*
Frank F. S. Lin,[5] Ph.D. .... *Chemistry*
Marino Martinez-Carrion,[6] Ph.D. .... *Chemistry*
Angelo Orio,[7] Ph.D. .... *Chemistry*
Claudio Rodrigues,[8] Ph.D. .... *Chemistry*
Jack T. Spence,[9] Ph.D. .... *Chemistry*
M. Robert Willcott III,[10] Ph.D. .... *Chemistry*

1Iowa State University of Science and Technology
2Union Oil Company
3Israel Institute of Technology
4University of Hong Kong
5California State College
6University of Notre Dame
7Universty of Padova, Italy
8Institute of Atomic Energy, Sao Paulo, Brazil
9Utah State University
10University of Houston

ASSOCIATE PROFESSORS

Jesse L. Beauchamp, Ph.D. .... *Chemistry*
George R. Gavalas, Ph.D. .... *Chemical Engineering*
William A. Goddard III, Ph.D. .... *Theoretical Chemistry*
Vincent McKoy, Ph.D. .... *Theoretical Chemistry*
John H. Seinfeld, Ph.D. .... *Chemical Engineering*
Fredrick H. Shair, Ph.D. .... *Chemical Engineering*

ASSISTANT PROFESSORS

Peter B. Dervan, Ph.D. .... *Chemistry*
Joseph G. Gordon II, Ph.D. .... *Chemistry*
L. Gary Leal, Ph.D. .... *Chemical Engineering*
George Rossman, Ph.D. .... *Mineralogy and Chemistry*
Robert M. Stroud, Ph.D. .... *Chemistry*
Robert W. Vaughan, Ph.D. .... *Chemical Engineering*
W. Henry Weinberg, Ph.D. .... *Chemical Engineering*

SENIOR RESEARCH FELLOWS

Eri Heller, Ph.D. .... *Chemistry*
H. Hollis Reamer, M.S. .... *Chemical Engineering*
William P. Schaefer, Ph.D. .... *Chemistry*
Stephen H. Smallcombe, Ph.D. .... *Chemistry*
Sandor Trajmar, Ph.D. .... *Chemistry*

LECTURERS

Robert F. Landel, Ph.D. .... *Chemical Engineering*
Alan Rembaum, Ph.D. .... *Chemical Engineering*

NOYES RESEARCH FELLOW

John Bercaw, Ph.D. .... *Chemistry*

INSTRUCTOR

Daniel C. Harris,* Ph.D. .... *Chemistry*

*In residence 1973 academic year

RESEARCH FELLOWS

Klaus Adam, Ph.D.
Gustav Albrecht, Ph.D.
Lynne M. Angerer,[1] Ph.D.
Ian Armitage, Ph.D.
Alex Avdeef, Ph.D.
Zvonimir Ban,[2] Ph.D.
Bahram Bastani, D.Sc.
Stefan Berger,[3] Ph.D.
Pierre Beslin,[4] Ph.D.
Jurgen Bode,[3] Doktor der Naturwissenschaften
A. Randell Bowen, Ph.D.
Thomas R. Broker,[5] Ph.D.
Joe N. Brown, Jr., Ph.D.[1]
Chin-An Chang, Ph.D.
Yuan Chao, Ph.D.
Seung Jung Choi, Ph.D.
Gary Christoph, Ph.D.
Kuang-Juh Chu, Ph.D.
Richard C. Deonier,[6] Ph.D.
Cecil R. Dybowski, Ph.D.
John E. Ellis,[7] Ph.D.
Donald R. Ferrier, Ph.D.
Arleen Forsheit,[7] Ph.D.
Steven N. Frank, Ph.D.
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Donald O. Giannini, Ph.D.
Rudolf Giger, Ph.D.
Donald Glover, Ph.D.
Ronald C. Griffith, Ph.D.
Allan M. Guest, Ph.D.
Esin C. Gulari, Ph.D.
Janis Gulens,[8] Ph.D.
Ramesh Gupta, Ph.D.
James C. Hall, Ph.D.
Raymond Harrigan, Ph.D.
Newton D. Hershey,[7] Ph.D.
Leslie M. Hodges, Ph.D.
Robert A. Holwerda, Ph.D.
Pauline P-J. Hsiao, Ph.D.
George C. Hsu, Ph.D.
Ming-Chu Hsu,[9] Ph.D.
Wei-jen Jenny Hu, Ph.D.
Hanspeter Huber, Dr. Phil. II
Janja O. Husar, Ph.D.
Matsatune Kainosho, D.Sc.
Donald Kaplan, Ph.D.
Kenneth Kaufmann, Ph.D.
Bang Mo Kim, Ph.D.
Herbert A. Kirst, Ph.D.
Anthony Kossiakoff, Ph.D.
Friedrich R. Kreissel,[10] Doktorprufung
Robert G. Lamb, Ph.D.
Pierre Le Breton, Ph.D.
Blair F. Lewis, Ph.D.
Dov A. Lichtenberg, Ph.D.
Rung T. Ling, Ph.D.
Thomas J. Lobl, Ph.D.
Hans Maag, Ph.D.
Gretchen S. Mandel, Ph.D.
Neil Mandel, Ph.D.
Jerry E. Manning,[11] Ph.D.
Thomas C. McKenzie,[9] Ph.D.
Minnie McMillan, Ph.D.
David R. McMillin, Ph.D.
Douglas C. Mohr, Ph.D.
Paul R. Monson, Jr.,[9] Ph.D.
Richard H. Mueller, Ph.D.
John Napierski, Ph.D.
Edward F. O'Brien, Ph.D.
Eiichi Ohtsubo, Ph.D.
John Y. Park, Ph.D.

Harry Pearson,[12] Ph.D.
Edward W. Petrillo, Jr., Ph.D.
Juta K. Reed, Ph.D.
Kenton L. Reed, Ph.D.
Thomas N. Rescigno, Ph.D.
W. K. Rhim, Ph.D.
Edward Rosenberg, Ph.D.
Robert C. Rosenberg, Ph.D.
Carl Schmid,[11] Ph.D.
Jakob Schmidt, M.D.
Robert R. Schmidt III, Ph.D.
Neil E. Schore, Ph.D.
Alan R. Sears, Ph.D.
Kenneth J. Shea, Ph.D.
Kelvin Kei-Wei Shen,[13] Ph.D.
Kosuke Shobatake, Ph.D.
Olavi Siiman, Ph.D.
Rosemarie Swanson,[9] Ph.D.
Benes L. Trus,[9] Ph.D.
Tadao Uyehara, Ph.D.
Richard Vandlen, Ph.D.
Peter Vollhardt, Ph.D.
Ira D. Warren,[9] Ph.D.
Michael J. Weaver, Ph.D.
Ben-Avi Weissman, Ph.D.
Stephen R. Wilson, Ph.D.
Chin-Hua S. Wu, Ph.D.

[1]Damon Runyon Cancer Research Fund
[2]Sr. Fulbright-Hays Fellowship
[3]Deutsche Forschungsgemeinschaft Fellowship
[4]NATO Postdoctoral Fellowship
[5]Helen Hay Whitney Foundation Fellowship
[6]National Institute of Arthritis and Metabolic Diseases
[7]Public Health Service Fellowship
[8]National Research Council of Canada Fellowship
[9]National Institutes of Health Fellowship
[10]Deutscher Akademischer Austauschdienst Fellowship
[11]Jane Coffin Childs Memorial Fund for Medical Research
[12]The Harkness Fellowship of Commonwealth Fund of New York
[13]U.S. Borax

GRADUATE STUDENTS 1972-73

Mark Andrew Allen, *Chemistry*
Robert James Almassy, *Chemistry*
Bjarne Bogeskov Andresen, *Chemistry*
William Michael Anthony, *Chemistry*
Amir Attar, *Chemical Engineering*
William Walter Bachovchin, *Chemistry*
Kiran Ravindra Bakshi, *Chemical Engineering*
Karl Ammon Bell, *Chemical Engineering*
Theodore I. Benzer, *Chemistry*
William Beranek, *Chemistry*
Jacqueline Berg, *Chemistry*
Ricardo Bloch, *Chemical Engineering*
Michael Blumenstein, *Chemistry*
Frank Wilhelm Bobrowicz, *Chemistry*
Joel Mark Bowman, *Chemistry*
Garth Gerald Brown, *Chemistry*
Ronald J. Brown, *Chemical Engineering*
Jonathan Arno Burke, *Chemistry*
John L. Chambers, *Chemistry*
Wen-ji Victor Chang, *Chemical Engineering*
Wen Hsiung Chen, *Chemical Engineering*
Paul How-Kei Cheong, *Chemical Engineering*
Louise Tsai Chow, *Chemistry*
Thomas Carl Clarke, *Chemistry*
Roger L. Clough, *Chemistry*
Michael John Coggiola, *Chemistry*
Donald Edward Cormack, *Chemical Engineering*
Charles Dane Cowman, Jr., *Chemistry*
Robert Luther Derham, *Chemical Engineering*
Kilian Dill, *Chemistry*
Kevin Gerard Donohoe, *Chemical Engineering*
Peter John Drivas, *Chemical Engineering*
Jack E. Drum, *Chemistry*
Robert Eager, *Chemistry*
James B. Ellern, *Chemistry*
Robert Allen Farr, *Chemistry*
Gerald W. Feigenson, *Chemistry*
Robert Wallace Fillers, *Chemical Engineering*
Harry Osborn Finklea, *Chemistry*
Wayne Michael Flicker, *Chemistry*

Manuel Ramon Florez, *Chemical Engineering*
William Paul Fornaciari, Jr., *Chemistry*
Michael Stewart Foster, *Chemistry*
Steven Neil Frank, *Chemistry*
Claude Clinton Frazier, *Chemistry*
Ben Sherman Freiser, *Chemistry*
Franklin Robert Fronczek, *Chemistry*
Gregory Geoffroy, *Chemistry*
Frank Grunthaner, *Chemistry*
Steven Lawrence Guberman, *Chemistry*
Erdogan Gulari, *Chemical Engineering*
Esin Gulari, *Chemical Engineering*
Amitava Gupta, *Chemistry*
Jeffrey Wayne Hare, *Chemistry*
Daniel Charles Harris, *Chemistry*
Thomas Arnold Hecht, *Chemistry*
Bosco Po-wai Ho, *Chemical Engineering*
Robert Alan Holwerda, *Chemistry*
Ming Ta Hsu, *Chemistry*
Shaw-Fen Sylvia Hu, *Chemistry*
Valerie Wailin Hu, *Chemistry*
Michael W. Hunkapiller, *Chemistry*
John N. Hurley, *Chemistry*
Richard Jones, *Chemistry*
Joseph F. Karnicky, *Chemistry*
Donald Ross Kelsey, *Chemistry*
Robert Andrew Keppel, *Chemistry*
Roger Erdman Koeppe II, *Chemistry*
Dale A. Kooistra, *Chemistry*
Conrad John Kowalski, *Chemistry*
Monty Krieger, *Chemistry*
Paulus Arie Kroon, *Chemistry*
Sudarsham Kumar, *Chemical Engineering*
Hsing Jien Kung, *Chemistry*
Chwan Pein Kyan, *Chemical Engineering*
Glenn Alan Laguna, *Applied Physics*
Charles Anderson Langhoff, *Chemistry*
Arthur Lai Yin Lau, *Chemistry*
Kei-Fung Lau, *Applied Physics*
Hung Jung Lee, *Chemistry*
Theodore Tsan-Tsung Lee, *Chemistry*
George Levin, *Chemistry*
David Harris Live, *Chemistry*
Franklin Asbury Long II, *Chemistry*
David Macmurchie, *Chemistry*
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Clyde William McCurdy, *Chemistry*
Terrance Brian McMahon, *Chemistry*
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Jeffrey Bernard Smith,*Chemistry*

Lois Elaine Smith, *Chemistry*
Steven Andrew Spencer, *Chemistry*
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Gregory Stone, *Chemical Engineering*
Chaim N. Sukenik, *Chemistry*
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Russell Timkovich, *Chemistry*
Ronald Irving Trust, *Chemistry*
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Erdinc Zana, *Chemical Engineering*

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Herbert B. Keller, Ph.D. . . . . *Applied Mathematics*
James K. Knowles, Ph.D. . . . . *Applied Mechanics*
Toshi Kubota, Ph.D. . . . . *Aeronautics*
Paco A. Lagerstrom, Ph.D. . . . . *Applied Mathematics*
Robert V. Langmuir, Ph.D. . . . . *Electrical Engineering*
Lester Lees, M.S. . . . . *Environmental Engineering and Aeronautics; Director, Environmental Quality Laboratory*
Hans W. Liepmann, Ph.D. . . . . *Aeronautics*
Frank E. Marble, Ph.D. . . . . *Jet Propulsion and Mechanical Engineering*
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James O. McCaldin, Ph.D. . . . . *Applied Science and Electrical Engineering*

Gilbert D. McCann, Ph.D. .... *Applied Science*
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Carver A. Mead, Ph.D. .... *Electrical Engineering*
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Marc-Aurele Nicolet, Ph.D., ... *Electrical Engineering*
Wheeler J. North, Ph.D. .... *Environmental Science*
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John R. Pierce, Ph.D., D.Sc., D.Eng., E.D. .... *Engineering*
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Fredric Raichlen, Sc.D. .... *Civil Engineering*
W. Duncan Rannie, Ph.D. .... *Robert H. Goddard Professor of Jet Propulsion*
Anatol Roshko, Ph.D. .... *Aeronautics*
Rolf H. Sabersky, Ph.D. .... *Mechanical Engineering*
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Ronald F. Scott, Sc.D. .... *Civil Engineering*
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Eli Sternberg, Ph.D., D.Sc. .... *Mechanics*
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Bradford Sturtevant, Ph.D. .... *Aeronautics*
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Thad Vreeland, Jr., Ph.D. .... *Materials Science*
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Gerald B. Whitham, Ph.D. .... *Applied Mathematics*
Charles H. Wilts, Ph.D. .... *Electrical Engineering*
David S. Wood, Ph.D. .... *Materials Science*
Theodore Y. Wu, Ph.D. .... *Engineering Science*
Amnon Yariv, Ph.D. .... *Electrical Engineering*
Edward E. Zukoski, Ph.D. .... *Jet Propulsion*

*On leave of absence
**Part-time
***On leave of absence 1st term

VISITING PROFESSOR

Charles R. O'Melia, Ph.D. .... *Environmental Engineering Science*

VISITING ASSOCIATES

Richard F. Baker, Ph.D. .... *Biomedical Engineering*
Hans R. Bilger, Ph.D. .... *Electrical Engineering*
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Kuen-Puo Chuang, Ph.D.* .... *Civil Engineering*
Wallace G. Frasher, M.D. .... *Biomedical Engineering*
George M. Hidy, D.Eng. .... *Environmental Engineering Science*
Yevgeniy I. Il'yashenko, Dr.Ing. .... *Electrical Engineering*
Kenneth M. Jassby, Ph.D.* .... *Materials Science*
Fritz John, Ph.D.* .... *Applied Mathematics*

Susumu Keitoku, Ph.D. . . . . *Electrical Engineering*
Helmut Kobus, Ph.D. . . . . *Hydraulics*
Feliks A. Kostanyan, Ph.D. . . . . *Electrical Engineering*
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Sami F. Masri, Ph.D.* . . . . *Mechanical Engineering*
Robert T. Menzies, Ph.D. . . . . *Electrical Engineering*
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Andrzej Turos, Ph.D.* . . . . *Electrical Engineering*
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Dean E. Wooldridge, Ph.D. . . . . *Engineering*
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Per Brinch-Hansen, M.S. . . . . *Computer Science*
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Andrea Prosperetti, *Engineering Science*
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Manuel Rebollo, *Aeronautics*
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Kendall C. Reyzer, *Engineering Science*
Magdi Rizk, *Aeronautics*
Henry M. Roberts, *Mechanical Engineering*
Paul T. Roberts, *Environmental Engineering Science*
Philip Joseph William Roberts, *Environnmental Engineering Science*
Theodore Rose, *Civil Engineering*
Scott Roth, *Engineering Science*
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Ernest John Wood, *Applied Physics*
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*On leave of absence 1973-74
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Richard Weiss, Ph.D.[1] .... *Applied Mathematics*

[1]Harry Bateman Research Instructor, 1973-74

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Barbara A. Zimmerman, Computing Analyst

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DEPARTMENT OF AIR FORCE AEROSPACE STUDIES (AFROTC)

Lt. Colonel Eugene W. Bendel, USAF, M.B.A. . . . . *Director, Lecturer in Air Force Aerospace Studies*
Captain Lee T. Smith, USAF, M.S. . . . . *Lecturer in Air Force Aerospace Studies*

DEPARTMENT OF ATHLETICS AND PHYSICAL EDUCATION

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

Full-time Staff
Thomas Gutman, M.S.
James H. Nerrie, B.S.
Edward T. Preisler, B.A.

Part-time Staff
David E. Beck
Dean G. Bond, B.A.
Delmar Calvert, B.M.
Donald R. Cameron, B.Sc.
Harold G. Cassriel, B.S.
John L. Lamb
Marie Marchowsky
Tsutomu Ohshima, B.A.
Hudson L. Scott, M.S.

Athletic Council

The intercollegiate athletic program is under the supervision of the Athletic Council, which consists of representatives of the faculty, the Associated Students of the California Institute of Technology (ASCIT), and the alumni of the Institute.

HEALTH CENTER

Gregory Ketabgian, M.D. . . . . *Director of Health Services*
Ian Hunter, Ph.D. . . . . *Administrator, Institute Psychologist*
R. Stewart Harrison, M.D. . . . . *Consulting Radiologist*
Richard F. Webb, M.D. . . . . *Consulting Physician*
Joseph Holt Rose, M.D. . . . . *Consultant in Radiation Safety*
Daniel C. Siegel, M.D. . . . . *Consulting Psychiatrist*
Nancy G. Beakel, Ph.D. . . . . *Institute Psychologist*
Judson S. James, M.D. . . . . *Attending Physician*
Gillian McClure, M.D. . . . . *Attending Physician*
Doreen Kroeger, R.N., B.S. . . . . *Nursing Supervisor*
Mrs. Suzanne M. Murray . . . . *Administrative Secretary*

MUSICAL ACTIVITIES

John C. Deichman . . . . *Director of Instrumental Music*
Olaf Frodsham . . . . *Director of Choral Music*
Priscilla C. Remeta . . . . *Assistant Director of Choral Music*

OFFICERS AND FACULTY

Harold Brown, Ph.D., D.Eng., LL.D., *President*
A.B., Columbia College, 1945; A.M., Columbia University, 1946; Ph.D., 1949. California Institute, 1969-. (Millikan)

Allan James Acosta, Ph.D., *Professor of Mechanical Engineering*
B.S., California Institute, 1945; M.S., 1949; Ph.D., 1952. Assistant Professor, 1954-58; Associate Professor, 1958-66; Professor, 1966-. (Thomas)

Klaus Adam, Ph.D., *Research Fellow in Chemistry*
B.S., St. Edwards University, 1964; M.S., Texas A & M University, 1967; Ph.D., 1971. California Institute, 1972-. (Church)

Prahlad C. Agrawal, Ph.D., *Research Fellow in Physics*
B.Sc., Virkam University (India), 1961; Ph.D., Tata Institute, 1972. California Institute, 1972-. (Downs)

Thomas J. Ahrens, Ph.D., *Associate Professor of Geophysics*
B.S., Massachusetts Institute of Technology, 1957; M.S., California Institute, 1958; Ph.D., Rensselaer Polytechnic Institute, 1962; California Institute, 1967-. (Seismo Lab.)

Arden Leroy Albee, Ph.D., *Professor of Geology; Academic Officer, Geological and Planetary Sciences*
A.B., Harvard College, 1950; A.M., Harvard University, 1951; Ph.D., 1957. Visiting Assistant Professor, California Institute, 1959-60; Associate Professor, 1960-66; Professor, 1966-; Academic Officer, 1971-. (Arms)

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

Carl David Anderson, Ph.D., Sc.D., LL.D., Nobel Laureate, *Professor of Physics*
B.S., California Institute, 1927; Ph.D., 1930. Research Fellow, 1930-33; Assistant Professor, 1933-37; Associate Professor 1937-39; Professor, 1939-; Chairman, Division of Physics, Mathematics and Astronomy, 1962-70. (E. Bridge)

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

Joel Hilary Anderson, Ph.D., *Assistant Professor of Mathematics*
B.A., Oberlin College, 1964; Ph.D., Indiana University, 1971. Bateman Research Instructor, California Institute, 1971-73; Assistant Professor, 1973-. (Sloan)

Thomas Howard Anderson, Ph.D., *Senior Research Fellow in Geology*
B.A., Franklin and Marshall College, 1964; M.S., University of Texas, 1967; Ph.D., 1968. Research Fellow, California Institute, 1968-72; Senior Research Fellow, 1972-. (Arms)

Lynne Musgrave Angerer, Ph.D., *Research Fellow in Chemistry*
B.Sc., The Ohio State University, 1966; M.Sc., 1967; Ph.D., The Johns Hopkins University, 1973. California Institute, 1973-. (Alles)

Robert C. Angerer, Ph.D., *Research Fellow in Biology*
B.Sc., The Ohio State University, 1966; Ph.D., The Johns Hopkins University, 1973. California Institute, 1973-. (Alles)

Michel Robert Anseau, M.S., *Research Fellow in Materials Science*
B.S., University of Mons, 1969; M.S., University of Cambridge, 1971. California Institute, 1972.

Fred Colvig Anson, Ph.D., *Professor of Analytical Chemistry; Executive Officer for Chemistry*
B.S., California Institute, 1954; Ph.D., Harvard University, 1957. Instructor, California Institute, 1957-58; Assistant Professor, 1958-62; Associate Professor, 1962-68; Professor, 1968-. Executive Officer for Chemistry, 1973-. (Gates)

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

Vijay H. Arakeri, Ph.D., *Research Fellow in Mechanical Engineering*
B.Sc., Utah State University, 1967; M.S., California Institute, 1968; Ph.D., 1972. Research Fellow, 1972-. (Karman)

Johann Arbocz,** Ph.D., *Senior Research Fellow in Aeronautics*
B.S., Northrop Institute of Technology, 1963; M.S., California Institute, 1964; Ph.D., 1968. Associate Professor, Northrop Institute of Technology, 1969-. Research Fellow, California Institute, 1968-71; Senior Research Fellow, 1971-. (Firestone)

Charles Bruce Archambeau, Ph.D., *Professor of Geophysics*
B.S., University of Minnesota, 1955; M.S., 1959; Ph.D., California Institute, 1965. Associate Professor, 1966-71; Professor, 1971-. (Seismo Lab.)

Ian MacLeod Armitage, Ph.D., *Research Fellow in Chemistry*
B.Sc., Bishop's University, Lennoxville, Quebec, 1968; Ph.D., University of British Columbia, 1972. California Institute, 1973-. (Crellin)

David Woods Arnett, Ph.D., *Research Fellow in Information Science*
B.S., Purdue University, 1964; M.S., University of Pennsylvania, 1966; Ph.D., California Institute, 1971. Research Fellow, 1971-. (Booth)

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

Michael Aschbacher, Ph.D., *Assistant Professor of Mathematics*
B.S., California Institute, 1966; Ph.D., University of Wisconsin, 1969. Bateman Research Instructor, California Institute, 1970-72; Assistant Professor, 1972-. (Sloan)

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

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

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

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

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

Gyorgy Bagi, Ph.D., *Research Fellow in Biology*
Dipl., Eotvos University (Budapest), 1964; Ph.D., 1973. California Institute, 1973-. (Kerckhoff)

**Part-time

Richard Freligh Baker,** Ph.D., *Visiting Associate in Biomedical Engineering*
B.S., The Pennsylvania State University, 1932; M.S., 1933; Ph.D., The University of Rochester, 1938. Professor of Microbiology, University of Southern California School of Medicine, 1958-. Senior Research Fellow in Chemistry, California Institute, 1953-57; Research Associate in Engineering Science, 1968-72; Visiting Associate in Biomedical Engineering, 1972-. (Thomas)

John Dickson Baldeschwieler, Ph.D., *Professor of Chemistry; Chairman of the Division of Chemistry and Chemical Engineering*
B.Chem.E., Cornell University, 1956; Ph.D., University of California, 1959. California Institute, 1973-. (Crellin)

Barry Clark Barish, Ph.D., *Professor of Physics*
B.A., University of California, 1957; Ph.D., 1962. Research Fellow, California Institute, 1963-66; Assistant Professor, 1966-69; Associate Professor, 1969-72; Professor, 1972-. (Lauritsen)

Steven Joseph Barker, Ph.D., *Senior Research Fellow in Aeronautics*
B.S., Harvey Mudd College, 1967; M.S., California Institute, 1968; Ph.D., 1971. Research Fellow, 1971-73; Senior Research Fellow, 1973-. (Guggenheim)

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

Robert Hinrichs Bates, Ph.D., *Assistant Professor of Political Science*
B.A., Haverford College, 1964; Ph.D., Massachusetts Institute of Technology, 1969. California Institute, 1969-. (Baxter)

Nancy G. Beakel,** Ph.D., *Lecturer in Psychology*
B.A., University of Texas, 1958; M.A., University of California, 1967; Ph.D., University of California (Los Angeles), 1970. Lecturer, California Institute, 1971-. (Health Center, Baxter)

Jesse Lee Beauchamp, Ph.D., *Associate Professor of Chemistry*
B.S., California Institute, 1964; Ph.D., Harvard University, 1967. Noyes Research Instructor, California Institute, 1967-69; Assistant Professor, 1969-71; Associate Professor, 1971-. (Crellin)

Eric Edward Becklin, Ph.D., *Senior Research Fellow in Physics*
B.S., University of Minnesota, 1963; Ph.D., California Institute, 1968. Research Fellow, 1968-70; Senior Research Fellow, 1971-; Staff Associate, Hale Observatories, 1971-. (Downs, Hale Office)

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

Robert M. Benbow, Ph.D., *Research Fellow in Biology*
B.S., Yale University, 1967; Ph.D., California Institute, 1972. Research Fellow, 1972.

Lt. Colonel Eugene W. Bendel, M.B.A., *Lecturer in Aerospace Studies*
B.A., University of Omaha, 1958; M.B.A., University of Southern California, 1967. California Institute, 1970-. (Air Force ROTC Bldg.)

Irving S. Bengelsdorf,** Ph.D., *Lecturer in Science Communication*
B.S., University of Illinois, 1943; M.S., University of Chicago, 1948; Ph.D., 1951. California Institute, 1971-. (Spalding)

Colin Bennett, Ph.D., *Assistant Professor of Mathematics*
B.Sc., University of Newcastle-upon-Tyne, 1967; Ph.D., 1971. Bateman Research Instructor, California Institute, 1971-73; Assistant Professor, 1973-. (Sloan)

Larry I. Benowitz, Ph.D., *Research Fellow in Biology*
B.ChE., The Cooper Union, 1966; Ph.D., California Institute, 1972. Research Fellow, 1972-73.

*Leave of absence, 1973-74
**Part-time

John Frederick Benton, Ph.D., *Professor of History*
B.A., Haverford College, 1953; M.A., Princeton University, 1955; Ph.D., 1959. Assistant Professor, California Institute, 1965-66; Associate Professor, 1966-70; Professor, 1970-. (Baxter)

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

John Edward Bercaw, Ph.D., *Arthur Amos Noyes Research Fellow in Chemistry*
B.S., North Carolina State University, 1967; Ph.D., University of Michigan, 1971. California Institute, 1972-. (Noyes)

Glenn Leroy Berge, Ph.D., *Senior Research Fellow in Planetary Science and Radio Astronomy*
B.A., Luther College, 1960; M.S., California Institute, 1962; Ph.D., 1965. Research Fellow in Radio Astronomy, 1965-70; Senior Research Fellow, 1970-72; Senior Research Fellow in Planetary Science and Radio Astronomy, 1972-. (Robinson)

Stefan Berger, Ph.D., *Research Fellow in Chemistry*
B.S., University of Tubingen, 1968; Dipl., 1970; Ph.D., 1973. California Institute, 1973-. (Crellin)

Robert George Bergman, Ph.D., *Professor of Chemistry*
B.A., Carleton College, 1963; Ph.D., University of Wisconsin, 1966. Noyes Research Instructor, California Institute, 1967-69; Assistant Professor, 1969-71; Associate Professor, 1971-73; Professor, 1973-. (Crellin)

Michael A. Berta, Major, Ph.D., *Senior Research Fellow in Aeronautics*
B.S., Allegheny College, 1961; M.S., The Johns Hopkins University, 1963; Ph.D., 1965. Air Force Weapons Laboratory, Department of the Air Force, 1968-. California Institute, 1972-73.

Pierre Jean Alfred Beslin, Ph.D., *Research Fellow in Chemistry*
Lic., University of Caen, 1962; Ing., 1963; Ph.D., 1969. California Institute, 1973-74.

Richard Henry Bigelow, Ph.D., *Research Fellow in Applied Science*
B.S., California Institute, 1966; M.S., 1967; Ph.D., 1973. Research Fellow, 1973.

Hans R. Bilger, Ph.D., *Visiting Associate in Electrical Engineering*
Ph.D., University of Basel, 1961. Associate Professor, Oklahoma State University, 1967-. Senior Research Fellow, California Institute, 1967; 1968; 1969; Visiting Associate, 1972; 1973-74.

Richard John Bing, M.D., *Visiting Associate in Biomedical Engineering*
M.D., University of Munich, 1934; M.D., University of Berne, 1935. Professor of Medicine, University of California; Director, Cardiology and Intramural Medicine, Huntington Memorial Hospital, 1969-. Research Associate in Engineering Science, California Institute, 1970-72; Visiting Associate in Biomedical Engineering, 1972-. (Thomas)

Norbert Bischof, Ph.D., *Sherman Fairchild Distinguished Scholar*
Ph.D., University of Munich, 1966. Scientific Member, Max Planck Institute for the Physiology of Behavior, 1966-. California Institute, 1973-74.

Robert J. Bishop, Ph.D., *Research Fellow in Biology*
B.S., Marietta College, 1961; M.S., Rutgers University, 1965; Ph.D., Princeton University, 1970. California Institute, 1970-. (Kerckhoff)

John Robert Blake, Ph.D., *Research Fellow in Engineering Science*
B.Sc., University of Adelaide, 1968; Ph.D., University of Cambridge, 1972. California Institute, 1972-. (Karman)

Stephan Jay Bless, Sc.D., *Research Fellow in Geophysics*
S.B., Massachusetts Institute of Technology, 1965; S.M., 1967; Sc.D., 1970. California Institute, 1973-. (Seismo Lab.)

Michael Blumenstein, Ph.D., *Research Fellow in Chemistry*
B.S., City College of New York, 1968; Ph.D., California Institute, 1972. Research Fellow, 1973.

Jurgen Bode, Dr.rer.nat., *Research Fellow in Chemistry*
Dipl., Technical University of Brunswick (Germany), 1969; Dr.rer.nat., 1971. California Institute, 1971-. (Church)

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

Gunther Boheim, Ph.D., *Research Fellow in Biology*
Dipl., Technical University of Aachen, 1967; Ph.D., 1972. California Institute, 1972-73.

Henri Frederic Bohnenblust, Ph.D., *Professor of Mathematics*
A.B., Federal Institute of Technology, Zurich, 1928; Ph.D., Princeton University, 1931. Professor, California Institute, 1946-; Dean of Graduate Studies, 1956-70; Executive Officer for Mathematics, 1964-66. (Sloan)

Charles D. Boley, Ph.D., *Research Fellow in Applied Science*
S.B., Massachusetts Institute of Technology, 1966; Ph.D., 1971. California Institute, 1973-74.

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

Lyman Gaylord Bonner, Ph.D., *Director of Student Relations; Associate in Chemistry*
B.A., University of Utah, 1932; Ph.D., California Institute, 1935. Director of Foundation Relations, 1965-67; Associate, 1966-; Assistant to the President, 1967-69; Director, 1969-. (Dabney)

Ermanno F. Borra, Ph.D., *Research Fellow in Astronomy*
Ph.D., University of Western Ontario, 1972. California Institute, 1972-. (Hale Office)

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

Aaron Randell Bowen, *Research Fellow in Chemistry*
B.S., University of South Carolina, 1968; Ph.D., Stanford University, 1973. California Institute, 1973-. (Noyes)

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

Arthur Gerald Brady, Ph.D., *Senior Research Fellow in Earthquake Engineering*
B.E., University of Auckland, 1959; M.E., 1960; B.Sc., 1961; Ph.D., California Institute, 1966. Research Fellow in Applied Mechanics, 1968-71; Senior Research Fellow in Earthquake Engineering, 1972-. (Thomas)

Steven Earle Brauth, Ph.D., *Research Fellow in Biology*
B.S., Rensselaer Polytechnic Institute, 1967; Ph.D., New York University, 1972. California Institute, 1972-. (Kerckhoff)

Louis Breger, Ph.D., *Associate Professor of Psychology*
B.A., University of California (Los Angeles), 1957; M.A., The Ohio State University, 1959; Ph.D., 1961. Visiting Associate Professor, California Institute, 1970-71; Associate Professor, 1971-. (Baxter)

Christopher Brennen, Ph.D., *Senior Research Fellow in Engineering Science*
B.A., Oxford University, 1963; M.A., Ph.D., 1966. Research Fellow, California Institute, 1969-72; Senior Research Fellow, 1972-. (Karman)

Dick Allen Bridges,** M.A., *Lecturer in Technical Presentation*
B.A., California State College (Fullerton), 1970; M.A., 1972. California Institute, 1972-. (Keck)

Per Brinch-Hansen, M.S., *Associate Professor of Computer Science*
M.S., Technical University of Denmark, 1963. California Institute, 1972-. (Jorgensen)

**Part-time

Roy John Britten, Ph.D., *Senior Research Associate in Biology*
B.S., University of Virginia, 1940; Ph.D., Princeton University, 1951. Staff Member, Carnegie Institution, 1951-. Visiting Associate, California Institute, 1971-73; Senior Research Associate, 1973-. (Kerckhoff Marine Lab.)

James Eugene Broadwell,** Ph.D., *Research Associate in Aeronautics*
B.S., Georgia Institute of Technology, 1942; M.S., California Institute, 1944; Ph.D., The University of Michigan, 1952. Senior Staff Engineer, TRW Systems, 1964-. Senior Research Fellow, California Institute, 1967-72; Research Associate, 1972-. (Karman)

George S. Brockway II,** Ph.D., *Research Fellow in Applied Mechanics*
B.S.C.E., University of Miami, 1966; M.S.E.M., Georgia Institute of Technology, 1968; Ph.D., California Institute, 1972. Research Fellow, 1972.

Charles Jacob Brokaw, Ph.D., *Professor of Biology*
B.S., California Institute, 1955; Ph.D., University of Cambridge, 1958. Visiting Assistant Professor, California Institute, 1960; Assistant Professor, 1961-63; Associate Professor, 1963-68; Professor, 1968-. (Alles, Kerckhoff Marine Lab.)

Thomas Richard Broker, Ph.D., *Research Fellow in Chemistry*
B.A., Wesleyan University, 1966; Ph.D., Stanford Medical School, 1971. California Institute, 1972-. (Crellin)

Norman Herrick Brooks, Ph.D., *Professor of Environmental Science and Civil Engineering; Academic Officer for Environmental Engineering Science*
A.B., Harvard College, 1949; M.S., Harvard University, 1950; Ph.D., California Institute, 1954. Instructor, 1953-54; Assistant Professor, 1954-58; Associate Professor, 1958-62; Professor, 1962-; Academic Officer, 1972-. (Keck)

Harold Brown, Ph.D., D.Eng., LL.D., *President*
(see page 53.)

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

Joe Ned Brown, Jr., Ph.D., *Research Fellow in Chemistry*
B.S., Texas A & M University, 1969; Ph.D., Louisiana State University in New Orleans, 1972. California Institute, 1972-. (Church)

Lee F. Browne,** M.S., *Lecturer in Education*
B.S., West Virginia State College, 1944; M.S., New York University, 1950. Director of Secondary School Relations, California Institute, 1970-; Lecturer, 1971-. (Dabney)

Robert Joseph Brucato, Ph.D., *Staff Associate, Hale Observatories*
B.S., University of Illinois, 1966; M.S., University of Chicago, 1968; Ph.D., Northwestern University, 1970. Research Fellow, California Institute, 1971-72; Staff Associate, 1972-. (Hale Office)

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

Leon J. Bruner, Ph.D., *Visiting Associate in Biology*
A.B., University of Chicago, 1952; M.S., 1955; Ph.D., 1959. Associate Professor, University of California (Riverside), 1967-. California Institute, 1972.

David A. Buchholz, Ph.D., *Research Fellow in Physics*
B.S., The University of Rochester, 1966; M.S., University of Pennsylvania, 1967; Ph.D., 1972. California Institute, 1972-. (National Accelerator Laboratory, Batavia, Ill.)

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

**Part-time

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

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

Stanley A. Butman,** Ph.D., *Lecturer in Electrical Engineering*
B.Eng., McGill University, 1960; M.S.E.E., Massachusetts Institute of Technology, 1962; Ph.D., California Institute, 1967. Group Supervisor, Telemetry Research Group, Jet Propulsion Laboratory, 1967-. Lecturer, California Institute, 1973.

Sidney E. Buttrill, Jr., Ph.D., *Visiting Associate in Chemistry*
B.S., Massachusetts Institute of Technology, 1966; Ph.D., Stanford University, 1969. Assistant Professor of Chemistry, University of Minnesota, 1969-. California Institute, 1973.

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

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

Klara Carmely, M.A., *Lecturer in German*
B.A., San Fernando Valley State College, 1969; M.A., University of Southern California, 1971. California Institute, 1973-74.

Daniele S. Carré, Ph.D., *Research Fellow in Biology*
Ph.D., University of Paris, 1972. California Institute, 1973-74.

Joseph E. Carroll, Ph.D., *Bateman Research Instructor in Mathematics*
B.S., University of Notre Dame, 1969; Ph.D., Harvard University, 1973. California Institute, 1973-74.

Kenneth R. Castleman, Ph.D., *Lecturer in Information Science*
B.S.E.E., University of Texas (Austin), 1965; M.S.E.E., 1967; Ph.D., 1970. Senior Scientist, Jet Propulsion Laboratory, 1969-. California Institute, 1973.

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

Catherine Cesarsky, Ph.D., *Research Fellow in Astrophysics*
Lic., University of Buenos Aires, 1965; Ph.D., Harvard University, 1971. California Institute, 1971-. (Robinson)

Diego A. Cesarsky, Ph.D., *Research Fellow in Radio Astronomy*
Lic., University of Buenos Aires, 1965; Ph.D., Harvard University, 1971. California Institute, 1971-. (Robinson)

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

Chin-an Chang, Ph.D., *Research Fellow in Chemistry*
B.S., Chung-Hsing University (Taiwan), 1963; M.S., Colorado State University, 1967; Ph.D., University of California, 1970. California Institute, 1972-. (Noyes)

Yuan Chao, Ph.D., *Research Fellow in Chemistry*
B.S., Stanford University, 1968; M.A., Columbia University, 1969; Ph.D., 1972. California Institute, 1972-. (Church)

**Part-time

Paul Kwan Chien, Ph.D., *Research Fellow in Environmental Science*
B.S., Chinese University (Hong Kong), 1964; Ph.D., University of California (Irvine), 1971. California Institute, 1971-. (Kerckhoff Marine Lab.)

Seung Jung Choi, Ph.D., *Research Fellow in Chemical Engineering*
B.S., Seoul National University, 1966; M.S., University of Notre Dame, 1968; M.A., Princeton University, 1969; Ph.D., 1972. California Institute, 1972-. (Spalding)

Gary Gordon Christoph, Ph.D., *Research Fellow in Chemistry*
B.S., California Institute, 1967; M.S., University of Chicago, 1969; Ph.D., 1971. California Institute, 1971-. (Noyes)

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

Kuang-Juh Chu, Ph.D., *Research Fellow in Chemical Engineering*
B.S., National Taiwan University, 1964; M.S., University of Houston, 1968; Ph.D., 1973. California Institute, 1973-. (Spalding)

Wei-Kan Chu, Ph.D., *Senior Research Fellow in Electrical Engineering*
B.S., Cheng Kung University (Taiwan), 1962; M.S., Baylor University, 1965; Ph.D., 1969. Research Fellow, California Institute, 1972-73; Senior Research Fellow, 1973-. (Steele)

Kuen-Puo Chuang, Ph.D., *Visiting Associate in Civil Engineering*
B.S., National Taiwan University, 1956; M.S., University of Illinois, 1959; Ph.D., 1962. Associate Professor, Loyola University of Los Angeles, 1966-. California Institute, 1972-. (Thomas)

Allen Tse-Yung Chwang, Ph.D., *Research Fellow in Engineering Science*
B.Sc., Chu Hai College, 1965; M.Sc., University of Saskatchewan, 1967; Ph.D., California Institute, 1971. Research Fellow, 1971-. (Karman)

Donald Sherman Clark, Ph.D., *Professor of Physical Metallurgy*
B.S., California Institute, 1929; M.S., 1930; Ph.D., 1934. Instructor in Mechanical Engineering, 1934-37; Director of Placements, 1935-71; Assistant Professor, 1937-45; Associate Professor, 1945-51; Professor, 1951-63; Professor of Physical Metallurgy, 1963-. (Keck)

J. Kent Clark, Ph.D., *Professor of English*
A.B., Brigham Young University, 1939; Ph.D., Stanford University, 1950; Instructor, California Institute, 1947-50; Assistant Professor, 1950-54; Associate Professor, 1954-60; Professor, 1960-. (Baxter)

Francis Hettinger Clauser, Ph.D., *Clark Blanchard Millikan Professor of Aeronautics; Chairman of the Division of Engineering and Applied Science*
B.S., California Institute, 1934; M.S., 1935; Ph.D., 1937. Millikan Professor, Division Chairman, 1969-. (Thomas)

Donald S. Cohen,* Ph.D., *Professor of Applied Mathematics*
Sc.B., Brown University, 1956; M.S., Cornell University, 1959; Ph.D., New York University (Courant Institute), 1962. Assistant Professor of Mathematics, California Institute, 1965-67; Associate Professor of Applied Mathematics, 1967-71; Professor, 1971-. (Firestone)

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

Eri Jay Cohen, Ph.D., *Research Fellow in Physics*
B.S., Brooklyn College, 1965; M.A., Harvard University, 1967; Ph.D., 1971. California Institute, 1971-. (W. Bridge)

Marshall Harris Cohen, Ph.D., *Professor of Radio Astronomy*
B.E.E., The Ohio State University, 1948; M.S., 1949; Ph.D., 1952. Visiting Associate Professor, California Institute, 1965; Professor, 1968-. (Robinson)

*Leave of absence
**Part-time

Robert E. Cohen, Ph.D., *Research Fellow in Chemical Engineering*
B.S., Cornell University, 1968; Ph.D., California Institute, 1972. Research Fellow, 1972.

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

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

William Harrison Corcoran, Ph.D., *Professor of Chemical Engineering; Vice President for Institute Relations*
B.S., California Institute, 1941; M.S., 1942; Ph.D., 1948. Associate Professor, 1952-57; Professor, 1957-; Executive Officer, 1967-69; Vice President, 1969-. (Spalding, Millikan)

Noel Robert David Corngold, Ph.D., *Professor of Applied Science*
A.B., Columbia College, 1949; A.M., Harvard University, 1950; Ph.D., 1954. California Institute, 1966-. (Thomas)

Paolo Emilio Costantino, Laurea, *Research Fellow in Biology*
Laurea, University of Rome, 1971. California Institute, 1972-. (Church)

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

William Reed Cozart, Ph.D., *Associate Professor of English*
A.B., University of Texas, 1958; M.A., Harvard University, 1960; Ph.D., 1963. Assistant Professor, California Institute, 1965-71; Associate Professor, 1971-. (Baxter)

Bernard Pierre Croizat, Ph.D., *Gosney Research Fellow in Biology*
M.S., University of Paris, 1963; Ph.D., 1970. California Institute, 1972-. (Church)

Richard Metcalf Crutcher, Ph.D., *Research Fellow in Radio Astronomy*
B.S., University of Kentucky, 1967; Ph.D., University of California (Los Angeles), 1972. California Institute, 1972-73. (Robinson)

Bibiana Cujec, Ph.D., *Visiting Associate in Physics*
M.Sc., Dipl., University of Ljubljana (Yugoslavia), 1950; Ph.D., 1959. Professor, Laval University (Quebec), 1970-. California Institute, 1971-72.

Fred E. C. Culick, Ph.D., *Professor of Jet Propulsion*
S.B., S.M., Massachusetts Institute of Technology, 1957; Ph.D., 1961. Research Fellow, California Institute, 1961-63; Assistant Professor, 1963-66; Associate Professor, 1966-71; Professor, 1971-. (Karman)

Douglas G. Currie, Ph.D., *Visiting Associate in Astronomy*
B.E., Cornell University, 1958; Ph.D., The University of Rochester, 1962. Associate Professor of Astronomy, University of Maryland, 1970-. California Institute, 1973-. (Hale Office)

David B. Curtis, Ph.D., *Research Fellow in Geochemistry*
B.A., University of Colorado, 1962; Ph.D., Oregon State University, 1973. California Institute, 1973-74.

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

Eric Harris Davidson, Ph.D., *Associate Professor of Biology*
B.A., University of Pennsylvania, 1958; Ph.D., Rockefeller University, 1963. Visiting Assistant Professor, California Institute, 1970; Associate Professor, 1971-. (Alles)

Norman Ralph Davidson, Ph.D., *Professor of Chemistry*
B.S., University of Chicago, 1937; B.Sc., Oxford University, 1938; Ph.D., University of Chicago, 1941. Instructor, California Institute, 1946-49; Assistant Professor, 1949-52; Associate Professor, 1952-57; Professor, 1957-. Executive Officer for Chemistry, 1967-73. (Crellin)

Geoffrey Frederick Davies, Ph.D., *Research Fellow in Geophysics*
B.S., Monash University (Australia), 1966; M.Sc., 1968; Ph.D., California Institute, 1973. Research Fellow, 1972-73.

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

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

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

Ilan Deak, Ph.D., *Gosney Research Fellow in Biology*
B.S., University of London, 1969; Ph.D., Oxford University, 1973. California Institute, 1973-74.

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

Nicolaas Govert de Bruijn, *Sherman Fairchild Distinguished Scholar*
Ph.D., University of Amsterdam, 1943. Professor of Mathematics and Applied Mathematics, Technological University of Eindhoven, 1960-. California Institute, 1973.

Max Delbrück, Ph.D., Sc.D., Nobel Laureate, *Albert Billings Ruddock Professor of Biology*
Ph.D., University of Gottingen, 1931. Sc.D., University of Chicago, 1967. Research Fellow, California Institute, 1937-39; Professor, 1947-71; Ruddock Professor, 1971-. (Alles)

Reinhard Herbert Dennin, Dr.rer.nat., *Research Fellow in Biology*
Dr.rer.nat., Kiel University, 1970. California Institute, 1973-. (Kerckhoff)

Edwin Walter Dennison, Ph.D., *Research Associate in Astronomy*
B.A., Swarthmore College, 1949; M.A., University of Michigan, 1952; Ph.D., 1954. Staff Member, Hale Observatories, California Institute, 1963-. Research Associate, 1971-. (Robinson)

Richard C. Deonier, Ph.D., *Research Fellow in Chemistry*
B.S., Oklahoma State University, 1964; Ph.D., University of Wisconsin, 1970. California Institute, 1971- (Crellin)

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

Peter B. Dervan, Ph.D., *Assistant Professor of Chemistry*
B.S., Boston College, 1967; Ph.D., Yale University, 1972. California Institute, 1973-. (Crellin)

George John Dick, Ph.D., *Senior Research Fellow in Physics*
A.B., Bethel College, 1961; Ph.D., University of California, 1969. Research Fellow, California Institute, 1969-73; Senior Research Fellow, 1973-. (Sloan)

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

Fisher William W. Dilke, Ph.D., *Research Fellow in Physics*
Ph.D., University of Cambridge, 1973. California Institute, 1973-74.

**Part-time

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

Paul Emmanuel Dimotakis, Ph.D., *Research Fellow in Aeronautics*
B.S., California Institute, 1968; M.S., 1969; Ph.D., 1973. Research Fellow, 1973-. (Karman)

Charles Hewitt Dix, Ph.D., *Professor of Geophysics, Emeritus*
B.S., California Institute, 1927; A.M., Rice Institute, 1928; Ph.D., 1931. Associate Professor, California Institute, 1948-54; Professor, 1954-73; Professor Emeritus, 1973-. (Mudd)

Angeline Douvas, Ph.D., *Research Fellow in Biology*
B.A., University of Colorado, 1967. Ph.D., University of California (San Diego), 1972. California Institute, 1973-. (Kerckhoff)

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

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

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

Thomas Harold Dunning, Jr., Ph.D., *Research Fellow and Instructor in Chemistry*
B.S., University of Missouri, 1965; Ph.D., California Institute, 1970. Research Fellow, 1969; 1971-72; Research Fellow and Instructor, 1972-. (Noyes)

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

Michael M. Dworetsky, Ph.D., *Research Fellow in Astronomy*
B.S., Harvey Mudd College, 1965; M.A., University of California (Los Angeles), 1966; Ph.D., 1971. California Institute, 1971-. (Hale Office)

Cecil Ray Dybowski, Ph.D., *Research Fellow in Chemical Engineering*
B.S., University of Texas (Austin), 1969; Ph.D., 1973. California Institute, 1973-74.

Peggy Lynn Dyer, Ph.D., *Research Fellow in Physics*
B.S., University of Texas (Austin), 1968; Ph.D., California Institute, 1973. Research Fellow, 1973-. (Kellogg)

Douglas M. Eardley, Ph.D., *Research Fellow in Physics*
B.S., California Institute, 1967; M.S., University of California, 1968; Ph.D., 1972. California Institute, 1972-. (Bridge)

Douglas C. Eaton, Ph.D., *Visiting Associate in Biology*
B.S., California Institute, 1967; M.S., Scripps Institute of Oceanography, University of California (San Diego), 1969; Ph.D., 1970. California Institute, 1973.

Paul Conant Eaton, A.M., *Professor of English, Emeritus*
S.B., Massachusetts Institute of Technology, 1927; A.M., Harvard University, 1930. Visiting Lecturer in English, California Institute, 1946; Associate Professor, 1947-71; Dean of Students 1952-69; Professor Emeritus, 1971-. (Baxter)

Charles Elachi,** Ph.D., *Research Fellow in Electrical Engineering*
Ing., Polytechnic Institute of Grenoble, 1968; M.S., California Institute, 1969; Ph.D., 1971. Staff Member, Jet Propulsion Laboratory, 1971-. California Institute, 1971-. (Steele)

Moshe Elitzur, Ph.D., *Research Fellow in Theoretical Physics*
B.Sc., Hebrew University of Jerusalem, 1964; M.Sc., Weizmann Institute, 1966; Ph.D., 1970. California Institute, 1972-. (Robinson)

**Part-time

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

David Clephan Elliot, Ph.D., *Professor of History*
M.A., St. Andrew's University, 1939; A.M., Harvard University, 1948; M.A., Oxford University, 1956; Ph.D., 1951. Assistant Professor, California Institute, 1950-53; Associate Professor, 1953-60; Professor, 1960-; Executive Officer, 1967-71. (Baxter)

Hubert Whitfield Ellis, Ph.D., *Visiting Associate in Mathematics*
B.Sc., Acadia University (Canada), 1940; M.Sc., 1942; M.A., University of Toronto, 1946; Ph.D., 1947. Professor of Mathematics, Queen's University (Canada), 1960-. California Institute, 1964-65; 1973.

Sterling Emerson, Ph.D., *Professor of Genetics, Emeritus*
B.Sc., Cornell University, 1922; M.A., University of Michigan, 1924; Ph.D., 1928. Assistant Professor, California Institute, 1928-37; Associate Professor, 1937-46; Professor, 1946-71; Professor Emeritus, 1971-. (Kerckhoff)

Warren G. Emery, M.S., *Director of Physical Education and Athletics*
B.S., University of Nebraska, 1948; M.S., University of California (Los Angeles), 1959. Coach, California Institute, 1955; Assistant Director, 1963-64; Director, 1964-. (Gymnasium)

Howard Wilson Emmons, *Sherman Fairchild Distinguished Scholar*
M.E., Stevens Institute of Technology, 1933; M.S., 1935; Sc.D., Harvard University, 1938. Professor of Mechanical Engineering, 1950-. California Institute, 1973-74.

Stuart Alan Ende, Ph.D., *Assistant Professor of English*
A.B., Cornell University, 1965; M.A., New York University, 1966; Ph.D., Cornell University, 1970. California Institute, 1970-. (Baxter)

James Morris England, Ph.D., *Research Fellow in Biology*
A.B., Lafayette College, 1964; Ph.D., Washington University (St. Louis), 1970. California Institute, 1970-. (Alles)

Robert Everett Enns, Ph.D., *Research Fellow in Biology*
B.S., San Diego State College, 1965; M.S., 1967; Ph.D., University of Oregon, 1971. California Institute, 1971-. (Kerckhoff)

Marcelle Christiane Epherre, Ph.D., *Visiting Associate in Geochemistry*
Lic., University of Paris, 1961; Dipl., 1962; Ph.D., 1972. Physicist, Institute of Nuclear Physics (Orsay), 1962-. California Institute, 1972.

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

Arturo P. Eslava, Ph.D., *Research Fellow in Biology*
B.S., University of Valencia, 1969; Ph.D., University of Seville, 1973. California Institute, 1973-74.

Karl E. Espelie, Ph.D., *Research Fellow in Biology*
B.A., Augustana College, 1967; Ph.D., University of Wisconsin, 1972. California Institute, 1972-. (Church)

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

Glennys R. Farrar, Ph.D., *Senior Research Fellow in Theoretical Physics*
B.A., University of California, 1967; Ph.D., Princeton University, 1970. California Institute, 1973-. (Downs)

Peter Ward Fay,* Ph.D., *Professor of History*
A.B., Harvard College, 1947; B.A., Oxford University, 1949; Ph.D., Harvard University, 1954. Assistant Professor, California Institute, 1955-60; Associate Professor, 1960-70; Professor, 1970-. (Baxter)

*Leave of absence, 1973-74
**Part-time

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

John Ferejohn, Ph.D., *Assistant Professor of Political Science*
B.A., San Fernando Valley State College, 1966; Ph.D., Stanford University, 1971. California Institute, 1971-. (Baxter)

Donald R. Ferrier, Ph.D., *Research Fellow in Chemistry*
B.S., University of Wisconsin, 1967; Ph.D., Wayne State University, 1971. California Institute, 1971-. (Noyes)

Richard Phillips Feynman, Ph.D., Nobel Laureate, *Richard Chace Tolman Professor of Theoretical Physics*
B.S., Massachusetts Institute of Technology, 1939; Ph.D., Princeton University, 1942. Visiting Professor, California Institute, 1950; Professor, 1950-59; Tolman Professor, 1959-. (Lauritsen)

Richard D. Field, Jr., Ph.D., *Research Fellow in Theoretical Physics*
B.S., University of California, 1966; Ph.D., 1971. California Institute, 1973-74.

Eva Fifkova, M.D., Ph.D., *Research Associate in Biology*
M.D., Charles University (Prague), 1957; Ph.D., Czechoslovakian Academy of Sciences, 1963. Research Fellow, California Institute, 1968-70; Senior Research Fellow, 1970-72; Research Associate, 1972-. (Kerckhoff)

Morris P. Fiorina, Ph.D., *Assistant Professor of Political Science*
B.A., Allegheny College, 1968; Ph.D., The University of Rochester, 1972. California Institute, 1972-. (Baxter)

Alexander Firestone, Ph.D., *Assistant Professor of Physics*
B.A., Columbia University, 1962; M.S., Yale University, 1964; Ph.D., 1966. California Institute, 1971-. (Lauritsen)

Arleen B. Forsheit, Ph.D., *Research Fellow in Chemistry*
B.S., Brooklyn College, The City University of New York, 1965; M.A., Columbia University, 1967; Ph.D., University of California (Los Angeles), 1970. California Institute, 1970-. (Crellin)

William Alfred Fowler, Ph.D., *Institute Professor of Physics*
B.Eng., The Ohio State University, 1933; Ph.D., California Institute, 1936. Research Fellow, 1936-39; Assistant Professor, 1939-42; Associate Professor, 1942-46; Professor, 1946-71; Institute Professor, 1971-. (Kellogg)

Geoffrey Charles Fox, Ph.D., *Assistant Professor of Theoretical Physics*
B.A., University of Cambridge, 1964; Ph.D., 1967. Millikan Research Fellow, California Institute, 1970-71; Assistant Professor, 1971-. (Lauritsen)

James R. Fox, Ph.D., *Research Fellow in Biomedical Engineering*
B.S., Northwestern University, 1966; M.S., 1967; Ph.D., University of Washington, 1972. California Institute, 1973-74.

Steven N. Frank, Ph.D., *Research Fellow in Chemistry*
B.S., Colorado State University, 1969; Ph.D., California Institute, 1973. Research Fellow, 1973-74.

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

Wallace Goodman Frasher, Jr.,** M.D., *Visiting Associate in Biomedical Engineering*
A.B., University of Southern California, 1941; M.D., 1951. Associate Research Professor of Medicine, Loma Linda University, 1963-. Research Fellow in Engineering, California Institute, 1961-63; Senior Research Fellow in Engineering Science, 1963-72; Visiting Associate in Biomedical Engineering, 1972-. (Thomas)

**Part-time

Steven Clark Frautschi, Ph.D., *Professor of Theoretical Physics*
B.S., Harvard College, 1955; Ph.D., Stanford University, 1958. Assistant Professor, California Institute, 1962-64; Associate Professor, 1964-66; Professor, 1966-. (Lauritsen)

Sheldon Kay Friedlander, Ph.D., *Professor of Chemical and Environmental Health Engineering*
B.S., Columbia University, 1949; M.S., Massachusetts Institute of Technology, 1951; Ph.D., University of Illinois, 1954. California Institute, 1964-. (Keck)

Harald Fritzsch, Ph.D., *Research Fellow in Theoretical Physics*
Dipl., University of Leipzig, 1968; Ph.D., Technical University of Munich, 1971. California Institute, 1972-. (Lauritsen)

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

Okitsugu Furuya, Ph.D., *Research Fellow in Mechanical Engineering*
B.S., University of Tokyo, 1965; M.S., California Institute, 1969; Ph.D., 1972. Research Fellow, 1972-. (Karman)

Robert Stephen Gall, Ph.D., *Research Fellow in Chemistry*
B.S., Michigan State University, 1968; Ph.D., University of Wisconsin, 1973. California Institute, 1973-74.

Ruth Lack Gall, Ph.D., *Visiting Associate in Chemistry*
B.Sc., University of Sydney, 1948; Ph.D., 1960. Associate Professor of Organic Chemistry, University of Sydney. Research Fellow, California Institute, 1966-67; Visiting Associate, 1973.

Elsa Meints Garmire,** Ph.D., *Senior Research Fellow in Applied Science*
A.B., Radcliffe College, 1961; Ph.D., Massachusetts Institute of Technology, 1965. Research Fellow, California Institute, 1966-71; Senior Research Fellow, 1971-; Lecturer in Art and Technology, 1972. (Steele)

Gordon Paul Garmire,*** Ph.D., *Professor of Physics*
A.B., Harvard College, 1959; Ph.D., Massachusetts Institute of Technology, 1962. Senior Research Fellow, California Institute, 1966-68; Associate Professor, 1968-72; Professor, 1972-. (Downs)

William T. Garrard, Jr., Ph.D., *Research Fellow in Biology*
B.S., University of Washington, 1966; Ph.D., University of California (Los Angeles), 1971. California Institute, 1971-. (Kerckhoff)

Justine Spring Garvey, Ph.D., *Senior Research Fellow in Chemistry*
B.S., The Ohio State University, 1944; M.S., 1948; Ph.D., 1950. Research Fellow, California Institute, 1951-57; Senior Research Fellow, 1957-. (Church)

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

Murray Gell-Mann, Ph.D., Sc.D., D.Sc., Nobel Laureate, *Robert Andrews Millikan Professor of Theoretical Physics*
B.S., Yale University, 1948; Ph.D., Massachusetts Institute of Technology, 1950; Sc.D., Yale University, 1959; D.Sc., University of Chicago, 1967. Associate Professor, California Institute, 1955-56; Professor, 1956-67; Millikan Professor, 1967-. (Lauritsen)

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

Bernard Clemence Gerstein, Ph.D., *Visiting Associate in Chemical Engineering*
B.S., Purdue University, 1953; Ph.D., Iowa State University, 1960. California Institute, 1972-73.

Alain Ghysen, D.Sc., *Research Fellow in Biology*
D.Sc., University of Brussels, 1971. California Institute, 1973-74.

**Part-time
***Leave of absence, second and third terms, 1973-74

Donald Dominic Giannini, Ph.D., *Research Fellow in Chemistry*
B.S., University of San Francisco, 1965; Ph.D., University of California (San Francisco), 1973. California Institute, 1973-74.

Rudolf Giger, Ph.D., *Research Fellow in Chemistry*
Dipl., Swiss Federal Institute of Technology (Zurich), 1968; Ph.D., 1973. California Institute, 1973-74.

Horace Nathaniel Gilbert, M.B.A., D.B.A., *Professor of Business Economics, Emeritus*
A.B., University of Washington, 1923; M.B.A., Harvard University, 1926; D.B.A., South Dakota School of Mines and Technology, 1971. Assistant Professor, California Institute, 1929-30; Associate Professor, 1930-47; Professor, 1947-69; Professor Emeritus, 1969-. (Baxter)

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

Donald Edmond Glover, Ph.D., *Research Fellow in Chemistry*
B.S., University of Redlands, 1968; Ph.D., Northwestern University, 1973. California Institute, 1972-. (Noyes)

William Andrew Goddard III, Ph.D., *Associate Professor of Theoretical Chemistry*
B.S., University of California (Los Angeles), 1960; Ph.D., California Institute, 1965. Noyes Research Fellow in Chemistry, 1964-66; Noyes Research Instructor, 1966-67; Assistant Professor of Theoretical Chemistry, 1967-71; Associate Professor, 1971-. (Noyes)

Elihu Goldish, Ph.D., *Visiting Associate in Chemistry*
B.Sc., Marietta College, 1949; Ph.D., California Institute, 1956. Research Chemist, Union Oil Company of California. California Institute, 1973-74.

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

Martin Goldsmith, Ph.D., *Visiting Associate in Environmental Engineering*
B.S., University of California, 1951; M.S., California Institute, 1952; Ph.D., 1955. Visiting Associate, 1971-. Group Director, Aerospace Corporation, 1961-. (Thomas, Dabney)

Richard Morris Goldstein,** Ph.D., *Research Associate in Planetary Science*
B.S., Purdue University, 1947; M.S., California Institute, 1959; Ph.D., 1962. Manager, Telecommunications Research Section, Jet Propulsion Laboratory, 1958-. Visiting Associate Professor of Planetary Science, California Institute, 1967-73; Research Associate, 1973-. (Mudd)

Ricardo Gomez, Ph.D., *Associate Professor of Physics*
S.B., Massachusetts Institute of Technology, 1953; Ph.D., 1956. Research Fellow, California Institute, 1956-59; Senior Research Fellow, 1959-71; Associate Professor, 1971-. (Lauritsen)

David Louis Goodstein, Ph.D., *Associate Professor of Physics*
B.S., Brooklyn College, 1960; Ph.D., University of Washington, 1965. Research Fellow, California Institute, 1966-67; Assistant Professor, 1967-71; Associate Professor, 1971-. (Sloan)

Harold William Gordon, Ph.D., *Research Fellow in Biology*
B.S., Case Institute of Technology, 1967; Ph.D., California Institute, 1973. Research Fellow, 1972-73.

Joseph Grover Gordon II, Ph.D., *Assistant Professor of Chemistry*
A.B., Harvard College, 1966; Ph.D., Massachusetts Institute of Technology, 1970. California Institute, 1970-. (Noyes)

J. Richard Gott III, Ph.D., *Research Fellow in Astrophysics*
A.B., Harvard College, 1969; Ph.D., Princeton University, 1972. California Institute, 1972-. (Robinson)

**Part-time

Roy Walter Gould, Ph.D., *Professor of Electrical Engineering and Physics; Executive Officer for Applied Physics*
B.S., California Institute, 1949; M.S., Stanford University, 1950; Ph.D., California Institute, 1956. Assistant Professor of Electrical Engineering, 1955-58; Associate Professor, 1958-60; Associate Professor of Electrical Engineering and Physics, 1960-62; Professor, 1962-; Executive Officer for Applied Physics, 1973-. (Steele)

Dale E. Graham, Ph.D., *Research Fellow in Biology*
B.S., University of Tennessee, 1966; Ph.D., 1971. California Institute, 1971-. (Kerckhoff)

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

Robert Davis Gray, B.S., *Professor of Economics and Industrial Relations; Director of Industrial Relations Center*
B.S., Wharton School of Finance and Commerce, University of Pennsylvania, 1930. Associate Professor, California Institute, 1940-42; Professor, 1942-; Director, Industrial Relations Center, 1941-. (Industrial Relations Center)

Norton Robert Greenfeld, Ph.D., *Research Fellow in Information Sciences*
B.S., California Institute, 1967; M.S., 1968; Ph.D., 1972. Research Fellow, 1972-. (Jorgensen)

Jesse Leonard Greenstein, Ph.D., *Lee A. DuBridge Professor of Astrophysics*
A.B., Harvard College, 1929; A.M., Harvard University, 1930; Ph.D., 1937. Associate Professor, California Institute, 1948-59; Professor, 1949-70; Staff Member, Hale Observatories, 1948-; Executive Officer for Astronomy, 1964-72; DuBridge Professor, 1970-. (Robinson)

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

Ronald C. Griffith, Ph.D., *Research Fellow in Chemistry*
B.A., Alfred University, 1969; Ph.D., Syracuse University, 1973. California Institute, 1973-74.

Martin Lewis Griss, Ph.D., *Research Fellow in Theoretical Physics*
B.Sc., Technion (Haifa), 1967; M.S., University of Illinois, 1969; Ph.D., 1971. California Institute, 1971-. (Lauritsen)

Karel Grohmann, Ph.D., *Research Fellow in Biology*
Dipl., University of Chemical Technology (Prague), 1965; Ph.D., University of Houston, 1972. California Institute, 1972-. (Church)

Daniel Grosjean, Ph.D., *Research Fellow in Environmental Science*
Ph.D., University of Paris, 1971. California Institute, 1972-. (Keck)

Lawrence Grossman, Ph.D., *Research Fellow in Biology*
B.S., City College of the City University of New York, 1961; Ph.D., Albert Einstein College of Medicine, 1970. California Institute, 1970-. (Crellin)

Francisco Alberto Grünbaum, Ph.D., *Assistant Professor of Applied Mathematics*
Lic., National University of Buenos Aires, 1966; Ph.D., The Rockefeller University, 1969. California Institute, 1973-. (Firestone)

Allen Matthew Guest, Ph.D., *Research Fellow in Chemistry*
B.S., Loyola University, 1966; Ph.D., Tulane University, 1970. California Institute, 1972-. (Church)

James Edward Gunn, Ph.D., *Professor of Astronomy*
B.A., Rice University, 1961; Ph.D., California Institute, 1966. Assistant Professor, 1970-72; Professor, 1972-; Staff Member, Hale Observatories, 1972-. (Robinson)

Ramesh Gupta, Ph.D., *Research Fellow in Chemical Engineering*
B.S., Indian Institute of Technology (Kanpur), 1969; M.A., Princeton University, 1970; Ph.D., 1973. California Institute, 1973-. (Spalding)

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

Arie Jan Haagen-Smit, Ph.D., *Professor of Bio-organic Chemistry, Emeritus*
A.B., University of Utrecht, 1922; A.M., 1926; Ph.D., 1929. Associate Professor, California Institute, 1937-40; Professor, 1940-71; Professor Emeritus, 1971-. (Kerckhoff)

Peter K. Haff, Ph.D., *Research Fellow in Physics*
A.B., Harvard College, 1966; Ph.D., University of Virginia, 1970. California Institute, 1972-. (Kellogg)

Eldon Lee Haines,** Ph.D., *Visiting Associate in Nuclear Geochemistry*
B.A., University of Kansas, 1957; Ph.D., University of California, 1962. Staff Member, Jet Propulsion Laboratory, 1968-. Visiting Associate, California Institute, 1971; Visiting Associate Professor, 1971-72; Visiting Associate, 1972-73.

James Ewbank Hall,** Ph.D., *Research Fellow in Chemistry*
B.S., Pomona College, 1963; M.S., Ph.D., University of California (Riverside), 1968. Research Fellow in Electrical Engineering, California Institute, 1970-72; Research Fellow in Chemistry, 1972-73.

Jeffrey C. Hall, Ph.D., *Research Fellow in Biology*
B.A., Amherst College, 1967; Ph.D., University of Washington, 1971. California Institute, 1971-. (Church)

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

Takashi Hamada, D.Eng., *Visiting Assistant Professor of Transportation*
B.Eng., University of Tokyo, 1964; M.Eng., 1966; D.Eng., 1969. Assistant Professor of the Institute of Industrial Science, University of Tokyo, 1969-. California Institute, 1973-74.

Laila Shukry El Hamamsy, Ph.D., *Visiting Associate in Sociology*
B.A., The American University in Cairo, 1946; M.S., Bryn Mawr College, 1950; Ph.D., Cornell University, 1954. Director of the Social Research Center and Professor of Anthropology and Social Research, The American University in Cairo, 1957-. California Institute, 1973.

Christopher John Hamer,** Ph.D., *Research Fellow in Physics*
B.Sc., University of Melbourne, 1966; M.S., 1968; Ph.D., California Institute, 1972. Research Fellow, 1972.

Charles Robert Hamilton, Ph.D., *Senior Research Fellow in Biology*
B.S., The University of the South, 1957; Ph.D., California Institute, 1964. Research Fellow, 1964-65; Senior Research Fellow, 1971-. (Alles)

Warren Bell Hamilton, Ph.D., *Visiting Professor of Geology*
A.B., University of California (Los Angeles), 1945; M.S., University of Southern California, 1949; Ph.D., University of California (Los Angeles), 1951. Geologist, U.S. Geodetic Survey (Denver), 1952-. California Institute, 1973.

Joseph Leonard Hammack, Jr., Ph.D., *Research Fellow in Civil Engineering*
B.S., University of North Carolina, 1966; M.S., 1968; Ph.D., California Institute, 1972. Research Fellow, 1972-. (Keck)

Mokhtar Hamza, Ph.D., *Research Fellow in Geochemistry*
B.Sc., Cairo University, 1961; M.Sc., 1966; Ph.D., Columbia University, 1972. California Institute, 1972-. (Arms)

Thomas C. Hanks, Ph.D., *Research Fellow in Applied Science and Geophysics*
B.S., Princeton University, 1966; Ph.D., California Institute, 1972. Research Fellow, 1972-. (Thomas)

David Garrison Harkrider, Ph.D., *Associate Professor of Geophysics*
B.A., Rice University, 1953; M.A., 1957; Ph.D., California Institute, 1963. Associate Professor, 1970-. (Seismo Lab.)

Raymond William Harrigan, Ph.D., *Research Fellow in Chemistry*
B.S., University of New Mexico, 1965; M.S., 1968; Ph.D., 1970. California Institute, 1972-. (Noyes)

Daniel Charles Harris, Ph.D., *Instructor in Chemistry*
S.B., Massachusetts Institute of Technology, 1968; Ph.D., California Institute, 1973. Instructor, 1972-73.

**Part-time

Michael H. Hart, Ph.D., *Research Fellow in Astronomy*
B.A., Cornell University, 1952; LL.B., New York Law School, 1958; M.S., Adelphi University, 1969; Ph.D., Princeton University, 1972. California Institute, 1972-. (Hale Office)

Jacob Daniel Haskell, Ph.D., *Royal W. Sorensen Instructor in Electrical Engineering*
B.Sc., University of Sussex (England), 1967; M.Sc., 1969; M.S. University of Wisconsin, 1969; Ph.D., University of Salford (England), 1971. Research Fellow, California Institute, 1971-72; Royal W. Sorensen Instructor, 1972-73.

Michael George Hauser, Ph.D., *Senior Research Fellow in Physics*
B.S., Cornell University, 1962; Ph.D., California Institute, 1967. Senior Research Fellow, 1972-. (Downs)

Eri Heller, Ph.D., *Senior Research Fellow in Chemistry*
B.Sc., Israel Institute of Technology, 1964; M.Sc., Hebrew University of Jerusalem, 1965; Ph.D., Weizmann Institute of Science, 1969. Research Fellow, California Institute, 1969-73; Senior Research Fellow, 1973-. (Church)

Donald Vincent Helmberger, Ph.D., *Assistant Professor of Geophysics*
B.S., University of Minnesota, 1961; M.S., University of California (San Diego), 1965; Ph.D., 1967. California Institute, 1970-. (Seismo Lab.)

Bozena Henisz-Dostert, Ph.D., *Research Associate in Linguistics*
M.A., University of Warsaw, 1956; M.S., Georgetown University, 1961; Ph.D., 1965. Lecturer in English, California Institute, 1969; Senior Research Fellow, 1969-73; Research Associate, 1973-. (Baxter)

Frank Herzl Herbstein, Ph.D., *Visiting Associate in Chemistry*
B.Sc., University of Cape Town, 1946; M.Sc., 1947; Ph.D., Hebrew University of Jerusalem, 1956; D.Sc., University of Cape Town, 1968. Professor of Chemistry, Israel Institute of Technology, 1965-. California Institute, 1972-73.

Richard O. Herrmann, Ph.D., *Research Fellow in Biology*
Ph.D., Max Planck Institute, 1969. California Institute, 1972-. (Kerckhoff)

Isom Harris Herron, Ph.D., *Research Fellow in Applied Mathematics*
S.B., Massachusetts Institute of Technology, 1967; Ph.D., The Johns Hopkins University, 1973. California Institute, 1972-73.

Newton Davis Hershey, Ph.D., *Research Fellow in Chemistry*
B.S., Bucknell University, 1965; Ph.D., Massachusetts Institute of Technology, 1970. California Institute, 1970-. (Crellin)

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

Albert Roach Hibbs,** Ph.D., *Lecturer in Physics*
B.S., California Institute, 1945; M.S., University of Chicago, 1947; Ph.D., California Institute, 1955. Senior Staff Scientist, Jet Propulsion Laboratory, 1950-. Lecturer, 1972-. (Thomas)

George Martel Hidy,** D.Eng., *Visiting Associate in Environmental Engineering Science*
B.A., Columbia University, 1956; B.S., 1957; M.S.E., Princeton University, 1958; D.Eng., The Johns Hopkins University, 1962. Staff Member, North American-Rockwell Corp. (Thousand Oaks), 1968-. Research Fellow in Environmental Health Engineering, California Institute, 1969-73; Visiting Associate in Environmental Engineering Science, 1973-. (Keck)

Yoshimitsu Hirao, Ph.D., *Research Fellow in Geochemistry*
B.S., Tokyo College of Science, 1966; M.S., Tokyo Kyoiku University, 1968; Ph.D., 1971. California Institute, 1972-. (Arms)

Richard Lawrence Hirsh, Ph.D., *Research Fellow in Biology*
B.A., The University of Rochester, 1963; Ph.D., Stanford University, 1969. California Institute, 1970-. (Kerckhoff)

Janet Mary Hock, D.D.S., *Research Fellow in Biomedical Engineering*
D.D.S., University of London, 1966; M.S., University of Iowa, 1970; California Institute, 1972-73.

H. Leslie Hodges, Ph.D., *Research Fellow in Chemistry*
B.S., University of Michigan, 1966; M.S., 1968; Ph.D., 1971. California Institute, 1971-. (Noyes)

**Part-time

Michael R. Hoffman, Ph.D., *Research Fellow in Environmental Engineering Science*
B.A., Northwestern University, 1968; Ph.D., Brown University, 1973. California Institute, 1973-74.

John Paul Holdren, Ph.D., *Senior Research Fellow in Population Studies*
B.S., Massachusetts Institute of Technology, 1965; M.S., 1966; Ph.D., Stanford University, 1970. California Institute, 1972-. (Dabney)

John Holt, Ph.D., *Research Fellow in Solar Physics*
B.S., University of Queensland, 1967; Ph.D., 1970. California Institute, 1973-74.

Leroy E. Hood, M.D., Ph.D., *Associate Professor of Biology*
B.S., California Institute, 1960; M.D., The Johns Hopkins University, 1964; Ph.D., California Institute, 1967. Assistant Professor, 1970-73; Associate Professor, 1973-. (Church)

Norman Harold Horowitz, Ph.D., *Professor of Biology; Executive Officer for Biology*
B.S., University of Pittsburgh, 1936; Ph.D., California Institute, 1939. Research Fellow, 1940-42; Senior Research Fellow, 1946; Associate Professor, 1947-53; Professor, 1953-; Executive Officer, 1971-; Acting Chairman, Division of Biology, 1973. (Kerckhoff)

Barbara Raymond Hough, Ph.D., *Senior Research Fellow in Biology*
B.A., Swarthmore College, 1945; M.A., Cornell University, 1948; Ph.D., State University of New York (Stony Brook), 1968. Research Fellow, California Institute, 1971-72; Senior Research Fellow, 1972-. (Alles)

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

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

Fred Hoyle,** M.A., D.Sc., *Visiting Associate in Physics*
M.A., University of Cambridge, 1939; D.Sc., University of Norwich, 1967; University of Leeds, 1969. Professor of Astronomy, Royal Institution (London), 1969-; Honorary Research Professor, University of Manchester, 1972-. Visiting Professor of Astronomy, California Institute, 1953; 1954; 1956; Addison White Greenway Visiting Professor of Astronomy; Staff Member, Hale Observatories, 1957-62; Visiting Associate, 1963-. (Kellogg)

Pauline Pai-Jen Hsiao, Ph.D., *Research Fellow in Chemistry*
B.S., National Taiwan University, 1969; Ph.D., University of California, 1973. California Institute, 1973-74.

George Chi Hsu, Ph.D., *Research Fellow in Chemical Engineering*
B.S., Tunghai University (Taiwan), 1964; M.S., Illinois Institute of Technology, 1967; Ph.D., California Institute, 1972. Research Fellow, 1972-. (Spalding)

Wei-Jen Jenny Hu, Ph.D., *Research Fellow in Chemistry*
B.S., National Taiwan University, 1969; M.A., Columbia University, 1970; Ph.D., 1973. California Institute, 1973-74.

Hans Peter Huber, Ph.D., *Research Fellow in Chemistry*
Dipl., Swiss Federal Institute of Technology (Zurich), 1968; Ph.D., University of Basel, 1972. California Institute, 1972-. (Crellin)

Franz-Herbert Hubmann, M.D., Ph.D., *Research Fellow in Biology*
M.D., University of Munich, 1968; Ph.D., 1972. California Institute, 1973-74.

Donald Ellis Hudson, Ph.D., *Professor of Mechanical Engineering and Applied Mechanics*
B.S., California Institute, 1938; M.S., 1939; Ph.D., 1942. Instructor of Machine Design, 1942-43; Assistant Professor of Mechanical Engineering, 1943-49; Associate Professor, 1949-55; Professor, 1955-63; Professor of Mechanical Engineering and Applied Mechanics, 1963-. (Thomas)

David Lee Huestis, Ph.D., *Research Fellow in Applied Physics*
B.A., Macalester College, 1968; M.S., California Institute, 1969; Ph.D., 1972. Research Fellow, 1972.

**Part-time

Wray Hughes Huestis, Ph.D., *Research Fellow in Chemistry*
B.S., Macalester College, 1967; Ph.D., California Institute, 1972. Research Fellow, 1972.

Arthur Hurn Huffman, Ph.D., *Senior Research Fellow in Physics*
B.S., Virginia Polytechnic Institute, 1961; S.M., Massachusetts Institute of Technology, 1965; Ph.D., University of Washington, 1968. Research Fellow, California Institute, 1970-72; Senior Research Fellow, 1972-. (Kellogg)

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

Henry Grady Hughes III, Ph.D., *Research Fellow in Physics*
B.A., Rice University, 1968; M.A., 1969; Ph.D., 1971. California Institute, 1972.

Floyd Bernard Humphrey, Ph.D., *Professor of Electrical Engineering*
B.S., California Institute, 1950; Ph.D., 1956. Senior Research Fellow, 1960-64; Associate Professor, 1964-71; Professor, 1971-. (Steele)

John Clifton Huneke, M.S., *Senior Research Fellow in Planetary Science*
B.S., University of Redlands, 1961; M.S., University of Minnesota, 1964. California Institute, 1972-. (Arms)

Ian Hunter,** Ph.D., *Lecturer in Psychology*
B.A., Occidental College, 1960; M.S., University of Oregon, 1963; Ph.D., 1966. Lecturer, California Institute, 1971-. (Health Center, Baxter)

Stirling Louis Huntley, Ph.D., *Lecturer in Drama; Associate Dean of Graduate Studies; Director of Admissions and Financial Aid*
B.A., University of California (Los Angeles), 1945; M.S., 1949; Ph.D., Stanford University, 1956. Associate Dean of Graduate Studies, California Institute, 1971-; Lecturer, 1973-; Director, 1973-. (Dabney)

James J. Huntzicker, Ph.D., *Research Fellow in Environmental Health Engineering*
B.S., University of Michigan, 1963; Ph.D., University of California, 1968. California Institute, 1972-. (Keck)

Edward Hutchings, Jr., B.A., *Lecturer in Journalism*
B.A., Dartmouth College, 1933. Editor of Engineering and Science Magazine, California Institute, 1948-. Lecturer, 1952-; Director of Institute Publications, 1964-. (1107 San Pasqual)

Robert A. Huttenback, Ph.D., *Professor of History; Chairman of the Division of Humanities and Social Sciences*
B.A., University of California (Los Angeles), 1951; Ph.D., 1959. Master of Student Houses, California Institute, 1958-69; Lecturer in History, 1958-60; Assistant Professor, 1960-63; Associate Professor, 1963-66; Professor, 1966-; Dean of Students, 1969-72; Acting Division Chairman, 1970-72; Division Chairman, 1972-. (Baxter)

Yevgeniy Ivanovich Il'yashenko, Dr.Ing., *Visiting Associate in Electrical Engineering*
Dr.Ing., Moscow Power Engineering Institute, 1960. Scientific Collaborator, Institute of Control Problems, Moscow, 1965-. California Institute, 1973.

Giorgio Ingargiola, Ph.D., *Assistant Professor of Applied Science*
D.E.E., University of Rome, 1963; Ph.D., University of Pennsylvania, 1967. California Institute, 1968-. (Booth)

Andrew Perry Ingersoll, Ph.D., *Associate Professor of Planetary Science*
B.A., Amherst College, 1960; A.M., Harvard University, 1961; Ph.D., 1966. Assistant Professor, California Institute, 1966-71; Associate Professor, 1971-; Staff Associate, Hale Observatories, 1971-. (Mudd)

Marylou Ingram, M.D., *Research Associate in Biomedical Engineering*
B.A., Western Reserve University, 1942; M.S., 1943; M.D., The University of Rochester, 1947. California Institute, 1971-. (Jet Propulsion Lab.)

**Part-time

Devrie Shapiro Intriligator, Ph.D., *Visiting Associate in Physics*
S.B., Massachusetts Institute of Technology, 1962; S.M., 1964; Ph.D., University of California (Los Angeles), 1967. Assistant Professor, University of Southern California, 1972-. Research Fellow, California Institute, 1969-72; Visiting Associate, 1972-73.

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

Wilfred Dean Iwan, Ph.D., *Professor of Applied Mechanics*
B.S., California Institute, 1957; M.S., 1958; Ph.D., 1961. Assistant Professor, 1964-67; Associate Professor, 1967-72; Professor, 1972-. (Thomas)

Kenneth Mark Jassby, Ph.D., *Visiting Associate in Materials Science*
B.E., McGill University, 1965; M.E., 1967; Ph.D., California Institute, 1970. Research Fellow, 1970-73; Visiting Associate, 1973.

Paul Christian Jennings, Ph.D., *Professor of Applied Mechanics*
B.S., Colorado State University, 1958; M.S., California Institute, 1960; Ph.D., 1963. Research Fellow in Civil Engineering, 1965; Assistant Professor of Applied Mechanics, 1966-68; Associate Professor, 1968-72; Professor, 1972-. (Thomas)

Elmar Jessberger, Ph.D., *Research Fellow in Planetary Science*
Dipl., University of Munich, 1967; Dipl., University of Heidelberg, 1969; Ph.D., Max Planck Institute, 1971. California Institute, 1972-. (Arms)

Fritz John, Ph.D., *Visiting Associate in Applied Mathematics*
Ph.D., University of Göttingen, 1933. Professor, Courant Institute of Mathematical Sciences, 1939-. California Institute, 1973.

Stanley Roy Johns, Ph.D., *Visiting Associate in Chemistry*
B.Sc., University of New England (Australia), 1956; Ph.D., University of Sydney, 1960. Senior Research Scientist, CSIRO, 1964-. California Institute, 1971-72.

Jerry Dana Johnson, Ph.D., *Research Fellow in Biology*
B.S., Wisconsin State University, 1967; Ph.D., Iowa State University, 1971. California Institute, 1971-. (Kerckhoff)

Ross Glenn Johnson, Ph.D., *Visiting Associate in Biology*
B.A., Augustana College, 1964; M.S., Iowa State University, 1966; Ph.D., 1968. Assistant Professor, University of Minnesota, 1968-. California Institute, 1973.

Jack Randolph Jokipii, Ph.D., *Associate Professor of Theoretical Physics*
B.S., University of Michigan, 1961; Ph.D., California Institute, 1965. Associate Professor, 1969-. (Downs)

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

William Thomas Jones,** Ph.D., *Andrew W. Mellon Professor of Philosophy*
A.B., Swarthmore College, 1931; B.Litt., Oxford University, 1933; A.M., Princeton University, 1936; Ph.D., 1937. Visiting Professor, California Institute, 1970-72; Andrew W. Mellon Professor, 1972-. (Baxter)

Richard Douglas Kerr Josslin, Ph.D., *Research Fellow in Biology*
S.B., Massachusetts Institute of Technology, 1965; Ph.D., California Institute, 1970. Research Fellow, 1972-73.

Masatsune Kainosho, D.Sc., *Research Fellow in Chemistry*
B.Sc., Tokyo Metropolitane University, 1964; D.Sc., 1970. California Institute, 1973-74.

**Part-time
***Leave of absence, third term, 1973-74

Walter Barclay Kamb, Ph.D., *Professor of Geology and Geophysics; Chairman of the Division of Geological and Planetary Sciences*
B.S., California Institute, 1952; Ph.D., 1956. Assistant Professor of Geology, 1956-60; Associate Professor, 1960-62; Professor, 1962-63; Professor of Geology and Geophysics, 1963-; Division Chairman, 1972-. (Mudd)

Hiroo Kanamori, Ph.D., *Professor of Geophysics*
B.S., Tokyo University, 1959; M.S., 1961; Ph.D., 1964. Research Fellow, California Institute, 1965-66; Professor, 1972-. (Seismo Lab)

Donald S. Kaplan, Ph.D., *Research Fellow in Chemical Engineering*
B.S., Fairleigh Dickinson University, 1968; Ph.D., Adelphi University, 1972. California Institute, 1972-73.

Harumi Uwatoko Kasamatsu, Ph.D., *Senior Research Fellow in Biology*
B.S., University of Osaka, 1961; Ph.D., 1969. Research Fellow, California Institute, 1970-73; Senior Research Fellow, 1973-. (Church)

Milton Katz, J.D., *Sherman Fairchild Distinguished Scholar*
A.B., Harvard University, 1927; J.D., 1931. Henry L. Stimson Professor and Director of International Legal Studies, 1954-. California Institute, 1973-74.

Kenneth James Kaufmann, Ph.D., *Research Fellow in Chemistry*
B.S., City College of New York, 1968; Ph.D., Massachusetts Institute of Technology, 1973. California Institute, 1973-74.

Ralph William Kavanagh, Ph.D., *Professor of Physics*
B.A., Reed College, 1950; M.A., University of Oregon, 1952; Ph.D., California Institute, 1956. Research Fellow, 1956-58; Senior Research Fellow, 1958-60; Assistant Professor, 1960-65; Associate Professor, 1965-70; Professor, 1970-. (Kellogg)

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

Jay Edward Kent, Ph.D., *Visiting Associate in Chemistry*
B.S., Washington State University, 1961; Ph.D., 1966. California Institute, 1972-73.

Gregory Ketabgian, M.D., *Director of Health Services*
B.A., University of California (Los Angeles), 1959; M.D., University of Southern California Medical School, 1963. California Institute, 1973-. (Health Center)

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

Jungsuh Park Kim, Ph.D., *Research Fellow in Biology*
B.S., Seoul National University, 1966; Ph.D., California Institute, 1972. Research Fellow, 1972-. (Crellin)

William M. Kinnersley, Ph.D., *Visiting Assistant Professor of Applied Mathematics*
B.S., Rensselaer Polytechnic Institute, 1964; Ph.D., California Institute, 1969. Assistant Professor, Montana State University, 1971-. California Institute, 1973-. (Firestone)

Hershy Harry Kisilevsky, Ph.D., *Assistant Professor of Mathematics*
B.S., McGill University, 1964; Ph.D., Massachusetts Institute of Technology, 1968. Ford Foundation Research Fellow, California Institute, 1968-70; Instructor, 1970-71; Assistant Professor, 1971-. (Sloan)

Michael Jay Klass, Ph.D., *Research Fellow in Mathematics*
B.A., University of California (Los Angeles), 1968; Ph.D., 1972. California Institute, 1972-. (Sloan)

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

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

William H. Klein, Ph.D., *Research Fellow in Biology*
B.S., University of Michigan, 1968; M.S., 1970; Ph.D., University of Illinois, 1973. California Institute, 1973-. (Alles)

Joan L. Klotz, Ph.D., *Research Fellow in Biology*
B.A., San Fernando Valley State College, 1967; M.S., 1970; Ph.D., University of California (Los Angeles), 1973. California Institute, 1973-74.

Gillian R. Knapp, Ph.D., *Research Fellow in Radio Astronomy*
B.Sc., University of Edinburgh, 1966; Ph.D., University of Maryland, 1972. California Institute, 1974-75.

Wolfgang Gustav Knauss, Ph.D., *Associate Professor of Aeronautics*
B.S., California Institute, 1958; M.S., 1959; Ph.D., 1963. Research Fellow, 1963-65; Assistant Professor, 1965-69; Associate Professor, 1969-. (Firestone)

Dennis W. Kneff, Ph.D., *Research Fellow in Physics*
B.A., University of California, 1965; M.A., University of Oregon, 1967, Ph.D., 1972. California Institute, 1973-74.

James Kenyon Knowles, Ph.D., *Professor of Applied Mechanics; Academic Officer for Applied Mechanics*
B.S., Massachusetts Institute of Technology, 1952; Ph.D., 1957. Assistant Professor, California Institute, 1958-61; Associate Professor, 1961-65; Professor, 1965-; Academic Officer, 1972-. (Thomas)

Helmut Kobus, Ph.D., *Visiting Associate in Hydraulics*
Dipl., Technical University of Stuttgart, 1961; M.S., State University of Iowa, 1963; Ph.D., 1965. Chief Engineer, Hydromechanic Institute, Technical University of Karlsruhe, 1968-. California Institute, 1973-74.

Joseph Blake Koepfli, D.Phil., *Research Associate in Chemistry, Emeritus*
A.B., Stanford University, 1924; M.A., 1925; D.Phil., Oxford University, 1928. Research Associate, California Institute, 1932-72. Research Associate Emeritus, 1972-. (Church)

Robert C. Y. Koh, Ph.D., *Research Associate in Environmental Engineering Science*
B.S., California Institute, 1960; M.S., 1961; Ph.D., 1964. Research Fellow, 1964-65; Research Associate, 1972-. (Keck)

Warner T. Koiter, Ph.D., *Sherman Fairchild Distinguished Scholar*
Ph.D., University of Delft, 1945. Professor of Applied Mechanics, 1949-. California Institute, 1973-74.

Yehoshua Kolodny, Ph.D., *Research Fellow in Geochemistry*
M.Sc., Hebrew University, 1965; Ph.D., University of California (Los Angeles), 1969. California Institute, 1973-74.

Anthony Alexander Kossiakoff, Ph.D., *Research Fellow in Chemistry*
B.S., Davis and Elkins College, 1968; Ph.D., University of Delaware, 1972. California Institute, 1972-. (Crellin)

Feliks A. Kostanyan, Ph.D., *Visiting Associate in Electrical Engineering*
Dipl., Yerevan State University, 1965; Ph.D., Yerevan Physics Institute, 1973. Junior Research Associate, Institute of Radiophysics and Electronics, Academy of Sciences, Armenian S.S.R., 1965-. California Institute, 1973-. (Steele)

Joseph Morgan Kousser, Ph.D., *Assistant Professor of History*
B.A., Princeton University, 1965; M.A., Yale University, 1968; Ph.D., 1971. Instructor, California Institute, 1969-71; Assistant Professor, 1971-. (Baxter)

Herbert Kraütle, Ph.D., *Research Fellow in Electrical Engineering*
Dipl., University of Tübingen, 1969; Ph.D., University of Heidelberg, 1971. California Institute, 1972-. (Steele)

Friedrich R. Kreissel, Ph.D., *Research Fellow in Chemistry*
Dipl., Technical University of Munich, 1970; Ph.D., 1973. California Institute, 1973-74.

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

Toshi Kubota, Ph.D., *Professor of Aeronautics*
B.E., Tokyo University, 1947; M.S., California Institute, 1952; Ph.D., 1957. Research Fellow, 1957-59; Assistant Professor, 1959-63; Associate Professor, 1963-71; Professor, 1971-. (Firestone)

Ramohalli Kumar, Ph.D., *Research Fellow in Jet Propulsion*
B.S., Bangalore University, 1967; M.S., Indian Institute of Science (Bangalore), 1968; Ph.D., Massachusetts Institute of Technology, 1971. California Institute, 1971-. (Karman)

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

John Ying-Kuen Kwan, Ph.D., *Research Fellow in Astrophysics*
B.S., Utah State University, 1969; Ph.D., California Institute, 1972. Research Fellow, 1972-. (Robinson)

Jenijoy LaBelle, Ph.D., *Assistant Professor of English*
B.A., University of Washington, 1965; Ph.D., University of California (San Diego), 1969. California Institute, 1969-. (Baxter)

Thomas Labhart, Ph.D., *Research Fellow in Biology*
Dipl., University of Zurich, 1970; Ph.D., 1973. California Institute, 1973-74.

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

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

Ting Fong Lai, Ph.D., *Visiting Associate in Chemistry*
B.Sc., University of Hong Kong, 1954; M.Sc., 1957; Ph.D., St. Hilda's College, Oxford University, 1960. Senior Lecturer, University of Hong Kong, 1969-. California Institute, 1965; 1968-69; 1973.

Robert Goodman Lamb, Ph.D., *Research Fellow in Chemical Engineering*
B.S., University of California, 1966; M.S., University of California (Los Angeles), 1968; Ph.D., 1971. California Institute, 1971-. (Spalding)

Christopher Allen Landauer,** Ph.D., *Research Fellow in Mathematics*
B.A., University of California (Los Angeles), 1969; Ph.D., California Institute, 1973. Research Fellow, 1972-. (Sloan)

Aurora Mamauag Landel, Ph.D., *Senior Research Fellow in Biomedical Engineering*
B.S., University of the Philippines, 1949; M.S., University of Wisconsin, 1952; Ph.D., 1955. Research Fellow in Chemistry, California Institute, 1968-71; Senior Research Fellow in Biomedical Engineering, 1973-. (Thomas)

Robert Franklin Landel,** Ph.D., *Lecturer in Chemical Engineering*
B.S., State University of New York (Buffalo), 1949; M.S., 1950; Ph.D., University of Wisconsin, 1954. Chief, Solid Propellant Chemistry, Jet Propulsion Laboratory, 1959-. Senior Research Fellow in Materials Science, California Institute, 1965-67; Senior Research Fellow in Chemical Engineering, 1967-69; Lecturer, 1970-. (Keck)

**Part-time

Raymond O. Lane, Ph.D., *Visiting Associate in Physics*
B.S., Drexel Institute of Technology, 1948; Ph.D., Iowa State University, 1953. Professor, Ohio State University, 1966-. California Institute, 1973.

Kenneth Robert Lang, Ph.D., *Research Fellow in Astrophysics*
B.S., University of Colorado, 1964; M.S., Stanford University, 1966; Ph.D., 1969. California Institute, 1972-. (Bridge)

Eric Siddon Langford, Ph.D., *Visiting Associate Professor of Mathematics*
S.B., Massachusetts Institute of Technology, 1959; M.S., Rutgers, The State University, 1960; Ph.D., 1963. Associate Professor of Mathematics, University of Maine, 1969-. California Institute, 1972-. (Sloan)

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

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

Silvanus S. Lau, Ph.D., *Bechtel Instructor in Materials Science*
B.S., University of California, 1964; M.S., 1966; Ph.D., 1969. California Institute, 1972-. (Keck)

John H. Laub,** D.Eng., *Lecturer in Mechanical Engineering*
M.A., Institute of Technology (Stuttgart), 1923; Ph.D., 1930. California Institute, 1972-. (Thomas)

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

Roger G. Lautzenheiser, Ph.D., *Bateman Research Instructor in Mathematics*
B.A., Indiana University, 1968; M.A., 1969; Ph.D., 1973. California Institute, 1973-74.

Leslie Gary Leal, Ph.D., *Assistant Professor of Chemical Engineering*
B.S., University of Washington, 1965; Ph.D., Stanford University, 1969. California Institute, 1970-. (Spalding)

Lester Lees, M.S., *Professor of Environmental Engineering and Aeronautics; Director of Environmental Quality Laboratory*
S.B., Massachusetts Institute of Technology, 1940; M.S., 1941. Associate Professor, California Institute, 1953-55; Professor, 1955-; Director, Environmental Quality Laboratory, 1971-. (Firestone)

Evelyn May Lee-Teng, Ph.D., *Visiting Associate in Biology*
B.S., Taiwan University, 1959; M.A., Stanford University, 1960. Ph.D., 1963. Assistant Professor, University of Southern California Medical School, 1972-. Research Fellow, California Institute, 1963-68; Senior Research Fellow, 1969-72; Visiting Associate, 1972-. (Church)

Robert Benjamin Leighton, Ph.D., *Professor of Physics; Chairman of the Division of Physics, Mathematics and Astronomy*
B.S., California Institute, 1941; M.S., 1944; Ph.D., 1947. Research Fellow, 1947-49; Assistant Professor, 1949-53; Associate Professor, 1953-59; Professor, 1959-; Staff Member, Hale Observatories, 1963-; Division Chairman, 1970-. (E. Bridge)

Henry A. Lester, Ph.D., *Assistant Professor of Biology*
A.B., Harvard College, 1966; Ph.D., The Rockefeller University, 1971. California Institute, 1973-. (Kerckhoff)

Fritz Leuterer, Dr.Ing., *Research Fellow in Electrical Engineering*
Dipl., Technical University of Munich, 1965; Dr.Ing., 1969. California Institute, 1972-. (Steele)

Heinrich Leutwyler, Dr.phil.nat., *Visiting Associate in Theoretical Physics*
Liz.phil.nat., University of Bern, 1961; Dr.phil.nat., 1962. Professor Ordinarius, 1969-. California Institute, 1973.

**Part-time

Michael E. Levine, LL.B., *Luce Professor of Law and Social Change in the Technological Society*
B.A., Reed College, 1962; LL.B., Yale University, 1965. Associate Professor, University of Southern California, 1970-. California Institute, 1973-. (Baxter)

Rachmiel Levine,** M.D., *Visiting Associate in Biomedical Engineering*
B.A., McGill University, 1932; M.D., 1936. Director, City of Hope Medical Center (Duarte), 1971-. California Institute, 1973-. (Thomas)

Howard Levitin, M.D., *Visiting Associate in Biology*
M.D., Southwestern Medical College, 1949. Associate Dean, Yale University School of Medicine, 1972-. California Institute, 1973-74.

Blair Frederic Lewis, Ph.D., *Research Fellow in Chemical Engineering*
B.S., The University of Rochester, 1967; Ph.D., Yale University, 1972. California Institute, 1972-. (Spalding)

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

John Simpson Lewis, Ph.D., *Visiting Associate Professor of Planetary Science and Geochemistry*
A.B., Princeton University, 1962; M.A., Dartmouth College, 1964; Ph.D., University of California (San Diego), 1968. Associate Professor of Geochemistry and Chemistry, Massachusetts Institute of Technology, 1972-. California Institute, 1974.

Dov Azriel Lichtenberg, Ph.D., *Research Fellow in Chemistry*
B.S., Hebrew University of Jerusalem, 1963; M.S., 1967; Ph.D., 1972. California Institute, 1972-73.

Hans Wolfgang Liepmann, Ph.D., *Professor of Aeronautics; Director of Graduate Aeronautical Laboratories*
Ph.D., University of Zurich, 1938. Assistant Professor, California Institute, 1939-46; Associate Professor, 1946-49; Professor, 1949-; Director of Graduate Aeronautical Laboratories, 1972-. (Karman)

Frederick Charles Lindvall, Ph.D., D.Sc., D.Eng., *Professor of Engineering, Emeritus*
B.S., University of Illinois, 1924; Ph.D., California Institute, 1928; D.Sc., National University of Ireland, 1963; D.Eng., Purdue University, 1966. Instructor in Electrical Engineering, California Institute, 1930-31; Assistant Professor, 1931-37; Associate Professor of Electrical and Mechanical Engineering, 1937-41; Professor, 1942-70; Division Chairman, 1945-69; Professor Emeritus, 1970-. (Thomas)

Edward David Lipson, Ph.D., *Instructor in Biology*
B.Sc., University of Manitoba, 1966; Ph.D., California Institute, 1971. Research Fellow in Physics, 1971; Research Fellow in Biology, 1971-73; Instructor, 1973-. (Alles)

Ericson John List, Ph.D., *Associate Professor of Environmental Engineering Science*
B.E., University of Auckland, 1961; M.E., 1962; Ph.D., California Institute, 1965. Research Fellow, 1965-66; Assistant Professor, 1969-72; Associate Professor, 1972-. (Keck)

Sou-Yang Liu, Ph.D., *Research Fellow in Solar Physics*
B.S., Cheng Kung University (Taiwan), 1963; M.S., National Central University, 1966; M.S., University of Maryland, 1968; Ph.D., 1972. California Institute, 1973-74.

Ian Andrew Lockhart, Ph.D., *Research Fellow in Radio Astronomy*
B.S., University of Tasmania, 1964; M.S., 1965; Ph.D., Australian National University, 1971. California Institute, 1971-. (Robinson)

Raphael Loewy, Ph.D., *Research Fellow in Mathematics*
B.Sc., Israel Institute of Technology, 1965; M.Sc., 1969; Ph.D., California Institute, 1972. Research Fellow, 1972.

**Part-time

Malcolm Sim Longair, Ph.D., *Visiting Assistant Professor of Radio Astronomy*
B.Sc., University of St. Andrews, 1963; Ph.D., University of Cambridge, 1967. University Demonstrator, Department of Physics, University of Cambridge, 1971-. California Institute, 1972.

Gary Allen Lorden, Ph.D., *Associate Professor of Mathematics*
B.S., California Institute, 1962; Ph.D., Cornell University, 1966. Assistant Professor, California Institute, 1968-71; Associate Professor, 1971-. (Sloan)

George Lorentz, Ph.D., *Visiting Professor of Mathematics*
Dipl., University of Leningrad, 1931; Ph.D., University of Tübingen, 1945. Professor of Mathematics, Texas State University, 1968-. California Institute, 1973.

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

Peter Herman Lowy, Doctorandum, *Research Associate in Biology*
Doctorandum, University of Vienna, 1936. Research Fellow, California Institute, 1949-65; Senior Research Fellow, 1965-72; Research Associate, 1972-. (Kerckhoff)

Wilhelmus A. J. Luxemburg, Ph.D., *Professor of Mathematics; Executive Officer for Mathematics*
B.A., University of Leiden, 1950; M.A., 1953; Ph.D., Delft Institute of Technology, 1955. Assistant Professor, California Institute, 1958-60; Associate Professor, 1960-62; Professor, 1962-; Executive Officer, 1970-. (Sloan)

Hans Maag, Ph.D., *Research Fellow in Chemistry*
Dipl., Federal Institute of Technology, 1969; Ph.D., 1973. California Institute, 1973-74.

Richard Bruce MacAnally, Ph.D., *Senior Research Fellow in Electrical Engineering*
B.S., California Institute, 1959; M.S., 1960; Ph.D., University of Southern California, 1969. Research Fellow, California Institute, 1969-72; Senior Research Fellow, 1972-. (Steele)

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

Mordehai Magaritz, Ph.D., *Research Fellow in Geochemistry*
B.Sc., Hebrew University of Jerusalem, 1967; M.Sc., 1969; Ph.D., Weizmann Institute of Science, 1973. California Institute, 1973-74.

Hay Boon Mak, Ph.D., *Research Fellow in Physics*
B.Sc., McGill University, 1966; Ph.D., California Institute, 1971. Research Fellow, 1971-. (Kellogg)

Gretchen Sue Mandel, Ph.D., *Research Fellow in Chemistry*
B.S., University of Southern California, 1968; Ph.D., University of Pennsylvania, 1972. California Institute, 1972-. (Noyes)

Neil Stanley Mandel, Ph.D., *Research Fellow in Chemistry*
B.S., University of Southern California, 1968; Ph.D., University of Pennsylvania, 1971. California Institute, 1972-. (Noyes)

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

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

Jerry Edsel Manning, Ph.D., *Research Fellow in Chemistry*
B.S., University of Utah, 1966; Ph.D., 1971. California Institute, 1973-. (Crellin)

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

Panos Z. Marmarelis, Ph.D., *Research Fellow in Information Science*
B.S.E.E., Lehigh University, 1966; M.S., California Institute, 1967; Ph.D., 1972. Research Fellow, 1972-. (Jorgensen)

Richard Edward Marsh, Ph.D., *Research Associate in Chemistry*
B.S., California Institute, 1943; Ph.D., University of California (Los Angeles), 1950. Research Fellow, California Institute, 1950-55; Senior Research Fellow, 1955-73; Research Associate, 1973-. (Noyes)

Hardy Cross Martel, Ph.D., *Associate Professor of Electrical Engineering; Executive Assistant to the President; Secretary of the Board of Trustees*
B.S., California Institute, 1949; M.S., Massachusetts Institute of Technology, 1950; Ph.D., California Institute, 1956. Instructor, 1953-55; Assistant Professor, 1955-58; Associate Professor, 1958-; Executive Assistant to the President, 1969-; Secretary, 1973-. (Steele, Millikan)

Marino Martinez-Carrion, Ph.D., *Visiting Associate in Chemistry*
B.A., University of California, 1959; M.A., 1961; Ph.D., 1964. Associate Professor, University of Notre Dame, 1968-. California Institute, 1972-73.

Sami Faiz Masri, Ph.D., *Visiting Associate in Mechanical Engineering*
B.S., University of Texas, 1960; M.S., 1961; M.S., California Institute, 1962; Ph.D., 1965. Associate Professor of Civil Engineering, University of Southern California, 1969-. Research Fellow, California Institute, 1965-66; Visiting Associate, 1973.

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

Michel Maurette, Ph.D., *Visiting Associate in Geochemistry*
Lic., University of Paris, 1956; Ph.D., 1965. Director of Research, Institute of Nuclear Physics (Orsay), 1971-. California Institute, 1972.

James Walter Mayer, Ph.D., *Professor of Electrical Engineering*
B.S., Purdue University, 1952; Ph.D., 1959. Associate Professor, California Institute, 1967-71; Professor, 1971-. (Steele)

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

James Oeland McCaldin, Ph.D., *Professor of Applied Science and Electrical Engineering*
B.A., University of Texas, 1944; Ph.D., California Institute, 1954. Associate Professor of Applied Science, 1968-73; Professor of Applied Science and Electrical Engineering, 1973-. (Keck)

Gilbert Donald McCann, Ph.D., *Professor of Applied Science*
B.S., California Institute, 1934; M.S., 1935; Ph.D., 1939. Associate Professor of Electrical Engineering, 1946-47; Professor, 1947-66; Professor of Applied Science, 1966-; Director, Willis H. Booth Computing Center, 1966-71. (Booth)

Robert J. McEliece,** Ph.D., *Lecturer in Electrical Engineering*
B.S., California Institute, 1964; Ph.D., 1967. Supervisor, Information Processing Group, Jet Propulsion Laboratory, 1967-. Lecturer, California Institute, 1972-73.

Thomas C. McGill, Ph.D., *Assistant Professor of Applied Physics*
B.S., Lamar State College of Technology, 1964; M.S., California Institute, 1965; Ph.D., 1969. Assistant Professor, 1971-. (Steele)

Jack Edward McKee, Sc.D., D.Eng., *Professor of Environmental Engineering*
B.S., Carnegie Institute of Technology, 1936; M.S., Harvard University, 1939; Sc.D., 1941; D. Eng., Rose-Hulman Institute of Technology, 1973. Associate Professor of Sanitary Engineering, California Institute, 1949-56; Professor, 1956-60; Professor of Environmental Health Engineering, 1960-70; Professor of Environmental Engineering, 1970-. (Keck)

**Part-time

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

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

David R. McMillin, Ph.D., *Research Fellow in Chemistry*
B.A., Knox College, 1969; Ph.D., University of Illinois, 1973. California Institute, 1973-74.

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

Dwight J. Mellema, Ph.D., *Robert Andrews Millikan Research Fellow in Physics*
A.B., Calvin College, 1964; M.S., University of California (Los Angeles), 1966; Ph.D., 1970. California Institute, 1972-. (Lauritsen)

Robert Thomas Menzies,** Ph.D., *Visiting Associate in Electrical Engineering*
S.B., Massachusetts Institute of Technology, 1965; M.S., California Institute, 1967; Ph.D., 1970. Staff Scientist, Jet Propulsion Laboratory, 1970-. Research Fellow, 1970-73; Visiting Associate, 1973-. (Jet Propulsion Lab.)

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

Richard Alvin Mewaldt, Ph.D., *Research Fellow in Physics*
B.A., Lawrence University, 1965; M.A., 1967; Ph.D., 1971. California Institute, 1971-. (Downs)

William Whipple Michael, B.S., *Professor of Civil Engineering, Emeritus*
B.S., Tufts College, 1909. Associate Professor, California Institute, 1918-56; Professor Emeritus, 1956-. (Thomas)

Andrew G. Michalitsanos, Ph.D., *Research Fellow in Astrophysics*
B.A., University of Arizona, 1969; Ph.D., University of Cambridge, 1972. California Institute, 1972-. (Bridge)

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

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

Lois Kathryn Miller, Ph.D., *Research Fellow in Biology*
B.S., Upsala College, 1967; Ph.D., University of Wisconsin, 1971. California Institute, 1971-. (Alles)

Marcia Madsen Miller, Ph.D., *Research Fellow in Biology*
B.S., University of California (Davis), 1965; M.A., 1966; Ph.D., University of California (Los Angeles), 1972. California Institute, 1972-. (Alles)

Peter MacNaughton Miller, Ph.D., *Director of Admissions and of Undergraduate Scholarships; Lecturer in English*
A.B., Princeton University, 1934; Ph.D., 1939. Assistant Director of Admissions and of Undergraduate Scholarships, California Institute, 1956-63; Lecturer, 1957-; Associate Director of Admissions and of Undergraduate Scholarships, 1963-68; Director, 1968-. (Dabney)

**Part-time
***Leave of Absence, First Term 1973-74

Peter Minkowski, Ph.D., *Senior Research Fellow in Theoretical Physics*
Dipl., Federal Institute of Technology (Zurich), 1963. Ph.D., 1967. California Institute, 1973-74.

Carolyn Hattox Mitchell, Ph.D., *Research Fellow in Biology*
B.S., Louisiana State University, 1963; Ph.D., University of Texas, 1967. California Institute, 1971-. (Kerckhoff)

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

Tse-Chin Mo, Ph.D., *Senior Research Fellow in Electrical Engineering*
B.S., National Taiwan University, 1964; M.S., California Institute, 1966; Ph.D., 1969. Research Fellow, 1969-72; Senior Research Fellow, 1972-. (Steele)

Alan Theodore Moffet, Ph.D., *Professor of Radio Astronomy*
B.A., Wesleyan University, 1957; Ph.D., California Institute, 1961. Research Fellow, 1962-66; Assistant Professor, 1966-68; Associate Professor, 1968-71; Professor, 1971-. (Robinson)

Narla Mohandas, D.Sc., *Visiting Associate in Biomedical Engineering*
B.Tech., University of Madras, 1966; D.Sc., Washington University, 1972. California Institute, 1972-73.

Douglas Crane Mohr, Ph.D., *Research Fellow in Chemistry*
B.S., San Diego State College, 1963; Ph.D., California Institute, 1973. Research Fellow, 1972-. (Church)

Robert Serge Molday, Ph.D., *Research Fellow in Biology*
B.S., University of Pennsylvania, 1965; M.S., Georgetown University, 1970; Ph.D., University of Pennsylvania, 1971. California Institute, 1972-. (Church)

Galina Moller,** M.S., *Lecturer in Russian*
M.S., University of Moscow, 1968. California Institute, 1971-. (Baxter)

William David Montgomery, Ph.D., *Assistant Professor of Economics*
B.A., Wesleyan University, 1966; Ph.D., Harvard University, 1971. California Institute, 1971-. (Baxter)

Lawrence Carlton Moore, Jr., Ph.D., *Visiting Associate Professor of Mathematics*
B.S., University of North Carolina, 1961; Ph.D., California Institute, 1966. Associate Professor, Duke University, 1972-. California Institute, 1973-74.

Ronald Lee Moore, Ph.D., *Research Fellow in Solar Physics*
B.S., Purdue University, 1964; Ph.D., Stanford University, 1972. California Institute, 1972-. (Bridge)

James John Morgan, Ph.D., *Professor of Environmental Engineering Science; Dean of Students*
B.C.E., Manhattan College, 1954; M.S.E., University of Michigan, 1956; M.A., Harvard University, 1962; Ph.D., 1964. Associate Professor, California Institute, 1965-69; Professor, 1969-; Academic Officer for Environmental Engineering Science, 1971-72; Dean of Students, 1972-. (Keck, Dabney)

Takitaro Morikawa, Ph.D., *Visiting Associate in Electrical Engineering*
B.S., Tokyo University, 1963; M.S., 1965; Ph.D., 1968. Staff Member, Electrotechnical Laboratory, Ministry of International Trade and Industry, Tokyo, 1968-. California Institute, 1973-. (Steele)

Fernando B. Morinigo, Ph.D., *Visiting Associate in Physics*
B.S., University of Southern California, 1954; M.S.E., University of Michigan, 1956; Ph.D., California Institute, 1963. Professor of Physics, California State College (Los Angeles), 1970-. Research Fellow, California Institute, 1962-64; 1965-66; Visiting Associate, 1973.

**Part-time

Paul E. Morrison,** Ph.D., *Research Fellow in Chemical Engineering*
B.S., University of Michigan, 1965; Ph.D., California Institute, 1972. Research Fellow, 1972.

David W. Morrisroe,** M.B.A., *Lecturer in Business Economics*
B.A., Manhattan College, 1954; M.A., Columbia University, 1956; M.B.A., Harvard School of Business Administration, 1964. Director of Financial Services, California Institute, 1969-; Lecturer, 1971-. (Millikan)

Edward Randolph Moser, M.S., *Associate Director of Libraries*
A.B., Wheaton College, 1943; M.S., Cornell University, 1944. Associate Director, California Institute, 1967-. (Millikan Library)

Duane Owen Muhleman, Ph.D., *Professor of Planetary Science*
B.S., University of Toledo, 1953; Ph.D., Harvard University, 1963. Associate Professor, California Institute, 1967-71; Professor, 1971-. (Mudd)

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

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

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

Mark Nadel, Ph.D., *Bateman Research Instructor in Mathematics*
B.A., City University of New York (Brooklyn), 1966; Ph.D., University of Wisconsin, 1971. California Institute, 1972-. (Sloan)

Ken-Ichi Naka, D.Sc., *Research Associate in Biology and Applied Science*
B.S., Kyushu University, 1955; M.S., 1957; D.Sc., 1960. California Institute, 1967-. (Booth)

Yuval Ne'eman, Ph.D., *Sherman Fairchild Distinguished Scholar*
B.Sc., Israel Institute of Technology, 1945; Dipl., 1946; Ph.D., Imperial College of Science and Technology (London), 1961; D.Sc., Israel Institute of Technology, 1966. President, Tel-Aviv University, 1971-. Research Fellow, California Institute, 1963-64; Visiting Professor, 1964-65; Visiting Associate, 1969; Sherman Fairchild Distinguished Scholar, 1973-74.

Henry Victor Neher, Ph.D., Sc.D., *Professor of Physics, Emeritus*
A.B., Pomona College, 1926; Ph.D., California Institute, 1931; Sc.D., Pomona College, 1968. Research Fellow, California Institute, 1931-33; Instructor, 1933-37; Assistant Professor, 1937-40; Associate Professor, 1940-44; Professor, 1944-70; Professor Emeritus, 1970-.

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

Gerry Neugebauer, Ph.D., *Professor of Physics*
A.B., Cornell University, 1954; Ph.D., California Institute, 1960. Assistant Professor, 1962-65; Associate Professor, 1965-70; Professor, 1970-. Staff Member, Hale Observatories, 1970-. (Downs)

Carl Adams Newton, Ph.D., *Research Fellow in Geophysics*
B.S., University of Wisconsin, 1964; M.S., 1965; Ph.D., Pennsylvania State University, 1973. California Institute, 1972-. (Seismo Lab)

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

**Part-time

Mansour Niazi, Ph.D., *Visiting Associate in Geophysics*
B.S., University of Teheran, 1954; B.A., University of California, 1961; M.A., 1962; Ph.D., 1964. Professor and Vice Chancellor, University of Meshed (Iran), 1969-. Research Fellow, California Institute, 1964-65; Visiting Associate, 1972-73.

Marc-Aurele Nicolet, Ph.D., *Professor of Electrical Engineering*
Ph.D., University of Basel, 1958. Assistant Professor, California Institute, 1959-65; Associate Professor, 1965-73; Professor, 1973-. (Steele)

Roy Anthony Nicolaides, Ph.D., *Visiting Assistant Professor of Applied Mathematics*
B.Sc., University of London, 1968; Ph.D., 1972. Lecturer in Mathematics, Imperial College, 1971-. California Institute, 1973-74.

Roger Gordon Noll, Ph.D., *Professor of Economics*
B.S., California Institute, 1962; A.M., Harvard University, 1965; Ph.D., 1967. Instructor, California Institute, 1965-67; Assistant Professor, 1967-69; Associate Professor, 1969-71; Professor, 1973-. (Baxter)

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

Harris Anthony Notarys, Ph.D., *Senior Research Fellow in Physics*
S.B., Massachusetts Institute of Technology, 1954; Ph.D., California Institute, 1964. Research Fellow, 1969; Senior Research Fellow, 1970-. (Sloan)

Edward Francis O'Brien, Ph.D., *Research Fellow in Chemistry*
B.Sc., St. Dunstan's University (Canada), 1967; M.S., California Institute, 1970; Ph.D., 1972. Research Fellow, 1972-73.

Orpha Caroline Ochse,** Ph.D., *Andrew W. Mellon Lecturer in Music*
B.M., Central College (Missouri), 1947; M.M., Eastman School of Music, The University of Rochester, 1969; Ph.D., 1953. Lecturer in Music, California Institute, 1960-72; Andrew W. Mellon Lecturer, 1972-. (Baxter)

Eiichi Ohtsubo, Ph.D., *Research Fellow in Chemistry*
B.S., Osaka University, 1966; M.S., 1968; Ph.D., 1971. California Institute, 1971-. (Crellin)

Teruya Ohtsuka, Ph.D., *Research Fellow in Applied Science*
B.S., Hokkaido University, 1968, M.S., 1970; Ph.D., 1973. California Institute, 1973-74.

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

James Olds, M.D., Ph.D., *Bing Professor of Behavioral Biology*
B.A., Amherst College, 1947; M.D., Harvard University, 1951; Ph.D., 1952. Professor, California Institute, 1969-70; Bing Professor, 1970-. (Kerckhoff)

Marianne Nicole Olds, Ph.D., *Research Associate in Biology*
B.A., Smith College, 1947; M.A., Radcliffe College, 1950; Ph.D., 1952. Senior Research Fellow, California Institute, 1969-72; Research Associate, 1972-. (Kerckhoff)

Robert Warner Oliver, Ph.D., *Associate Professor of Economics*
A.B., University of Southern California, 1943; A.M., 1948; A.M., Princeton University, 1950; Ph.D., 1957. Assistant Professor, California Institute, 1959-61; Associate Professor, 1961-. (Baxter)

Charles Richard O'Melia, Ph.D., *Visiting Professor of Environmental Engineering Science*
B.C.E., Manhattan College, 1955; M.S.E., University of Michigan, 1956; Ph.D., 1963. Professor of Environmental Sciences and Engineering, University of North Carolina, 1970-. California Institute, 1973-74.

**Part-time

Angelo Antonio Orio, Ph.D., *Visiting Associate in Chemistry*
Ph.D., University of Padua (Italy), 1963. Associate Professor, 1972-. California Institute, 1973-74.

Hugh Osborn, Ph.D., *Visiting Associate in Theoretical Physics*
B.S., University College, London, 1964; Ph.D., 1967. Lecturer, University of Cambridge, 1971-. California Institute, 1974.

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

Aaron J. Owens, Ph.D., *Research Fellow in Theoretical Physics*
B.A., Williams College, 1969; Ph.D., California Institute, 1973. Research Fellow, 1973.

Bohdan Paczynski, Docent, *Visiting Professor of Astronomy*
Ph.D., Warsaw University, 1964; Docent, 1967. California Institute, 1973.

Gerasim A. Panosyan, Ph.D., *Visiting Associate in Biology*
B.S., Yerevan State University, 1953; Ph.D., Moscow State University, 1956. Acting Deputy Director, Institute of Experimental Biology, Academy of Sciences of the Armenian S.S.R. California Institute, 1972.

Dimitri A. Papanastassiou, Ph.D., *Senior Research Fellow in Geology and Physics*
B.S., California Institute, 1965; Ph.D., 1970. Research Fellow in Physics, 1970-72; Senior Research Fellow in Geology and Physics, 1972-. (Arms)

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

Robert Patenaude, Ph.D., *Research Fellow in Mathematics*
B.A., California State College (Humboldt), 1965; Ph.D., California Institute, 1972. Research Fellow, 1972.

Clair Cameron Patterson, Ph.D., *Senior Research Associate in Geochemistry*
A.B., Grinnell College, 1943; M.S., University of Iowa, 1944; Ph.D., University of Chicago, 1951. Research Fellow, California Institute, 1952-53; Senior Research Fellow, 1953-71; Research Associate, 1971-73; Senior Research Associate, 1973-. (Mudd)

Guy J. Pauker, Ph.D.,** *Visiting Associate in Political Science*
Ph.D., University of Bucharest, 1946; M.A., Harvard University, 1950; Ph.D., 1952. Staff Member, The RAND Corporation, 1960-. California Institute, 1970-. (Dabney)

Rodman Wilson Paul, Ph.D., *Edward S. Harkness Professor of History*
A.B., Harvard College, 1936; M.A., 1937; Ph.D., 1943. Associate Professor, California Institute, 1947-51; Professor, 1951-72; Harkness Professor, 1972-. (Baxter)

Linus Pauling, Ph.D., Sc.D., L.H.D., U.J.D., D.H.C., D.F.A., LL.D., Nobel Laureate, *Professor of Chemistry, Emeritus*
B.S., Oregon State College, 1922; Ph.D., California Institute, 1925. Research Associate, 1926-27; 1964-71; Assistant Professor, 1927-29; Associate Professor, 1929-31; Professor, 1931-64; Chairman of the Division of Chemistry and Chemical Engineering, 1936-58; Professor Emeritus, 1971-.

Harry Pearson, Ph.D., *Research Fellow in Chemistry*
B.S., University of Sheffield, 1969; Ph.D., University College (London), 1972. California Institute, 1973-. (Crellin)

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

**Part-time

Joyce Penn, Ph.D., *Assistant Professor of English*
B.A., City University of New York, 1968; M.A., Stanford University, 1970; Ph.D., 1973. California Institute, 1973-. (Baxter)

Edward W. Petrillo, Jr., Ph.D., *Research Fellow in Chemistry*
A.B., Princeton University, 1969; Ph.D., Yale University, 1973. California Institute, 1973-. (Crellin)

John D. Pettigrew, M.D., *Assistant Professor of Biology*
M.D., Sydney University Medical School, 1969. California Institute, 1973-. (Behavioral Biology)

Rona Pettigrew, Ph.D., *Research Fellow in Biology*
B.Sc., University of New South Wales, 1969; Ph.D., 1972. California Institute, 1973-74.

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

John Robinson Pierce, Ph.D., D.Sc., D.Eng., E.D., *Professor of Engineering*
B.S., California Institute, 1933; M.S., 1934; Ph.D., 1936. Professor, 1971-. (Steele)

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

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

Cornelius John Pings, Ph.D., *Professor of Chemical Engineering and Chemical Physics; Vice Provost and Dean of Graduate Studies*
B.S., California Institute, 1951; M.S., 1952; Ph.D., 1955. Associate Professor of Chemical Engineering, 1959-64; Professor, 1964-70; Professor of Chemical Engineering and Chemical Physics, 1970-; Executive Officer for Chemical Engineering, 1969-73; Vice Provost and Dean of Graduate Studies, 1971-. (Millikan)

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

Charles Raymond Plott, Ph.D., *Professor of Economics*
B.S., Oklahoma State University, 1961; M.S., 1964; Ph.D., University of Virginia, 1965. California Institute, 1971-. (Baxter)

Edward C. Posner,** Ph.D., *Lecturer in Electrical Engineering*
B.A., University of Chicago, 1952; M.S., 1953; Ph.D., 1957. Deputy Section Manager, Jet Propulsion Laboratory, 1967-. California Institute, 1970; 1973.

Richard James Powers, Ph.D., *Senior Research Fellow in Physics*
B.S., Illinois Institute of Technology, 1961; M.S., University of Chicago, 1962; Ph.D., 1967. California Institute, 1973-. (Bridge)

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

William Henry Press, Ph.D., *Assistant Professor of Theoretical Physics*
A.B., Harvard College, 1969; M.S., California Institute, 1971; Ph.D., 1973. Tolman Research Fellow in Physics, California Institute, 1972-73; Assistant Professor, 1973-. (Bridge)

**Part-time

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

Aimee Brown Price,** Ph.D., *Lecturer in Art*
B.A., Stanford University, 1961; M.A., Yale University, 1963; Ph.D., 1972. California Institute, 1973.

William G. Quinn, Jr., Ph.D., *Research Fellow in Biology*
A.B., Harvard College, 1966; Ph.D., Princeton University, 1971. Research Fellow, California Institute, 1971-. (Church)

James P. Quirk, Ph.D., *Professor of Economics*
B.A., University of Minnesota, 1948; M.A., 1949; Ph.D., 1959. California Institute, 1971-. (Baxter)

Mark S. Radomski, Ph.D., *Research Fellow in Physics*
B.S., California Institute, 1969; M.S., Stanford University, 1970; Ph.D., 1973. California Institute, 1973-74.

Michael Augustine Raftery, Ph.D., Sc.D., *Professor of Chemical Biology*
B.Sc., National University of Ireland, 1956; Ph.D., 1960; Sc.D., 1971. Noyes Research Instructor in Chemistry, California Institute, 1964-66; Assistant Professor of Chemical Biology, 1967-69; Associate Professor, 1969-72; Professor, 1972-. (Church)

Fredric Raichlen, Sc.D., *Professor of Civil Engineering*
B.E., The Johns Hopkins University, 1953; S.M., Massachusetts Institute of Technology, 1955; Sc.D., 1962. Assistant Professor, California Institute, 1962-67; Associate Professor, 1967-72; Professor, 1972-. (Keck)

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

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

Finn Ravndal, Ph.D., *Research Fellow in Theoretical Physics*
Lic.Tech., Norwegian Institute of Technology, 1968; Ph.D., California Institute, 1971. Research Fellow, 1971-. (Lauritsen)

Charles van Blekkingh Ray,** M.S., *Lecturer in Applied Sciences; Director, Willis H. Booth Computing Center*
B.E.E., Cornell University, 1952; M.S., California Institute, 1956. Senior Engineer, Computing Center, 1964-. Lecturer, 1965-; Acting Director, Willis H. Booth Computing Center, 1971-72; Director, 1972-. (Booth)

Donald Roy Rayburn, Ph.D., *Research Fellow in Astrophysics*
B.Sc., University of Calgary, 1968; Ph.D., Queen's University (Canada), 1971. California Institute, 1972-. (Robinson).

H. Hollis Reamer, M.S., *Senior Research Fellow in Chemical Engineering*
A.B., University of Redlands, 1937; M.S., California Institute, 1938; Research Assistant, 1938-52; Research Fellow, 1952-58; Senior Research Fellow, 1958-. (Spalding)

Juta Kuttis Reed, Ph.D., *Research Fellow in Chemistry*
B.A., Queen's University (Canada), 1966; M.Sc., University of Western Ontario, 1967; Ph.D., University of Wisconsin, 1972. California Institute, 1973-. (Church)

Kenton Lewis Reed, Ph.D., *Research Fellow in Chemistry*
B.S., University of Alaska, 1964; M.S., 1966; Ph.D., University of Wisconsin, 1973. California Institute, 1973-. (Church)

**Part-time

Alan Rembaum,** Ph.D., *Lecturer in Chemical Engineering*
Lic., University of Lyon, 1941; Ph.D., Syracuse University, 1955. Technical Staff Member, Jet Propulsion Laboratory, 1961-. California Institute, 1967-. (Spalding)

Justin J. Rennilson, A.B., *Senior Research Fellow in Planetary Science*
A.B., University of California, 1950. California Institute, 1969-. (Arms)

Thomas Nicola Rescigno, Ph.D., *Research Fellow in Chemistry*
B.A., Columbia University, 1969; A.M., Harvard University, 1971; Ph.D., 1973. California Institute, 1973-74.

Helen Ruth Revel, Ph.D., *Research Associate in Biology*
B.S., Mount Holyoke College, 1949; Ph.D., Harvard University, 1957. Senior Research Fellow, California Institute, 1971-72; Research Associate, 1972-. (Church)

Jean-Paul Revel, Ph.D., *Professor of Biology*
B.Sc., University of Strasbourg, 1949; Ph.D., Harvard University, 1957. California Institute, 1971-. (Alles)

David Rosser Richards,** Ph.D., *Research Fellow in Theoretical Physics*
B.S., Alma College, 1967; M.S., University of Michigan 1968; Ph.D., 1971. California Institute, 1972-. (Lawrence Radiation Laboratory, University of California, Berkeley)

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

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

Andre Rigaud, Dr.Ing., *Research Fellow in Electrical Engineering*
B.A., University of Lyon, 1963; Ing., 1969; Dr.Ing., 1972. California Institute, 1972.

William H. Riker, Ph.D., *Sherman Fairchild Distinguished Scholar*
A.B., DePauw University, 1942; Ph.D., Harvard University, 1948. Joseph C. Wilson Professor of Political Science and Chairman of the Department of Political Science, The University of Rochester, 1970-. California Institute, 1973-74.

Miguel Rios, Jr.,** Ph.D., *Visiting Associate in Physics*
B.S., University of Southern California, 1965; M.S., California State College (Los Angeles), 1967; Ph.D., University of Maryland, 1971. California Institute, 1972-. (Kellogg)

John D. Roberts,* Ph.D., Dr.rer.nat., Sc.D., *Institute Professor of Chemistry*
B.A., University of California (Los Angeles), 1941; Ph.D., 1944; Dr.rer.nat., University of Munich, 1962; Sc.D., Temple University, 1964. Professor, California Institute, 1953-72; Division Chairman, 1963-68; Institute Professor, 1972-; Acting Chairman, 1972-73. (Crellin)

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

William Stanley Rodney, Ph.D., *Visiting Associate in Physics*
B.S., Scranton University, 1949; M.S., Catholic University, 1953; Ph.D., 1955. Program Director, Nuclear Physics Program, National Science Foundation, 1962-. California Institute, 1973-74.

Claudio Rodrigues, D.Sc., *Visiting Associate in Chemistry and Geochemistry*
B.S., University of Sao Paulo, 1965; D.Sc., Catholic University of Campinas (Sao Paulo), 1970. California Institute, 1972-. (Noyes)

David H. Rogstad, Ph.D., *Senior Research Fellow in Radio Astronomy*
B.S., California Institute, 1962; M.S., 1964; Ph.D., 1967. Research Fellow, 1966-69; Senior Research Fellow, 1971-. (Robinson)

*Leave of Absence, 1973-74
**Part-time

Claus E. Rolfs, Ph.D., *Senior Research Fellow in Physics*
M.S., University of Freiburg, 1966; Ph.D., 1967. California Institute, 1973-74.

Edward Rosenberg, Ph.D., *Research Fellow in Chemistry*
B.S., City College of New York, 1966; Ph.D., Cornell University, 1970. California Institute, 1972-. (Crellin)

Robert Allan Rosenstone, Ph.D., *Associate Professor of History*
B.A., University of California (Los Angeles), 1957; Ph.D., 1965. Visiting Assistant Professor, California Institute, 1966-68; Assistant Professor, 1968-69; Associate Professor, 1969-. (Baxter)

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

Hugh Norman Ross, Ph.D., *Research Fellow in Radio Astronomy*
B.Sc., University of British Columbia, 1967; M.Sc., University of Toronto, 1968; Ph.D., 1972. California Institute, 1973-. (Robinson)

George Robert Rossman, Ph.D., *Assistant Professor of Mineralogy and Chemistry*
B.S., Wisconsin State University, 1966; Ph.D., California Institute, 1971. Instructor in Mineralogy, 1971; Assistant Professor, 1971-72; Assistant Professor of Mineralogy and Chemistry, 1972-. (Arms)

Jean-René Roy, Ph.D., *Research Fellow in Solar Physics*
B.Sc., University of Montreal, 1969; M.Sc., University of Western Ontario, 1971, Ph.D., 1973. California Institute 1973-74.

Bruce Herbert Rule, B.S., *Staff Member, Hale Observatories; Staff Member, Owens Valley Radio Observatory*
B.S., California Institute, 1932. Staff Member, 1965-. (Hale Office)

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

Robert D. Rutherford,** Ph.D., *Lecturer in Industrial Relations*
B.A., Stanford University, 1956; M.A., University of California, 1962; Ph.D., University of California (Los Angeles), 1970. Associate Director, Industrial Relations Center, California Institute, 1972-; Lecturer, 1972-. (Industrial Relations Center)

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

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

Inge-Juliana Sackmann, Ph.D., *Research Fellow in Physics*
B.A., University of Toronto, 1963; M.A., 1965; Ph.D., 1968. California Institute, 1971-. (Kellogg)

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

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

**Part-time

Kyohei Sakuda, Ph.D., *Research Fellow in Electrical Engineering*
B.S., Osaka University, 1956; M.S., University of California, 1963; Ph.D., New York University, 1970. California Institute, 1972-73.

Sten Otto Samson, Fil.Dr., *Research Associate in Chemistry*
Fil.kand., University of Stockholm, 1953; Fil.lic., 1956; Fil.Dr., 1968. Research Fellow, California Institute, 1953-56; 1957-61; Senior Research Fellow, 1969-72; Research Associate, 1973-. (Noyes)

Allan Rex Sandage, Ph.D., Sc.D., D.Sc., LL.D., *Staff Member, Hale Observatories*
A.B., University of Illinois, 1948; Ph.D., California Institute, 1953; Sc.D., Yale University, 1966; D.Sc., University of Chicago, 1967; LL.D., University of Southern California, 1971. Staff Member, Hale Observatories, 1948-. (Hale Office)

Wallace Leslie William Sargent, Ph.D., *Professor of Astronomy*
B.Sc., Manchester University, 1956; M.Sc., 1957; Ph.D., 1959. Research Fellow, California Institute, 1959-62; Assistant Professor, 1966-68; Associate Professor, 1968-71; Professor, 1971-. Staff Member, Hale Observatories, 1966-. (Robinson)

William Palzer Schaefer, Ph.D., *Senior Research Fellow in Chemistry; Assistant Director of Admissions; Registrar*
B.S., Stanford University, 1952; M.S., University of California (Los Angeles), 1954; Ph.D., 1960. Instructor, California Institute, 1960-62; Assistant Professor, 1962-66; Senior Research Fellow, 1968-; Assistant Director, 1968-; Registrar, 1971-. (Crellin, Dabney)

Joel Jean Scherk, Ph.D., *Richard Chace Tolman Senior Research Fellow in Theoretical Physics*
Dipl., Ecole Normale Superieure, 1967; Ph.D., University of Paris (Orsay), 1969. California Institute, 1974-75.

Richard Theodore Schilizzi, Ph.D., *Research Fellow in Radio Astronomy*
B.Sc., University of New England (Australia), 1966; Ph.D., University of Sydney, 1972. California Institute, 1973-. (Robinson)

Carl William Schmid, Jr., Ph.D., *Research Fellow in Chemistry*
B.S., Drexel Institute of Technology, 1967; Ph.D., University of California, 1971. California Institute, 1971-. (Church)

Jakob Schmidt, M.D., Ph.D., *Research Fellow in Chemistry*
M.D., University of Munich, 1963; Ph.D., University of California (Riverside), 1970. California Institute, 1971-. (Church)

Maarten Schmidt, Ph.D., Sc.D., *Professor of Astronomy; Executive Officer for Astronomy*
Ph.D., University of Leiden, 1956; Sc.D., Yale University, 1966. Carnegie Fellow, Hale Observatories, 1956-58; Associate Professor, California Institute, 1959-64; Professor, 1964-. Staff Member, Hale Observatories, 1959-. Executive Officer, 1972-. (Robinson)

Robert Rüben Schmidt III, Ph.D., *Research Fellow in Chemistry*
B.S., University of Texas (Austin), 1968; Ph.D., 1972. California Institute, 1972-73.

Harrison H. Schmitt, Ph.D., *Sherman Fairchild Distinguished Scholar*
B.S., California Institute, 1957; Ph.D., Harvard University, 1964. Scientist-Astronaut, National Aeronautics and Space Administration, 1965-. California Institute, 1973-74.

Alan Michael Schneider, Ph.D., *Visiting Associate in Environmental Engineering Science*
B.S., Villanova University, 1945; M.S., University of Wisconsin, 1948; Ph.D., Massachusetts Institute of Technology, 1957. Professor of System Sciences, University of California (San Diego), 1968-. California Institute, 1973.

Neil E. Schore, Ph.D., *Research Fellow in Chemistry*
B.A., University of Pennsylvania, 1969; Ph.D., Columbia University, 1973. California Institute, 1973-74.

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

John Henry Schwarz, Ph.D., *Research Associate in Theoretical Physics*
A.B., Harvard College, 1962; Ph.D., University of California, 1966. California Institute, 1972-. (Lauritsen)

Martin Schwarzschild, *Sherman Fairchild Distinguished Scholar*
Ph.D., University of Göttingen, 1935. Higgins Professor of Astrophysical Science, Princeton University, 1951-. California Institute, 1973-74.

Jeffrey Stewart Schweitzer, Ph.D., *Research Fellow in Physics*
B.S., Carnegie Institute of Technology, 1967; M.S., Purdue University, 1969; Ph.D., 1972. California Institute, 1972-. (Kellogg)

Frank Joseph Sciulli, Ph.D., *Associate Professor of Physics*
A.B., University of Pennsylvania, 1960; M.S., 1961; Ph.D., 1965. Research Fellow, California Institute, 1966-68; Assistant Professor, 1969-71; Associate Professor, 1971-. (Lauritsen)

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

Thayer Scudder, Ph.D., *Professor of Anthropology*
A.B., Harvard College, 1952; Ph.D., Harvard University, 1960. Assistant Professor, California Institute, 1964-66; Associate Professor, 1966-69; Professor, 1969-. (Baxter)

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

Ernest Edwin Sechler, Ph.D., *Professor of Aeronautics*
B.S., California Institute, 1928; M.S., 1929; Ph.D., 1934. Instructor, 1930-37; Assistant Professor, 1937-40; Associate Professor, 1940-46; Professor, 1946-; Executive Officer, 1966-71. (Firestone)

Adrian Segall, Ph.D., *Research Fellow in Electrical Engineering*
B.Sc., Israel Institute of Technology, 1965; M.Sc., 1971; Ph.D., Stanford University, 1973. California Institute, 1973-74.

George Andrew Seielstad, Ph.D., *Research Associate in Radio Astronomy*
A.B., Dartmouth College, 1959; Ph.D., California Institute, 1963. Research Fellow, 1964-67; Senior Research Fellow, 1967-72; Research Associate, 1972-. (Robinson)

John Hersh Seinfeld, Ph.D., *Associate Professor of Chemical Engineering; Acting Executive Officer for Chemical Engineering*
B.S., The University of Rochester, 1964; Ph.D., Princeton University, 1967. Assistant Professor, California Institute, 1967-70; Associate Professor, 1970-. Acting Executive Officer, 1973-. (Spalding)

Peter Van Horne Serrell,** M.S., *Lecturer in Design*
B.S., California Institute, 1936; M.S., 1939. Consulting Mechanical Engineer, 1965-. Lecturer, 1973.

Philip Serwer, Ph.D., *Research Fellow in Biology*
A.B., The University of Rochester, 1963; M.S., New York Medical College, 1968; Ph.D., Harvard University, 1973. California Institute, 1972-. (Kerckhoff)

J. Sanders Sevall, Ph.D., *Research Fellow in Biology*
B.A., Willamette University, 1967; Ph.D., Purdue University, 1971. California Institute, 1971-. (Kerckhoff)

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

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

**Part-time

Kenneth John Shea, Ph.D., *Research Fellow in Chemistry*
B.S., The University of Toledo, 1966; M.S., 1968; Ph.D., Pennsylvania State University, 1972. California Institute, 1973-. (Crellin)

Kelvin Kei-Wei Shen, Ph.D., *Research Fellow in Chemistry*
B.S., National Taiwan University, 1964; Ph.D., University of Massachusetts, 1968. California Institute, 1972-. (Crellin)

Young Tsun Shen,** Ph.D., *Research Fellow in Engineering Science*
B.S., National Taiwan University, 1960; M.S., University of Minnesota, 1964; Ph.D., University of Michigan, 1970. California Institute, 1972-73.

Kenneth Wayne Shepard, Ph.D., *Research Fellow in Physics*
B.S., University of Chicago, 1962; M.A., Dartmouth College, 1964; Ph.D., Stanford University, 1970. California Institute, 1970-. (Sloan)

Dennis John Shields,*** Ph.D., *Research Fellow in Physics*
B.S., University of San Francisco, 1964; Ph.D., University of California (San Diego), 1971. California Institute, 1971-. (Lauritsen)

Tateo Shimozawa, M.S., *Research Fellow in Biology*
B.S., Hokkaido University, 1966; M.S., 1968. California Institute, 1973-. (Kerckhoff)

Kosuke Shobatake, Ph.D., *Research Fellow in Chemistry*
B.S., Kyoto University, 1964; M.S., 1966; Ph.D., University of Chicago, 1972. California Institute, 1972-. (Noyes)

Eugene Merle Shoemaker, Ph.D., Sc.D., *Professor of Geology*
B.S., California Institute, 1947; M.S., 1948; M.S., Princeton University, 1954; Ph.D., 1960; Sc.D., Arizona State College, 1965; Sc.D., Temple University, 1967. Visiting Professor of Geology, California Institute, 1962; Research Associate in Astrogeology, 1964-68; Professor, 1969-; Division Chairman, 1969-72. (Arms)

Olavi Siimann, Ph.D., *Research Fellow in Chemistry*
B.Sc., McGill University, 1966; Ph.D., 1970. California Institute, 1970-. (Noyes)

Jack Silver, Ph.D., *Research Fellow in Biology*
B.S., Brooklyn College, 1966; Ph.D., Boston University, 1971. California Institute, 1971-. (Church)

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

Richard Neil Silver, Ph.D., *IBM Research Fellow in Applied Physics*
B.S., California Institute, 1966; Ph.D., 1971. IBM Research Fellow, 1972-. (Steele)

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

Donald W. Skelton,** M.S., *Lecturer in Physics*
B.A., California State College (Los Angeles), 1963; M.S., 1965. California Institute, 1973-. (Bridge)

Carlos Sledge, Ph.D., *Research Fellow in Biology*
B.S., Knoxville College, 1968; M.S., Virginia State College, 1969; Ph.D., Michigan State University, 1972. California Institute, 1972-. (Church)

Stephen Hugh Smallcombe, Ph.D., *Senior Research Fellow in Chemistry*
B.S., Alma College, 1965; Ph.D., University of California (Irvine), 1970. Research Fellow, California Institute, 1970-73; Senior Research Fellow, 1973-. (Church)

**Part-time
***Leave of Absence, First Term, 1973-74

Annette Jacqueline Smith,** Ph.D., *Lecturer in French*
B.A., University of Paris (Sorbonne), 1947; M.A., 1950; Ph.D., 1970. Visiting Assistant Professor, California Institute, 1970-71; Lecturer, 1971-. (Baxter)

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

Hallett D. Smith, Ph.D., L.H.D., *Professor of English*
B.A., University of Colorado, 1928; Ph.D., Yale University, 1934; L.H.D., University of Colorado, 1968. Professor, California Institute, 1949-; Division Chairman, 1949-70. (Baxter)

Captain Lee T. Smith, M.S., *Lecturer in Aerospace Studies*
B.S., Air Force Academy, 1966; M.S., Purdue University, 1967. California Institute, 1973-. (Air Force ROTC Bldg.)

Michael Joseph Smith, Ph.D., *Research Fellow in Biology*
B.Sc., St. Mary's of California, 1963; Ph.D., University of British Columbia, 1969. California Institute, 1971-. (Kerckhoff Marine Lab)

Peter Lloyd Smith, Ph.D., *Visiting Associate in Physics*
B.Sc., University of British Columbia, 1965; Ph.D., California Institute, 1972. Assistant Professor, Harvey Mudd College, 1972-; Research Fellow, California Institute, 1972; Visiting Associate, 1972-73.

Stephen D. Smith, Ph.D., *Bateman Research Instructor in Mathematics*
S.B., Massachusetts Institute of Technology, 1967; Ph.D., Oxford University, 1973. California Institute, 1973-74.

Vernon L. Smith, Ph.D., *Sherman Fairchild Distinguished Scholar*
B.S.E.E., California Institute, 1949; M.A., University of Kansas, 1952; Ph.D., Harvard University, 1955. Professor of Economics, University of Massachusetts, 1968-. California Institute, 1973-74.

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

Laurence Albert Soderblom,** Ph.D., *Visiting Associate in Planetary Science*
B.S., New Mexico Institute of Mining and Technology, 1966; Ph.D., California Institute, 1970. Geophysicist, Center of Astrogeology, U.S. Geological Survey, 1970-. Research Fellow, 1970-72; Visiting Associate, 1972-. (Arms)

Johan Adolf Sparenberg, Ph.D., *Visiting Associate in Engineering Science*
B.S., University of Amsterdam, 1952; Ph.D., Technical University of Delft, 1957. Professor of Mathematics, University of Groningen. California Institute, 1973.

Jack T. Spence, Ph.D., *Visiting Associate in Chemistry*
B.S., University of Utah, 1951; Ph.D., 1957. Professor, Utah State University, 1967-. California Institute, 1973-. (Noyes)

Roger Wolcott Sperry, Ph.D., D.Sc., *Hixon Professor of Psychobiology*
A.B., Oberlin College, 1935; A.M., 1937; Ph.D., University of Chicago, 1941; D.Sc., University of Cambridge, 1972. California Institute, 1954-. (Alles)

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

**Part-time

Roger Fellows Stanton, Ph.D., *Professor of English, Emeritus*
B.S., Colgate University, 1920; M.A., Princeton University, 1924; Ph.D., 1931. Instructor, California Institute, 1925-31; Assistant Professor, 1931-47; Associate Professor, 1947-55; Professor, 1955-65; Director of Institute Libraries, 1949-63; Professor Emeritus, 1966-.

Alfred Stern, Ph.D., *Professor of Philosophy, Emeritus*
Ph.D., University of Vienna, 1923. Instructor, California Institute, 1947-48; Lecturer, 1948-50; Assistant Professor, 1950-53; Associate Professor, 1953-60; Professor, 1960-68; Professor Emeritus, 1968-.

Eli Sternberg, Ph.D., D.Sc., *Professor of Mechanics*
B.C.E., University of North Carolina, 1941; M.S., Illinois Institute of Technology, 1942; Ph.D., 1945; D.Sc., University of North Carolina, 1963. Professor of Applied Mechanics, California Institute, 1964-70; Professor of Mechanics, 1970-. (Thomas)

Paul R. Stevens, Ph.D., *Research Fellow in Physics*
B.S., University of California (Los Angeles), 1965; M.S., 1966; Ph.D., 1969. California Institute, 1972.

Homer Joseph Stewart, Ph.D., *Professor of Aeronautics*
B.Aero.E., University of Minnesota, 1936; Ph.D., California Institute, 1940. Instructor, 1939-42; Assistant Professor, 1942-46; Associate Professor, 1946-49; Professor, 1949-. (Firestone)

Edward Carroll Stone, Jr., Ph.D., *Associate Professor of Physics*
M.S., University of Chicago, 1957; Ph.D., 1963. Research Fellow, California Institute, 1964-66; Senior Research Fellow, 1967; Assistant Professor, 1967-71; Associate Professor, 1971-. (Downs)

Erik Storm, Ph.D., *Research Fellow in Aeronautics*
B.S., California Institute, 1967; M.S., 1968; Ph.D., 1973. Research Fellow, 1972-. (Karman)

William David Stratton, Ph.D., *Ford Instructor in Electrical Engineering*
B.A., Wesleyan University, 1955; M.S., Massachusetts Institute of Technology, 1966; Ph.D., 1973. California Institute, 1973-74.

Ellen Glowacki Strauss, Ph.D., *Senior Research Fellow in Biology*
B.A., Swarthmore College, 1960; Ph.D., California Institute, 1966. Research Fellow, 1969-73; Senior Research Fellow, 1973-. (Church)

James Henry Strauss, Jr., Ph.D., *Assistant Professor of Biology*
B.S., Saint Mary's University, 1960; Ph.D., California Institute, 1967. Assistant Professor, 1969-. (Church)

Thomas Foster Strong, M.S., *Dean of Freshmen, Emeritus*
B.S., University of Wisconsin, 1922; M.S., California Institute, 1937. Assistant Professor of Physics, 1944-65; Associate Professor, 1965-69; Dean of Freshmen, 1946-68; Dean Emeritus, 1969-. (Bridge)

Robert Michael Stroud, Ph.D., *Assistant Professor of Chemistry*
B.A., University of Cambridge, 1964; M.A., 1967; Ph.D., London University, 1968. Research Fellow, California Institute, 1968-71; Noyes Research Instructor, 1971-73; Assistant Professor, 1973-. (Church)

Felix Strumwasser, Ph.D., *Professor of Biology*
B.A., University of California (Los Angeles), 1953; Ph.D., 1957. Associate Professor, California Institute, 1964-69; Professor, 1969-. (Kerckhoff)

Bradford Sturtevant, Ph.D., *Professor of Aeronautics; Executive Officer for Aeronautics*
B.E., Yale University, 1955; M.S., California Institute, 1956; Ph.D., 1960. Research Fellow, 1960-62; Assistant Professor, 1962-66; Associate Professor, 1966-71; Professor, 1971-; Executive Officer, 1972-. (Karman)

Verner E. Suomi, Ph.D., *Visiting Professor of Atmospheric Sciences*
B.E., Winona Teachers College (Minnesota), 1938; Ph.D., University of Chicago, 1953. Professor of Meteorology, University of Wisconsin, 1966-. California Institute, 1974.

Henry Suter, Ph.D., *Research Fellow in Physics*
B.S., Geneva College, 1961; M.S., University of Geneva, 1966; Ph.D., 1972. California Institute, 1972-. (National Accelerator Laboratory, Batavia, Illinois)

Tetsuro Suzuoki, Ph.D., *Visiting Associate in Geochemistry*
B.S., Nagoya University, 1958; M.S., 1960; Ph.D., Tokyo Kyoiku University, 1965. Associate Professor, Meteorological College (Japan), 1970-. Research Fellow, California Institute, 1968-70; Visiting Associate, 1972.

Rosemarie Swanson, Ph.D., *Research Fellow in Chemistry*
S.B., University of Chicago, 1965; Ph.D., Stanford University, 1969. California Institute, 1970-. (Church)

Alan R. Sweezy, Ph.D., *Professor of Economics*
B.A., Harvard University, 1929; Ph.D., 1934. Visiting Professor, California Institute, 1949-50; Professor, 1950-. (Baxter)

Ernest Haywood Swift, Ph.D., LL.D., *Professor of Analytical Chemistry, Emeritus*
B.S., University of Virginia, 1918; M.S., California Institute, 1920; Ph.D., 1924; LL.D., Randolph-Macon College, 1960. Instructor, California Institute, 1920-28; Assistant Professor, 1928-39; Associate Professor, 1939-43; Professor, 1943-67; Division Chairman, 1958-63; Professor Emeritus, 1967-. (Gates)

Zygmunt Edward Switkowski, Ph.D., *Research Fellow in Physics*
B.Sc., University of Melbourne, 1969; Ph.D., 1973. California Institute, 1973-. (Kellogg)

Aladar Szalay, D.Sc., *Gosney Research Fellow in Biology*
B.S., University Halle/Saale, 1966; D.Sc., German Academy of Sciences, 1971. Research Associate, Hungarian Academy of Sciences. California Institute, 1973-74.

Johanna E. Tallman, Certificate in Librarianship, *Director of Libraries*
A.B., University of California, 1936; Certificate in Librarianship, 1937. California Institute, 1973-. (Millikan Library)

Abraham Haskel Taub, Ph.D., *Visiting Associate in Physics*
B.S., University of Chicago, 1931; Ph.D., Princeton University, 1935. Professor of Mathematics, University of California, 1964-. California Institute, 1973.

Hugh Pettingill Taylor, Jr., Ph.D., *Professor of Geology*
B.S., California Institute, 1954; A.M., Harvard University, 1955; Ph.D., California Institute, 1959. Assistant Professor, 1959-61; Research Fellow, 1961; Assistant Professor, 1962-64; Associate Professor, 1964-69; Professor, 1969-. (Mudd)

Keith Taylor, Ph.D., *Research Fellow in Astronomy*
B.Sc., University of Nottingham, 1969; M.Phil., 1970; Ph.D., University of Manchester, 1973. California Institute, 1973-74.

Fouad Tera, Ph.D., *Senior Research Fellow in Geochemistry*
B.S., University of Cairo, 1957; Ph.D., University of Vienna, 1962. Research Fellow, California Institute, 1966-67; Senior Research Fellow, 1967-. (Arms)

Massimo Testa, Ph.D., *Research Fellow in Theoretical Physics*
Ph.D., University of Rome, 1969. California Institute, 1974-75.

Frederick Burtis Thompson, Ph.D., *Professor of Applied Science and Philosophy*
A.B., University of California (Los Angeles), 1946; M.A., 1947; Ph.D., University of California, 1952. California Institute, 1965-. (Steele, Baxter)

Peter Thompson, Ph.D., *Research Fellow in Geochemistry*
B.Sc., Bradford University (England), 1965; Ph.D., McMaster University (Canada), 1973. California Institute, 1973-74.

Kip Stephen Thorne,*** Ph.D., *Professor of Theoretical Physics*
B.S., California Institute, 1962; Ph.D., Princeton University, 1965. Research Fellow in Physics, California Institute, 1966-67; Associate Professor of Theoretical Physics, 1967-70; Professor, 1970-. (E. Bridge)

***Leave of Absence, First and Second Terms, 1973-74

Anantanarayanan Thyagaraja, Ph.D., *Research Fellow in Applied Mathematics*
B.Sc., Loyola College (Madras University), 1967; M.Sc., Indian Institute of Technology, 1969; Ph.D., California Institute, 1972. Research Fellow, 1972-73.

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

Olga Taussky Todd, Ph.D., *Professor of Mathematics*
Ph.D., University of Vienna, 1930; M.A., University of Cambridge, 1937; Research Associate, California Institute, 1957-71; Professor, 1971-. (Sloan)

M. Nafi Toksoz, Ph.D., *Visiting Associate in Geophysics*
M.S., California Institute, 1960; Ph.D., 1963. Associate Professor, Massachusetts Institute of Technology, 1967-. Research Fellow, California Institute, 1963-65; Visiting Associate, 1973-. (Seismo Lab)

Alvin Virgil Tollestrup, Ph.D., *Professor of Physics*
B.S., University of Utah, 1944; Ph.D., California Institute, 1950. Research Fellow, 1950-53; Assistant Professor, 1953-58; Associate Professor, 1958-62; Professor, 1962-. (Lauritsen)

Thomas Anthony Tombrello, Jr., Ph.D., *Professor of Physics*
B.A., Rice University, 1958; M.A., 1960; Ph.D., 1961. Research Fellow, California Institute, 1961-62; 1964-65; Assistant Professor, 1965-67; Associate Professor, 1967-71; Professor, 1971-. (Kellogg)

Mihailo Dimitrije Trifunac, Ph.D., *Assistant Professor of Applied Science*
B.S., University of Belgrade, 1965; M.S., Princeton University, 1966; Ph.D., California Institute, 1969. Research Fellow, 1969-70; Assistant Professor, 1972-. (Thomas)

Benes Louis Trus, Ph.D., *Research Fellow in Chemistry*
B.S., Tulane University, 1968; Ph.D., California Institute, 1972. Research Fellow, 1972-. (Church)

Nicholas William Tschoegl, Ph.D., *Professor of Chemical Engineering*
B.Sc., New South Wales University of Technology, 1954; Ph.D., University of New South Wales, 1958. Associate Professor of Materials Science, California Institute, 1965-67; Professor of Chemical Engineering, 1967-. (Spalding)

Chang-Chyi Tsuei, Ph.D., *Research Associate in Applied Physics*
B.S., National Taiwan University, 1960; M.S., California Institute, 1963; Ph.D., 1966. Research Fellow in Materials Science, 1966-69; Senior Research Fellow, 1969-72; Research Associate in Applied Physics, 1972-. (Keck)

Andrzej Turos, Ph.D., *Visiting Associate in Electrical Engineering*
Ph.D., Warsaw Technical University, 1969. Senior Scientific Officer, Institute of Nuclear Research, Warsaw, 1961-. California Institute, 1973.

Lior Tzafriri, Ph.D., *Visiting Associate Professor of Mathematics*
M.Sc., Hebrew University of Jerusalem, 1964; Ph.D., 1966. Senior Lecturer, Hebrew University, 1970-. California Institute, 1973-74.

Firdaus E. Udwadia, Ph.D., *Research Fellow in Applied Science*
B.Tech., Indian Institute of Technology, 1968; M.S., California Institute, 1969; Ph.D., 1972. Research Fellow, 1972-. (Thomas)

Roger K. Ulrich, Ph.D., *Visiting Associate in Physics*
B.S., University of California, 1963; Ph.D., 1968. Research Fellow, California Institute, 1968-69; Assistant Professor, University of California (Los Angeles) 1969-. California Institute, 1973.

Mamoru Umemoto, Ph.D., *Research Fellow in Biology*
B.A., University of Tokyo, 1961; M.A., 1963; Ph.D., Kurume University, 1970. California Institute, 1972-. (Kerckhoff)

Ray Edward Untereiner, Ph.D., *Professor of Economics, Emeritus*
A.B., University of Redlands, 1920; M.A., Harvard University, 1921; J.D., Mayo College of Law, 1925; Ph.D., Northwestern University, 1932. Professor, California Institute, 1925-68; Professor Emeritus, 1968-.

Lynda Lou Uphouse, Ph.D., *Research Fellow in Biology*
B.A., Austin College, 1967; M.A., University of Colorado, 1969; Ph.D., 1971. California Institute, 1971-. (Kerckhoff)

Tadao Uyehara, Ph.D., *Research Fellow in Chemistry*
B.S., Tohoku University, 1966; M.Sc., 1968; Ph.D., 1971. California Institute, 1973-74.

Pieter van der Kruit, Ph.D., *Research Fellow in Astronomy*
Ph.D., University of Leiden, 1971. California Institute, 1972-. (Hale Office)

Werner Friedrich Van Der Weg, Ph.D., *Research Fellow in Applied Physics*
B.S., University of Amsterdam, 1963; M.S., 1965; Ph.D., 1969. California Institute, 1972-. (Steele)

Richard L. Vandlen, Ph.D., *Research Fellow in Chemistry*
B.S., Michigan State University, 1969; Ph.D., 1972. California Institute, 1972-. (Church)

Anthonie van Harreveld,** Ph.D., M.D., *Professor of Physiology*
B.A., Amsterdam University, 1925; M.A., 1928; Ph.D., 1929; M.D., 1931. Research Assistant, California Institute, 1934-35; Instructor, 1935-40; Assistant Professor, 1940-42; Associate Professor, 1942-47; Professor, 1947-. (Kerckhoff)

Vito August Vanoni,** Ph.D., *Professor of Hydraulics*
B.S., California Institute, 1926; M.S., 1932; Ph.D., 1940. Associate Professor, 1942-55; Professor, 1955-. (Keck)

Danica Vasileva, M.S., *Research Fellow in Geophysics*
M.S., University of Belgrade (Yugoslavia), 1970. California Institute, 1974.

Arthur Harris Vaughan, Jr., Ph.D., *Staff Member, Hale Observatories*
B.E., Cornell University, 1958; Ph.D., The University of Rochester, 1964. Research Fellow, California Institute, 1964-66; Staff Associate, Hale Observatories, 1966-67; Staff Member, 1967-. (Hale Office)

Robert Walton Vaughan, Ph.D., *Assistant Professor of Chemical Engineering*
B.S., University of Oklahoma, 1963; M.S., University of Illinois, 1965; Ph.D., 1967. Lecturer, California Institute, 1968-69; Assistant Professor, 1969-. (Spalding)

Robert Emerick Villagrana, Ph.D., *Assistant Professor of Materials Science*
Met. Eng., Colorado School of Mines, 1963; M.S., University of California, 1965; Ph.D., 1967. California Institute, 1968-. (Keck)

Jerome Vinograd, Ph.D., *Professor of Chemistry and Biology*
M.A., University of California (Los Angeles), 1937; Ph.D., Stanford University, 1939. Senior Research Fellow in Chemistry, California Institute, 1951-56; Research Associate, 1956-64; Research Associate in Chemistry and Biology, 1964-65; Professor, 1965-. (Church)

Petr Vogel, Ph.D., *Senior Research Fellow in Physics*
Ph.D., Joint Institute of Nuclear Research (USSR), 1966. California Institute, 1970-. (W. Bridge)

Rochus E. Vogt, Ph.D., *Professor of Physics*
S.M., University of Chicago, 1957; Ph.D., 1961. Assistant Professor, California Institute, 1962-65; Associate Professor, 1965-70; Professor, 1970-. (Downs)

Peter Kurt Christian Vollhardt, Ph.D., *Research Fellow in Chemistry*
Dipl., University of Munich, 1968; Ph.D., University College (London), 1972. California Institute, 1972-. (Crellin)

Hans-Peter Vosberg, M.D., *Senior Research Fellow in Biology*
M.D., University of Heidelberg, 1967. California Institute, 1973-74.

Thad Vreeland, Jr., Ph.D., *Professor of Materials Science*
B.S., California Institute, 1949; M.S., 1950; Ph.D., 1952. Research Fellow in Engineering, 1952-54; Assistant Professor of Mechanical Engineering, 1954-58; Associate Professor, 1958-63; Associate Professor of Materials Science, 1963-67; Professor, 1968-. (Keck)

**Part-time

David Bertram Wales, Ph.D., *Associate Professor of Mathematics*
B.S., University of British Columbia, 1961; M.A., 1962; Ph.D., Harvard University, 1967. Bateman Research Fellow, California Institute, 1967-68; Assistant Professor, 1968-71; Associate Professor, 1971-. (Sloan)

Robert Lee Walker, Ph.D., *Professor of Physics*
B.S., University of Chicago, 1941; Ph.D., Cornell University, 1948. Assistant Professor, California Institute, 1949-53; Associate Professor, 1953-59; Professor, 1959-. (Lauritsen)

Raymond J. Wall,** M.S.E.E., *Lecturer in Information Science*
B.S.E., Loyola University, 1960; M.S.E.E., University of Southern California, 1963. Senior Engineer, Jet Propulsion Laboratory, 1965-. California Institute, 1973.

Frederic Yui Ming Wan, Ph.D., *Visiting Associate in Applied Mechanics*
S.B., Massachusetts Institute of Technology, 1959; S.M., 1962; Ph.D., 1965. Associate Professor, Massachusetts Institute of Technology, 1969-. California Institute, 1972-73.

William Roger Ward, Ph.D., *Research Fellow in Planetary Science*
B.S., University of Missouri (Kansas City), 1968; Ph.D., California Institute, 1972. Research Fellow, 1973.

Randle William Ware, Ph.D., *Research Fellow in Biology*
B.S., California Institute, 1963; M.S., 1964; Ph.D., Massachusetts Institute of Technology, 1971. California Institute, 1971-. (Kerckhoff)

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-. (Baxter)

Jürg Waser, Ph.D., *Professor of Chemistry*
B.S., University of Zurich, 1939; Ph.D., California Institute, 1944. Professor, 1958-. (Gates)

Gerald J. Wasserburg, Ph.D., *Professor of Geology and Geophysics*
S.B., University of Chicago, 1951; S.M., 1952; Ph.D., 1954. Assistant Professor of Geology, California Institute, 1955-59; Associate Professor, 1959-62; Professor, 1962-63; Professor of Geology and Geophysics, 1963-. (Arms)

J. Harold Wayland,*** Ph.D., *Professor of Engineering Science*
B.S., University of Idaho, 1931; M.S., California Institute, 1935; Ph.D., 1937. Research Fellow in Applied Mechanics, 1939-41; Associate Professor, 1949-57; Professor, 1957-63; Professor of Engineering Science, 1963-. (Thomas)

Robert D. Wayne, M.A., *Associate Professor of German*
Ph.B., Dickinson College, 1935; M.A., Columbia University, 1940. Instructor, California Institute, 1952-62; Assistant Professor, 1962-69; Associate Professor, 1969-. (Baxter)

Michael J. Weaver, Ph.D., *Research Fellow in Chemistry*
B.Sc., London University, 1968; Ph.D., 1972. California Institute, 1972-. (Noyes)

H. Jürgen Weber, Dr.rer.nat., *Research Fellow in Biology*
Dr.rer.nat., Max Planck Institute, 1972. California Institute, 1973-74.

William Henry Weinberg, Ph.D., *Assistant Professor of Chemical Engineering*
B.S., University of South Carolina, 1966; Ph.D., University of California, 1969. California Institute, 1972-. (Spalding)

Jerome M. Weingart, Ph.D., *Senior Research Fellow in Environmental Engineering*
S.B., Massachusetts Institute of Technology, 1961; M.A., Brandeis University, 1964; Ph.D., 1969. Staff Member, Jet Propulsion Laboratory, 1969-. California Institute, 1971-. (Thomas)

Meir Weinstein, Ph.D., *Visiting Assistant Professor of Information Science*
M.S., Hebrew University of Jerusalem, 1960; Ph.D., University of Pennsylvania, 1970. Senior Engineer, Jet Propulsion Laboratory, 1970-. Lecturer in Information Science, California Institute, 1972-73; Visiting Assistant Professor, 1973-. (Jorgensen)

**Part-time
***Leave of absence, first term, 1973-74

Peter J. Weisbeek, Ph.D., *Research Fellow in Biology*
B.S., State University of Groningen, 1964; M.S., 1967; Ph.D., State University of Utrecht, 1972. California Institute, 1972-. (Alles)

Richard Karl Weiss, Ph.D., *Bateman Research Instructor in Applied Mathematics*
Dipl., Technical University (Vienna), 1969; Ph.D., The Australian National University, 1972. California Institute, 1972-. (Firestone)

Ben-Avi Weissman, Ph.D., *Research Fellow in Chemistry*
B.Sc., Hebrew University of Jerusalem, 1964; M.Sc., 1968; Ph.D., 1972. California Institute, 1972-. (Crellin)

David Franklin Welch, I.D., *Associate Professor of Engineering Design*
A.B., Stanford University, 1941; I.D., California Institute, 1943. Instructor in Engineering Graphics, 1943-51; Assistant Professor, 1951-61; Associate Professor of Engineering Design, 1961-. (Thomas)

John R. Wells, Ph.D., *Research Fellow in Biology*
B.A., University of California (Los Angeles), 1966; M.S., California State University (Northridge), 1969; Ph.D., University of California (Los Angeles), 1972. California Institute, 1973-74.

William Weltner, Jr., *Visiting Associate in Biology*
B.E., The Johns Hopkins University, 1943; Ph.D., University of California, 1950. Professor of Chemistry, University of Florida, 1966-. California Institute, 1972-73.

Michael W. Werner, Ph.D., *Assistant Professor of Physics*
B.A., Haverford College, 1963; Ph.D., Cornell University, 1968. California Institute, 1972-. (Downs)

James Adolph Westphal, B.S., *Associate Professor of Planetary Science*
B.S., University of Tulsa, 1954. Senior Research Fellow, California Institute, 1966-71; Staff Associate, Hale Observatories, 1966-; Associate Professor, 1971-. (Arms)

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

Warren Humphreys White, Ph.D., *Research Fellow in Environmental Health Engineering*
B.S., California Institute, 1963; M.S., University of Wisconsin, 1964; Ph.D., 1967. Staff Member, Institute of Mathematics (Brazil), 1969-. California Institute, 1972-. (Keck)

Gerald Beresford Whitham, Ph.D., *Professor of Applied Mathematics; Executive Officer for Applied Mathematics*
B.Sc., University of Manchester, 1948; M.Sc., 1949; Ph.D., 1953. Visiting Professor of Applied Mechanics, California Institute, 1961-62; Professor of Aeronautics and Mathematics, 1962-67; Professor of Applied Mathematics, 1967-; Executive Officer, 1971-. (Firestone)

John Hales Whitney, *Visiting Associate in Art and Artist in Residence*
California Institute, 1973.

Richard M. Wieland, Ph.D., *Research Fellow in Physics*
B.S., Notre Dame University, 1967; M.Phil., Yale University, 1969; Ph.D., 1972. California Institute, 1973-. (Kellogg)

Cornelis A. G. Wiersma, Ph.D., *Professor of Biology*
B.A., University of Leiden, 1926; M.A., University of Utrecht, 1929; Ph.D., 1933. Associate Professor, California Institute, 1933-47; Professor, 1947-. (Kerckhoff)

Mark Robert Willcott III, Ph.D., *Visiting Associate in Chemistry*
B.A., Rice Institute, 1955; M.S., Yale University, 1959; Ph.D., 1963. Associate Professor, University of Houston, 1968-. California Institute, 1972-73.

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

Stephen Ross Wilson, Ph.D., *Research Fellow in Chemistry*
B.A., Rice University, 1969; Ph.D., 1972. California Institute, 1972-. (Crellin)

Charles Harold Wilts, Ph.D., *Professor of Electrical Engineering; Executive Officer for Electrical Engineering*
B.S., California Institute, 1940; M.S., 1941; Ph.D., 1948. Assistant Professor, 1947-52; Associate Professor, 1952-57; Professor, 1957-; Executive Officer, 1972-. (Steele)

Eric Jean Wolanski, Ph.D., *Research Fellow in Environmental Engineering Science*
B.S., Catholic University of Louvain (Belgium), 1969; M.S., Princeton University, 1970; Ph.D., The Johns Hopkins University, 1972. California Institute, 1972-. (Keck)

David Shotwell Wood, Ph.D., *Professor of Materials Science; Associate Dean of Students*
B.S., California Institute, 1941; M.S., 1946; Ph.D., 1949. Lecturer in Mechanical Engineering, 1949-50; Assistant Professor, 1950-55; Associate Professor, 1955-61; Professor, 1961-63; Professor of Materials Science, 1963-; Acting Associate Dean, 1968-69; Associate Dean, 1969-. (Keck, Dabney)

James Wood, Ph.D., *Research Fellow in Biology*
B.S., Springfield College, 1962; Ph.D., University of Connecticut, 1968. California Institute, 1972-. (Kerckhoff)

Lincoln J. Wood, Ph.D., *Bechtel Instructor in Engineering*
B.S., Cornell University, 1968; M.S., Stanford University, 1969; Ph.D., 1972. California Institute, 1972-. (Karman)

William Barry Wood, Ph.D., *Professor of Biology*
A.B., Harvard College, 1959; Ph.D., Stanford University, 1963. Assistant Professor, California Institute, 1964-68; Associate Professor, 1968-70; Professor, 1970-. (Kerckhoff)

Dean Everett Wooldridge, Ph.D., *Visiting 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 in Engineering, 1950-52; 1962-73; Visiting Associate, 1973-.

Dorothy Scholl Woolum, Ph.D., *Research Fellow in Geology and Physics*
B.A., Cornell University, 1964; Ph.D., Washington University, 1971. California Institute, 1971-. (Arms)

Stanford Earl Woosley, Ph.D., *Research Fellow in Physics*
B.A., Rice University, 1966; M.S., 1969; Ph.D., 1971. California Institute, 1973-74.

Melvyn C. H. Wright** Ph.D., *Visiting Associate in Radio Astronomy*
B.A., University of Cambridge, 1966; M.A., 1969; Ph.D., 1970. Research Associate, University of California, 1972-. California Institute, 1972-. (Robinson)

Cheng-Chin Wu, Ph.D., *Research Fellow in Theoretical Physics*
B.S., National Taiwan University, 1967; Ph.D., Yale University, 1972. California Institute, 1972-. (Lauritsen)

Theodore Yao-Tsu Wu, Ph.D., *Professor of Engineering Science*
B.S., Chiao-Tung University, 1946; M.S., Iowa State University, 1948; Ph.D., California Institute, 1952. Research Fellow in Hydrodynamics, 1952-55; Assistant Professor of Applied Mechanics, 1955-57; Associate Professor, 1957-61; Professor, 1961-66; Professor of Engineering Science, 1966-. (Thomas)

Oliver Reynolds Wulf, Ph.D., *Research Associate in Physical Chemistry, Emeritus*
B.S., Worcester Polytechnic Institute, 1920; M.S., American University, 1922; Ph.D., California Institute, 1926. Research Associate, 1945-67; Research Associate Emeritus, 1967-. (Noyes)

Masanobu Yamamasu, Ph.D., *Visiting Associate in Engineering Science*
M.A., Nagoya Imperial University, 1942; Ph.D., 1961. Professor of Mechanical Engineering, Kantogakuin University. California Institute, 1972-73.

Amnon Yariv, Ph.D., *Professor of Electrical Engineering*
B.S., University of California, 1954; M.S., 1956; Ph.D., 1958. Associate Professor, California Institute, 1964-66; Professor, 1966-. (Steele)

**Part-time

Jui Lin Yen, Ph.D., *Visiting Associate in Radio Astronomy*
B.Sc., Chiao-Tung University, 1947; M.Sc., University of Toronto, 1950; Ph.D., 1953. Professor of Electrical Engineering, University of Toronto, 1953-. California Institute, 1972-73.

Michiteru Yoshida, Ph.D., *Research Fellow in Biology*
B.S., Tohoku University, 1963; Ph.D., 1968. California Institute, 1973-74.

Don M. Yost, Ph.D., *Professor of Inorganic Chemistry, Emeritus*
B.S., University of California, 1923; Ph.D., California Institute, 1926. Instructor, 1927-29; Assistant Professor, 1929-35; Associate Professor, 1935-41; Professor, 1941-64; Professor Emeritus, 1964-. (Gates)

Kenneth Young,** Ph.D., *Research Fellow in Physics*
B.S., California Institute, 1969; Ph.D., 1972. Research Fellow, 1972.

Paul Gary Young, Ph.D., *Research Fellow in Biology*
B.Sc., University of Victoria, 1968; Ph.D., University of Toronto, 1972. California Institute, 1972-. (Church)

Benjamin David Zablocki, Ph.D., *Senior Research Fellow and Lecturer in Sociology*
A.B., Columbia University, 1962; Ph.D., The Johns Hopkins University, 1967. California Institute, 1972-73.

Fredrik Zachariasen, Ph.D., *Professor of Theoretical Physics*
B.S., University of Chicago, 1951; Ph.D., California Institute, 1956. Assistant Professor, 1960-62; Associate Professor, 1962-66; Professor, 1966-. (Lauritsen)

Robert R. Zappala, Ph.D., *Research Fellow in Astronomy*
B.S., Case Institute of Technology, 1964; M.S., University of Chicago, 1967; Ph.D., University of California (Santa Cruz), 1971. California Institute, 1971-. (Hale Office)

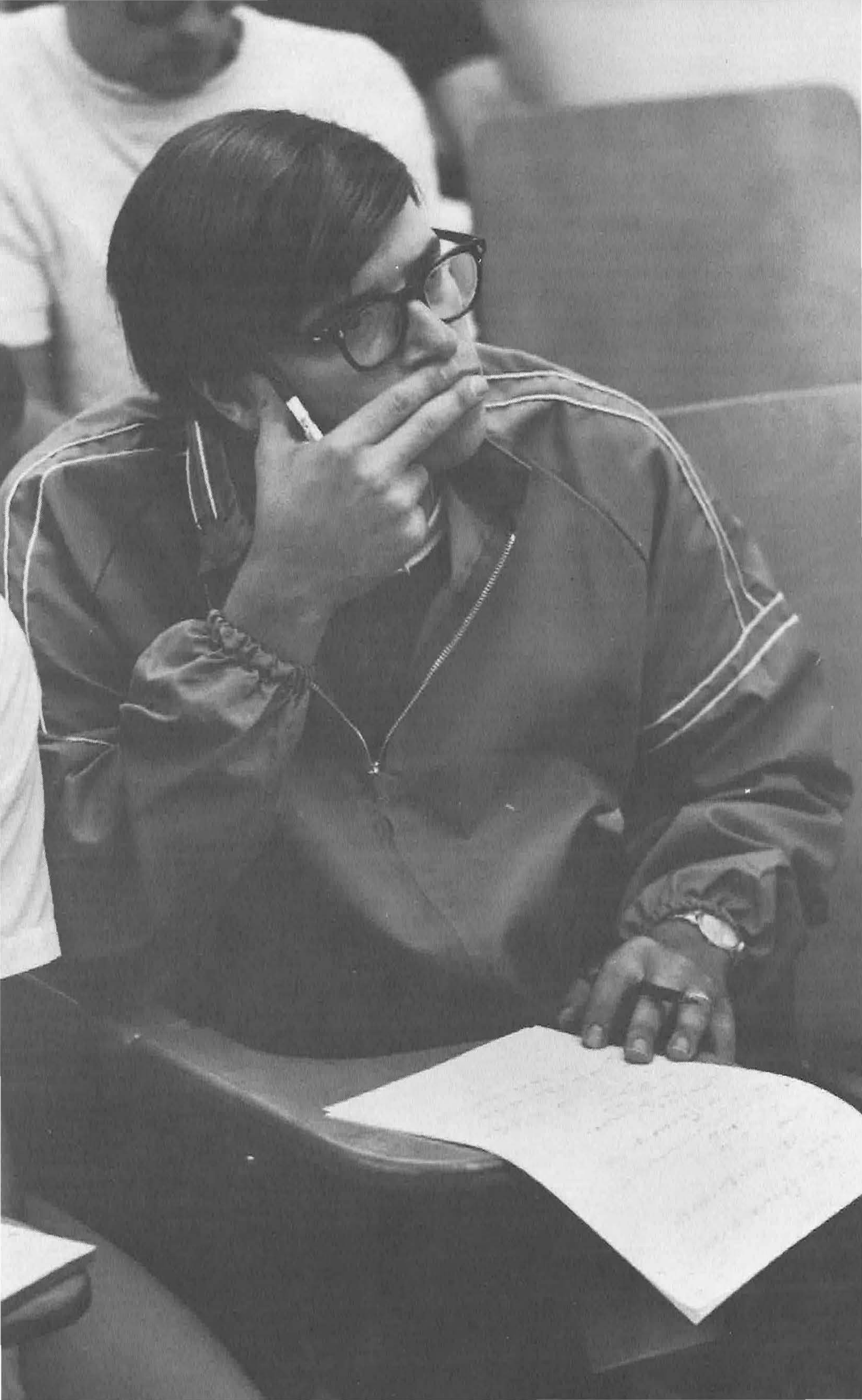
Harold Zirin, Ph.D., *Professor of Astrophysics; Chief Astronomer of Big Bear Solar Observatory*
A.B., Harvard College, 1950; A.M., Harvard University, 1951; Ph.D., 1953. Visiting Associate, California Institute, 1963; Professor, 1964-. Staff Member, Hale Observatories, 1964-. Chief Astronomer, Big Bear Solar Observatory, 1970-. (Robinson, Big Bear Solar Observatory)

Edward Edom Zukoski, Ph.D., *Professor of Jet Propulsion*
B.S., Harvard College, 1950; M.S., California Institute, 1951; Ph.D., 1954. Research Engineer, Jet Propulsion Laboratory, 1950-57; Lecturer, California Institute, 1956-57; Assistant Professor, 1957-60; Associate Professor, 1960-66; Professor, 1966-. (Karman)

George Zweig, Ph.D., *Professor of Theoretical Physics*
B.S., University of Michigan, 1959; Ph.D., California Institute, 1964. Research Fellow in Physics, 1963; Assistant Professor, 1964-66; Associate Professor, 1966-67; Professor of Theoretical Physics, 1967-. (Lauritsen)

Fritz Zwicky, Ph.D., *Professor of Astrophysics, Emeritus*
B.S., Federal Institute of Technology, Zurich, 1920; Ph.D., 1922. Research Fellow, California Institute, 1925-27; Assistant Professor of Theoretical Physics, 1927-29; Associate Professor, 1929-41; Professor of Astrophysics, 1941-68; Staff Member, Hale Observatories, 1948-68; Professor Emeritus, 1968-. (Robinson)

**Part-time



Section II

GENERAL INFORMATION

THE California Institute of Technology is an independent, privately supported and privately controlled institution, officially classed as a university, carrying on undergraduate and graduate instruction and research, principally in the various fields of science and engineering. It is fully accredited by the Western Association of Schools and Colleges.

Including its off-campus facilities, it is also one of the world's major research centers. According to *World* magazine: "In a number of countries today, there is at least one magnificently equipped scientific research institution that is proudly referred to as the nation's 'center of excellence.' Caltech, though, in the words of a senior Dutch astrophysicist, 'may well have become the center of scientific excellence for the entire world.' "

The Institute is organized into six divisions: Biology; Chemistry and Chemical Engineering; Engineering and Applied Science; Geological and Planetary Sciences; The Humanities and Social Sciences; and Physics, Mathematics and Astronomy.

The Undergraduate Program

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 purpose is attained at the Institute because of the contacts of its relatively small group of students with the members of its relatively large research staff. Advancement in understanding is best acquired by intimate association with creative workers who are, through research and reflection, extending the boundaries of knowledge.

Caltech offers a four-year undergraduate course with options available in various fields of science, engineering, applied science, and certain humanities subjects, all leading to the degree of Bachelor of Science. The curricula are planned so that interchange between options is not too difficult to the end of the second year. During the first year, the work of all undergraduates is almost identical, but there is opportunity for some differentiation between the various options during the second year.

The undergraduate options are: applied mathematics, applied physics, astronomy, biology, chemical engineering, chemistry, economics, engineering and applied science, English, geochemistry, geology, geophysics, history, independent studies program, mathematics, physics, and social science.

The science courses afford an intensive training in physics, chemistry, and mathematics, with further specialization in a chosen field of science during the third and fourth years.

The courses in engineering and applied science are of a general fundamental character, with a minimum of specialization in the separate branches. There is an unusually thorough training in the basic sciences of physics, chemistry, and mathematics, as well as in the professional subjects common to all branches of engineering. The major concentration in a chosen field occurs during the fourth year.

Students electing a humanities or social science option will pursue the same curriculum as all other students during the freshman year, and will continue with the regular sophomore courses in mathematics and physics. During the last two years, they specialize in a chosen field of humanities or social science but will continue substantial work in science and engineering subjects.

The undergraduate options in science, engineering, and applied science themselves contain a large proportion of humanistic and cultural studies – with 20 percent, or more, of the time during the entire four years being devoted to such subjects. The purpose of this requirement is to provide a combination of fundamental scientific training with a broad human outlook and to enlarge the student's mental horizon beyond the limits of his immediate professional interest.

Caltech also encourages a reasonable participation in extracurricular activities, largely managed by the students themselves. These include student publications, dramatics, music, and public affairs. All undergraduates are required to take three terms of physical education prior to graduation and may elect additional work through participation in a program of intercollegiate and intramural sports.

In short, every effort is made to provide the undergraduate student with a well-rounded, integrated program which will not only give him sound training in his professional field, but which will also develop character, breadth of view, general culture, and physical well-being.

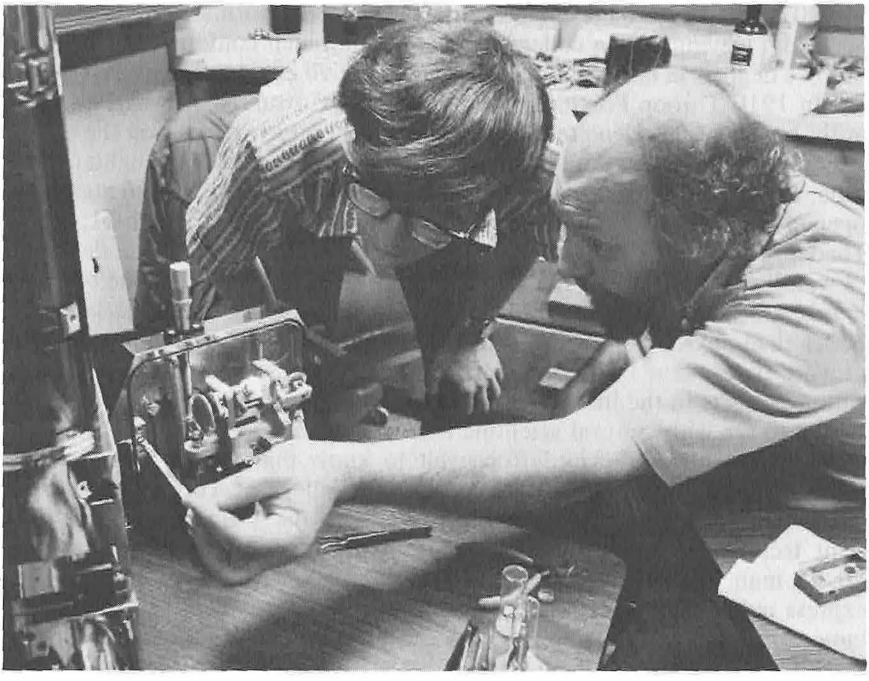
The Graduate Program

In the graduate school Caltech offers courses leading to the degree of Master of Science, which normally involves one year of graduate work; the Engineer's degree in certain branches of engineering, with a minimum of two years; and the degree of Doctor of Philosophy. In all the graduate work, research is strongly emphasized, not only because of its importance in contributing to the advancement of science and thus to the intellectual and material welfare of mankind, but also because research activities add vitality to the educational work of Caltech.

The graduate options are: aeronautics, applied mathematics, applied mechanics, applied physics, astronomy, biology, chemical engineering, chemistry, civil engineering, electrical engineering, engineering science, environmental engineering science, geological and planetary science, material science, mathematics, mechanical engineering, physics, and social science.

Graduate students constitute a comparatively large portion (almost 50 percent) of the total student body. Engaged as they are in research problems of varying degrees of complexity, and taught by faculty members who are also actively engaged in research, they contribute materially to the general atmosphere of intellectual curiosity and creative activity which is engendered on the Institute campus.

In order to utilize Caltech's resources most effectively, two general lines of procedure are followed. First, the Institute restricts the number of fields in engineering and science in which it offers undergraduate and graduate study, believing that it is better to provide thoroughly for a limited number of curricula than to risk diffusion of personnel, facilities, and funds in attempting to cover a wide variety of fields. Second, and in line with this policy of conservation of resources, the student body is strictly limited to that number which can be satisfactorily provided for. Admission is granted after a careful study of the merits of each applicant, including the results of entrance examinations, school records, and interviews by members of the Caltech staff. These procedures result, it is believed, in a body of students of exceptional ability. A high standard of scholarship is also maintained, as is appropriate for students of such competence.



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 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.

George Ellery Hale, astronomer and first director of the Mount Wilson Observatory, foresaw the development in Pasadena of a distinguished institution of engineering and scientific research. Hale well knew that a prime necessity was modern well-equipped laboratories, but he stressed to his fellow trustees that the aim was not machines, but men. "We must not forget," he wrote in 1907, "that the greatest engineer is not the man who is trained merely to understand machines and apply formulas, but is the man who, while knowing these things, has not failed to develop his breadth of view and the highest qualities of his imagination. No creative work, whether in engineering or in art, in literature or in science, has been the work of a man devoid of the imaginative faculty."

The realization of these aims meant specializing, so the trustees decided in 1907 to separate the elementary department, the normal school, and the academy, leaving only a college of technology 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 from 1913 as Throop College of Technology, would have again raised its sights, leaving to others the training of more efficient technicians and concentrating its own efforts on Roosevelt's "hundredth man." On November 29, 1921, the trustees declared it to be the express policy of the Institute to pursue scientific researches of the greatest importance and at the same time "to continue to conduct thorough courses

Hale

Noyes

Millikan

in engineering and pure science, basing the work of these courses on exceptionally strong instruction in the fundamental sciences of mathematics, physics, and chemistry; broadening and enriching the curriculum by a liberal amount of instruction in such subjects as English, history, and economics; and vitalizing all the work of the Institute by the infusion in generous measure of the spirit of research."

Three men were responsible for the change in the Institute. George Ellery Hale still held to his dream. Arthur Amos Noyes, professor of physical chemistry and former acting president of the Massachusetts Institute of Technology, served part of each year as professor of general chemistry and research associate from 1913 to 1919, when he resigned from MIT to devote full time to Throop as director of chemical research. In a similar way Robert Andrews Millikan began, in 1916-17, to spend a few months a year at Throop as director of physical research. In 1921, when Dr. Norman Bridge agreed to provide a research laboratory in physics, Dr. Millikan resigned from the University of Chicago and became administrative head of the Institute as well as director of the Norman Bridge Laboratory.

The great period of the Institute's life began, then, under the guidance of three men of vision – Hale, Noyes, and Millikan. They were distinguished research scientists, and they soon attracted graduate students. In 1920 the enrollment was 9 graduate students and 359 undergraduates under a faculty of 60; a decade later there were 138 graduate students, 510 undergraduates, and a faculty of 180. At the present time there are about 750 undergraduates, 650 graduate students, and a faculty (including postdoctoral fellows) of about 650.

The Institute also attracted financial support from individuals, corporations, and foundations. In January 1920 the endowment had reached half a million dollars. In February of that year it was announced that $200,000 had been secured for research in chemistry and a like amount for research in physics. Other gifts followed from trustees and friends who could now feel pride in the Institute as well as hope for its future. The Southern California Edison Company provided a high-voltage laboratory, with the million-volt Sorensen transformer. Philanthropic foundations bearing the names of Carnegie, Rockefeller, and Guggenheim came forth with needed help when new departments or projects were organized.

In 1923 Millikan received the Nobel Prize in Physics. He had attracted to the Institute such men as Charles Galton Darwin, Paul Epstein, and Richard C. Tolman. In 1924 the Ph.D. degree was awarded to nine candidates.

It was inevitable that the Institute would enlarge its fields; it could not continue to be merely a research and instructional center in physics, chemistry, and engineering. But the trustees pursued a cautious and conservative policy, not undertaking to add new departments except when the work done in them would be at the same high level as that in physics and chemistry. In 1925 a gift of $25,000 from the Carnegie Corporation of New York made possible the opening of a department of instruction and research in geology. A seismological laboratory was constructed, and Professors John P. Buwalda and Chester Stock came from the University of California to lead the work in the new division.

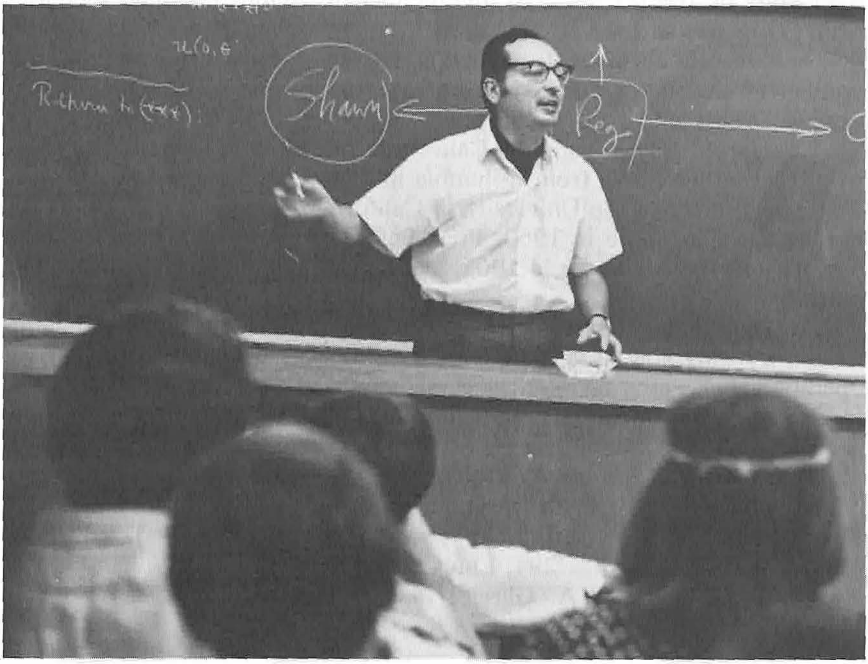
In 1928 the California Institute began its program of research and instruction in biology. Thomas Hunt Morgan became the first chairman of the new Division of Biology and a member of Caltech's Executive Council. Under Morgan's direction the work in biology developed rapidly, especially in genetics and biochemistry. Morgan received the Nobel Prize in 1933.

The Guggenheim Graduate School of Aeronautics was founded at Caltech in the summer of 1926 and a laboratory was built in 1929, but courses in theoretical aerodynamics had been given at the Institute for many years by Professors Harry Bateman and P. S. Epstein. As early as 1917 Throop Institute had had a wind tunnel in which, the catalog proudly boasted, constant velocities of 4 to 40 miles an hour could be maintained, "the controls being very sensitive." The new program, under the leadership of Theodore von Karman, included graduate study and research at the level of the other scientific work at the Institute, and GALCIT (Guggenheim Aeronautical Laboratory at the California Institute of Technology) was soon a world-famous research center in aeronautics.

In 1928 George Ellery Hale and his associates at the Mount Wilson Observatory developed a proposal for a 200-inch telescope and attracted the interest of the General Education Board in providing $6,000,000 for its construction. The Board proposed that the gift be made to the California Institute of Technology, and Caltech agreed to be responsible for the construction and operation. The huge instrument was erected on Palomar Mountain, and the Mount Wilson and Palomar Observatories are now operated jointly as the Hale Observatories through an agreement between Caltech and the Carnegie Institution of Washington. Teaching and research in astronomy and astrophysics thus became a part of the Caltech program.

Although the emphasis upon the humanities or liberal arts as an important part of the education of every scientist and engineer was traditional even in the Throop College days, a reiterated insistence upon this principle was made when Hale, Noyes, and Millikan created the modern Caltech. In 1924, when a five-year engineering course leading to the M.S. degree was offered, the humanities requirement was included. In 1925 William Bennett Munro, chairman of the Division of History, Government and Economics at Harvard, joined the Institute staff, and soon became a member of the Executive Council. Students were required to spend between 20 and 25 percent of their undergraduate years in the Division of Humanities – mainly in literature and history, with some economics. In the fifties the relation of science to society became increasingly important, and in 1966 the division changed its name to the Division of the Humanities and Social Sciences. Studies of modern society were added by processes of formal analysis based on the social and political sciences. Undergraduate options in English, history, economics, and social science are now offered.

For the five years beginning with the summer of 1940, Caltech devoted an increasingly large part of its personnel and facilities to the furthering of national defense and the war effort. Caltech's work during this period fell mainly into two categories: special instructional programs and research on the development of the instrumentalities of war. The research and development work was carried on for the most part under non-profit con-



tracts with the Office of Scientific Research and Development. Rockets, jet propulsion, and antisubmarine warfare were the chief fields of endeavor. The Jet Propulsion Laboratory in the upper Arroyo Seco continues under Institute management to carry on a large-scale program of research for the National Aeronautics and Space Administration in the science and technology of unmanned space exploration. The Laboratory launched the first U.S. satellite, Explorer I, in 1958, and conducted the Ranger, Mariner, and Surveyor programs of lunar and planetary exploration for NASA. The Laboratory also operates the NASA worldwide deep-space tracking network and conducts a program of supporting research in space science and engineering.

In 1945 Robert A. Millikan retired as chairman of the executive council but served as vice chairman of the board of trustees until his death in 1953. Dr. Lee A. DuBridge became president of Caltech on September 1, 1946. Formerly chairman of the physics department and dean of the faculty at the University of Rochester, he came to the Institute after five years as wartime director of the MIT Radiation Laboratory – and remained 22 years.

DuBridge was also committed to the concept of a small, select institution offering excellence in education. Facts and figures are only part of the story, but the statistical record of change during the DuBridge administration indicates how he held to that concept. The 30-acre campus of 1946 grew to 90 acres; the $17 million endowment grew to over $100 million; the faculty of 260 became 550; the number of campus buildings increased from 20 to 64; and the budget went from something under $8 million to $30 million. But enrollment remained relatively constant. In 1946 the total number of students, graduate and undergraduate, was 1,391. In 1968, the year DuBridge left, it was 1,492.

Dr. Harold Brown came to Caltech as president in 1969. A physicist who received his Ph.D. from Columbia in 1949, he succeeded Dr. Edward Teller as director of the University of California's Lawrence Radiation Laboratory in Livermore in 1960. President Lyndon Johnson named Brown Secretary of the Air Force in 1965, and he came to the Institute from that office.

As Caltech has developed in effectiveness and in prestige, it has attracted a steady flow of gifts for buildings, for endowment, and for current operations. The gifts invested in plant now total $103,000,000 and those invested in endowment about $145,000,000. Very substantial grants and contracts from the federal government support many research activities.

Today Caltech has about 13,000 alumni scattered all over the world, many eminent in their fields of engineering and science. Six of them have received Nobel Prizes: Carl D. Anderson (B.S. '27, Ph.D. '30), Edwin M. McMillan (B.S. '27, M.S. '29), Linus Pauling (Ph.D. '25), William Shockley (B.S. '32), Donald A. Glaser (Ph.D. '50), and Charles H. Townes (Ph.D. '39).

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.

NORMAN BRIDGE LABORATORY OF PHYSICS: first unit, 1922; second unit, 1924; third unit, 1925. The gift of Dr. Norman Bridge of Los Angeles, president of the Board of Trustees, 1896-1917.

HIGH VOLTAGE RESEARCH LABORATORY, 1923. Erected with funds provided by the Southern California Edison Company. Retired in 1959 with basic research completed and rebuilt in 1960 as the Alfred P. Sloan Laboratory of Mathematics and Physics.

DABNEY HALL OF THE HUMANITIES, 1928. The gift of Mr. and Mrs. Joseph B. Dabney of Los Angeles.

GUGGENHEIM AERONAUTICAL LABORATORY, 1929. Erected with funds provided by the Daniel Guggenheim Fund for the Promotion of Aeronautics. A substantial addition was erected in 1947.

WILLIAM G. KERCKHOFF LABORATORIES OF THE BIOLOGICAL SCIENCES: first unit, 1928; second unit, 1939; annex, 1948. The gift of Mr. and Mrs. William G. Kerckhoff of Los Angeles.

ATHENAEUM, 1930. A clubhouse for the use of the teaching, research, and administrative staffs of the Institute, the Huntington Library and Art Gallery, and the Hale Observatories; of the Associates of the California Institute of Technology; and of others who have demonstrated their interest in advancing the educational objectives of the Institute. The gift of Mr. and Mrs. Allan C. Balch of Los Angeles. He was president of the Board of Trustees, 1933-1943.

UNDERGRADUATE HOUSES, 1931:

Blacker House. The gift of Mr. and Mrs. R. R. Blacker of Pasadena.

Dabney House. The gift of Mr. and Mrs. Joseph B. Dabney of Los Angeles.

Fleming House. Erected with funds provided by some twenty donors and named in honor of Mr. Arthur H. Fleming of Pasadena, president of the Board of Trustees, 1917-1933.

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

W. K. KELLOGG RADIATION LABORATORY (Nuclear Physics), 1932. The gift of Mr. W. K. Kellogg of Battle Creek, Michigan.

HENRY M. ROBINSON LABORATORY OF ASTROPHYSICS, 1932. Erected with funds provided by the International Education Board and the General Education Board, and named in honor of Mr. Henry M. Robinson of Pasadena, member of the Board of Trustees, 1907-1937, and of the Executive Council of the Institute.

CHARLES ARMS LABORATORY OF THE GEOLOGICAL SCIENCES, 1938. The gift of Mr. and Mrs. Henry M. Robinson of Pasadena, in memory of Mrs. Robinson's father, Mr. Charles Arms.

SEELEY W. MUDD LABORATORY OF THE GEOLOGICAL SCIENCES, 1938. The gift of Mrs. Seeley W. Mudd of Los Angeles, in memory of her husband.

FRANKLIN THOMAS LABORATORY OF ENGINEERING: first unit, 1945; second unit, 1950. Funds for the first unit were allocated from the Eudora Hull Spalding Trust with the approval of Mr. Keith Spalding, trustee. Named in honor of Dean Franklin Thomas, professor of civil engineering and first chairman of the Division of Engineering, 1924-1945.

ALUMNI SWIMMING POOL, 1954. Provided by the Alumni Fund through contributions of the alumni of the Institute.

SCOTT BROWN GYMNASIUM, 1954. Erected with funds provided by the trust established by Mr. Scott Brown of Pasadena and Chicago, who was a member and director of the Caltech Associates.

NORMAN W. CHURCH LABORATORY FOR CHEMICAL BIOLOGY, 1955. Erected with funds provided through a gift and bequest by Mr. Norman W. Church of Los Angeles, who was a member of the Caltech Associates.

EUDORA HULL SPALDING LABORATORY OF ENGINEERING, 1957. 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, who was a member and director of the Caltech Associates.

PHYSICAL PLANT BUILDING AND SHOPS, 1959. Erected with funds provided by many donors to the Caltech development program.

GORDON A. ALLES LABORATORY FOR MOLECULAR BIOLOGY, 1960. Erected with the gift of Dr. Gordon A. Alles of Pasadena, research associate in biology at the Institute, an alumnus and a member of the Caltech Associates, 1947-1963; and with funds provided by the Health Research Facilities Branch of the National Institutes of Health.

UNDERGRADUATE HOUSES, 1960. Erected with funds provided by the Lloyd Foundation and other donors to the Caltech development program.

Lloyd House. Named in memory of Mr. Ralph B. Lloyd and his wife Mrs. Lulu Hull Lloyd of Beverly Hills. He was a member of the Board of Trustees, 1939-1952.

Page House. Named in honor of Mr. James R. Page of Los Angeles, a member of the Board of Trustees, 1931-1962, and chairman, 1943-1954.

Ruddock House. Named in honor of Mr. Albert B. Ruddock of Santa Barbara, a member of the Board of Trustees, 1938-1971, and chairman, 1954-1961.

HARRY CHANDLER DINING HALL, 1960. The gift of the Chandler family, the Pfaffinger Foundation, and the Times Mirror Company of Los Angeles.

W. M. KECK ENGINEERING LABORATORIES, 1960. The gift of the W. M. Keck Foundation and the Superior Oil Company of Los Angeles.

GRADUATE HOUSES, 1961:

Braun House. Erected with funds provided by the trustees of the Carl F. Braun Trust Estate in his memory.

Keck House. The gift of Mr. William M. Keck, Jr. of Los Angeles.

Marks House. The gift of Dr. David X. Marks of Los Angeles.

Mosher-Jorgensen House. The gift of Mr. Samuel B. Mosher of Los Angeles and Mr. Earle M. Jorgensen of Los Angeles. Mr. Jorgensen is a member of the Board of Trustees.

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

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

FIRESTONE FLIGHT SCIENCES LABORATORY, 1962. The gift of the Firestone Tire and Rubber Company.

WINNETT STUDENT CENTER, 1962. The gift of Mr. P. G. Winnett of Los Angeles, a member of the Board of Trustees, 1939-1968.

WILLIS H. BOOTH COMPUTING CENTER, 1963. Erected with funds given by the Booth-Ferris Foundation of New York, and by the National Science Foundation. Named in memory of Mr. Willis H. Booth, a member of the Caltech Associates.

BECKMAN AUDITORIUM, 1964. The gift of Dr. and Mrs. Arnold O. Beckman of Corona del Mar. Dr. Beckman, an alumnus, was a member of the Institute's faculty from 1928 to 1939, and is now chairman of the Board of Trustees.

HARRY G. STEELE LABORATORY OF ELECTRICAL SCIENCES, 1965. Erected with funds provided by the Harry G. Steele Foundation and the National Science Foundation.

CENTRAL ENGINEERING SERVICES BUILDING, 1966.

ROBERT A. MILLIKAN MEMORIAL LIBRARY, 1967. Erected with the gift of Dr. Seeley G. Mudd and named in honor of Dr. Robert Andrews Millikan, director of the Bridge Laboratory of Physics and chairman of the Executive Council of the Institute, 1921-1945.

ARTHUR A. NOYES LABORATORY OF CHEMICAL PHYSICS, 1967. Erected with funds provided by the National Science Foundation and an anonymous donor, and named in honor of Arthur Amos Noyes, director of the Gates and Crellin Laboratories of Chemistry and chairman of the Division of Chemistry and Chemical Engineering, 1917-1936.

CENTRAL PLANT, 1967.

GEORGE W. DOWNS LABORATORY OF PHYSICS AND CHARLES C. LAURITSEN LABORATORY OF HIGH ENERGY PHYSICS, 1969. The Downs wing was erected with funds provided by George W. Downs and the National Science Foundation. The Lauritsen wing was erected with Atomic Energy Commission funds and named in honor of Dr. Charles C. Lauritsen, a member of the Institute faculty, 1930-1968.

KEITH SPALDING BUILDING OF BUSINESS SERVICES, 1969.

DONALD E. BAXTER, M.D., HALL OF THE HUMANITIES AND SOCIAL SCIENCES, 1971. Erected with funds provided by Mrs. Delia B. Baxter of Atherton and named in honor of her late husband, Donald E. Baxter, M.D. Additional funds were given by Dr. and Mrs. Simon Ramo and the U.S. Department of Health, Education, and Welfare.

THE EARLE M. JORGENSEN LABORATORY OF INFORMATION SCIENCE, 1971. Erected with the gift of Mr. and Mrs. Earle M. Jorgensen and with additional funds provided by the Booth-Ferris Foundation and other private donors.

Off-Campus Facilities

KRESGE SEISMOLOGICAL LABORATORY, 1928 (of the Division of the Geological and Planetary Sciences), 220 North San Rafael Avenue, Pasadena. Named in recognition of a gift from The Kresge Foundation of Detroit, Michigan.

WILLIAM G. KERCKHOFF MARINE BIOLOGICAL LABORATORY, Corona Del Mar, 1930. Rehabilitated with funds provided by the National Science Foundation in 1966.

JET PROPULSION LABORATORY, 1944, 4800 Oak Grove Drive, Pasadena. Administered by the Institute; owned and supported by the National Aeronautics and Space Administration.

PALOMAR OBSERVATORY, San Diego County, 1948. Owned by the Institute and, with the Mount Wilson Observatory, operated jointly as the Hale Observatories by the Carnegie Institution of Washington and the Institute.

DONNELLEY SEISMOLOGICAL LABORATORY, 1957 (of the Division of the Geological and Planetary Sciences), 295 North San Rafael Avenue, Pasadena. The gift of Mr. and Mrs. C. Pardee Erdman of Santa Barbara, The Kresge Foundation of Detroit, and the James Irvine Foundation of San Francisco. Named in honor of Mrs. Erdman's father, Mr. Reuben H. Donnelley.

OWENS VALLEY RADIO OBSERVATORY, near Bishop, 1958.

BIG BEAR SOLAR OBSERVATORY, BIG BEAR LAKE, 1969. Built with funds provided by the National Science Foundation and the Max C. Fleischmann Foundation of Nevada.

Libraries

The Robert A. Millikan Memorial Library houses the general administrative activities of the Institute's library system as well as the following divisional collections: biology, chemistry, engineering, humanities and social sciences, mathematics, and physics.

Millikan Memorial, completed in 1967, is a nine-story building with 63,000 feet of floor space. It has an eventual capacity of 400,000 volumes and provides seats for about 250 students. Book collections have been distributed throughout the building in such a way that each major subject has its own area and retains its identity and its close relationship with its parent academic division. Library administrative services are concentrated on the second floor; here also are the catalog of campus libraries and general reference and information services. The first-floor reception area also houses the reserve book services. The various divisional collections are on floors four through nine. The basement contains reproduction equipment, the Institute's archives, and mail and distribution facilities. A small microfilm reading room is located on the fifth floor. Millikan Memorial is open daily throughout the school year from 8 a.m. to 2 a.m. and during the summer from 8 a.m. to midnight.

In addition to this central library there are library collections elsewhere on campus in aeronautics, astrophysics, chemical engineering, electrical engineering, geology, hydraulics and environmental engineering, and industrial relations. The libraries collectively subscribe to about 4,200 journals and contain about 265,000 volumes.

The Industrial Relations Center

The objectives of the Industrial Relations Center are to increase and disseminate a knowledge and an understanding of the philosophies, principles, policies, and procedures of employer-employee relations influencing the motivation, development, utilization, compensation, and supervision of rank-and-file, professional, and managerial personnel.

Representatives of many organizations in both the private and public sectors receive training in the field of management in general and in the specialized field of personnel administration. Special attention is given to programs for technical supervisors and managers who function in engineering and research laboratories. Other series are designed for the first- and second-line supervisors of non-exempt employees. The courses are presented on a number of bases: on-campus or off-campus; full-time or part-time; for representatives of a variety of companies or for representatives of a specific company. These courses do not carry academic credit.

The staff of the Center also participates in the education of undergraduate and graduate students of the California Institute of Technology, stressing the fundamentals of management and employer-employee relations.

The office, library, and conference rooms of the Center are located on campus at 383 South Hill Avenue. Detailed information about the specific services of the Center and the fees involved can be secured from the Director of the Industrial Relations Center.

The Willis H. Booth Computing Center

The Computing Center offers a comprehensive integrated set of facilities for the research and educational use of all divisions of the Institute.

These include an IBM 370/155 computer and a PDP-10 computer which, in addition to servicing batch processing functions, provides for a variety of user communication modes through 40 remote typewriter consoles at various locations on the campus.

SPECIAL PROGRAM

Sherman Fairchild Distinguished Scholars Program

The Sherman Fairchild Distinguished Scholars Program at Caltech brings some of the world's great intellectual leaders to the campus – scholars, industrial executives, and figures from government. Through this program, eminent world leaders in various fields have the opportunity to share their wisdom with Caltech's faculty and student body, to influence teaching and research, and, in turn, to be influenced by them.

When the program is in full operation, about 20 Scholars will be in residence on the campus at any one time. They will not all be scientists and engineers, though they will all be people who have exhibited an interest in science and technology, and in applying knowledge from these fields to meeting human needs. Most appointments are for one year, but may be lengthened or shortened to accommodate the needs of the Scholar and the Institute.

The emphasis on the program is to give Scholars maximum exposure to faculty and students in all academic divisions – through teaching, seminars, and lectures – and to establish a new forum for the exchange of ideas among the Fairchild Scholars, Caltech faculty, students, and industry on new directions and ideas in science and engineering.

Study and Research

AERONAUTICS

The Guggenheim Aeronautical Laboratory (1929), the Karman Laboratory of Fluid Mechanics and Jet Propulsion (1961), and the Firestone Flight Sciences Laboratory (1962) form the Graduate Aeronautical Laboratories, widely known as GALCIT. In this complex are housed the Applied Mathematics group, the Jet Propulsion Center, and the Hydrodynamics Laboratory, as well as the various disciplines making up the broad field known as Aeronautics.

Areas of Study and Research

The term aeronautics has been at Caltech traditionally applied to the study of the applied-science and engineering problems which arose during the development of the airplane. The inability to hide ignorance behind large safety factors in airplane design forced aeronautical engineers into a much more sophisticated approach to design problems, and a corresponding demand for fundamental understanding of the underlying fluid dynamics and structural mechanics. The development of space exploration and spacecraft engineering accentuated the same trend and in addition greatly expanded the interface with basic science. Indeed, the need for a mastery of concrete problems close to or beyond the edge of available scientific understanding has been the cause for the unusually strong interaction of aeronautics with other fields of science and technology such as applied mathematics, meteorology, materials science, and even astrophysics.

Instruction and research in GALCIT is not, and has never been, aimed at a complete coverage of the aerospace field, nor is it restricted to problems within this field. For instance the flow of superfluid helium, of plasmas, and problems in acoustics as well as polymer fracture are investigated at GALCIT. Research in vehicle dynamics includes automobiles and their air resistance, and sailing- and ship-related problems. Research which originally may have been stimulated by an aeronautical problem often becomes viable in its own right and at times even leads to spin-off of independent groups and organizations. At Caltech the Jet Propulsion Laboratory and Environmental Quality Laboratory as well as the Applied Mathematics group are cases in point.

Education at GALCIT is intended to be so broadly and thoroughly based on fundamentals and engineering principles that a graduate is capable of adapting rapidly to new technological demands, whether they involve the design of, say, a chemical laser, an analysis of the effect of blast waves, an advanced composite material, or transonic aerodynamics.

The present active research areas in GALCIT are best judged on a representative sample of thesis topics:

An Experimental Investigation of the Effect of a Density Gradient on Shear Layer Instability. (1971)

An Experimental Investigation of the Incompressible Turbulent Boundary Layer over a Wavy Wall. (1971)

Crack Propagation Under General In-Plane Loading. (1971)

Experimental Investigation of the Effect of Cooling on Near Wake of Circular Cylinder at Mach Number Six. (1971)

A Study of Fleet Composition and Route Determination for a Small Airline. (1971)

The Effect of a Circular Hole on the Buckling of Cylindrical Shells. (1970)

Laser Velocimeter Measurements of Reynolds Stress and Turbulence in Dilute Polymer Solutions. (1972)

The Hypersonic Laminar Boundary Layer Near a Sharp Expansion Corner. (1969)

Spectroscopic Investigation of Argon in a Convergent Shock Tube. (1972)

Optimal Simple Structures with Bending and Membrane Stresses. (1972)

An Investigation of a Two-Dimensional Propulsive Lifting System. (1971)

The Daniel and Florence Guggenheim Jet Propulsion Center conducts a large portion of its instruction and research in close cooperation with Aeronautics. The fields of study covered are described on page 150 under the separate heading of Jet Propulsion. Students in Aeronautics are able to pursue studies and research leading to graduate degrees in Aeronautics utilizing facilities, courses, and research supervision by the faculty of the Jet Propulsion Center.

Physical Facilities

The Graduate Aeronautical Laboratories contain a diversity of experimental facilities in support of the above programs. Low-speed wind tunnels include the Merrill Wind Tunnel, which can be operated by a single student, the GALCIT 10-ft. Wind Tunnel, and many special-purpose flow facilities. Both a High-Speed Water Tunnel (100 feet per second) and a Free-Surface Water Tunnel are housed in the Hydrodynamics Laboratory; they are used for studies of hydrofoils, cavitation, and acoustics. A smaller water channel for studies of wave motion and flow visualization is also available. For investigations of high-speed flows there is a hypersonic wind tunnel and a supersonic wind tunnel, each with two different working sections. Shock tubes, plasma tunnels, and other special facilities are available for the study of extreme temperatures, shock waves, acoustics, and cryogenic flow.

The solid mechanics laboratories contain standard as well as special testing machines for research in aircraft and spacecraft structures and materials under static and dynamic loads. Fatigue machines and photoelastic equipment are available. Special apparatus, including laser equipment and a number of high-speed cameras, is available for study of elastic waves, dynamic buckling, and the mechanics of static and dynamic fracture.

Electronic instrumentation up to the present state-of-the-art is being developed and used. Both small specialized computers as well as terminals to the time-shared campus computer are available.

The facilities of the Jet Propulsion Laboratory, an off-campus laboratory owned and supported by NASA and administered by Caltech, may under special circumstances also be used for research in aeronautics and jet propulsion. Among the experimental facilities are space environment simulators, large supersonic and hypersonic wind tunnels and test cells for rockets and thermal jets, as well as facilities for the study of refractory materials, hydraulics, combustion, and other chemical processes.

APPLIED MATHEMATICS

It is the broad aim of the applied mathematics program at Caltech to stimulate and explore the interplay between mathematics and the various non-mathematical disciplines. On the one hand there is an active group of pure mathematicians devoting themselves mainly to the more abstract and foundational branches of mathematics, and on the other hand there is wide diversity of research in physics, engineering, biology, chemistry, geophysics, and economics. Ideas travel in both directions, bringing mathematical tools to bear for synthesis and solution of practical problems in various fields and, of equal importance, generating new mathematical ideas and points of view which arise from physical problems. The research and educational program reflects this aim in its organization.

This program is a joint effort of the Division of Physics, Mathematics and Astronomy and the Division of Engineering and Applied Science. Students majoring in applied mathematics are enrolled in either division and the professors of applied mathematics are also in these two divisions. Further, professors from various other divisions take part supervising research and offering courses of special interest. Close contact is maintained with experimental programs in fluid and solid mechanics. The present graduate program is one leading mainly to the Ph.D. degree. The curriculum consists of two types of courses: those which survey the methods used in applied mathematics, and those which have a special applied mathematics flavor and represent active research interests of the members of the faculty. Among the latter have been wave motion, perturbation theory, stochastic processes, linear programming, numerical analysis of partial differential equations, group theory applied to physics, and advanced elasticity. Further, by study outside of applied mathematics each student is expected to become competent in some special physical or non-mathematical field. In this way, subjects for research appear naturally, and a broad educational program is provided. In addition to the connections mentioned above, special notice should be taken of the existence of a computer and information science group at Caltech which provides the chance for practical experience with the most modern computers and further fields of research. Library facilities are excellent, comprising all the journals, a complete general library, and a special research library in applied mathematics.

The present group primarily interested in applied mathematics consists of approximately 25 students and 8 professors. Also, each year many distinguished visitors come either to present lectures or remain in residence for large parts of the academic year. There is much stimulating activity in the form of research, courses, working seminars, and colloquia.

Areas of Research

Research is particularly strong in fluid dynamics (including magnetohydrodynamics, plasma physics, and kinetic theory), elasticity, dynamics and celestial mechanics, numerical analysis, differential equations, integral equations, asymptotic methods, and other related branches of analysis.

APPLIED MECHANICS

Areas of Research

Advanced instruction and research leading to degrees of Master of Science and Doctor of Philosophy in Applied Mechanics are offered in such fields as elasticity, plasticity, wave propagation in solid and fluid media, fluid mechanics, dynamics and mechanical vibrations, stability and control, and certain areas in the fields of propulsion and heat transfer.

Research studies in these areas which illustrate current interests include: linear and nonlinear vibrations, structural dynamics and design for earthquake and blast loads, linear and nonlinear problems in static and dynamic elasticity, plasticity and viscoelasticity, wave propagation in elastic and viscoelastic media, diffraction of elastic waves by cavities and inclusions, boundary layer problems in plates and shells, stratified flow, unsteady cavity flow, oscillatory flow of blood in very small tubes, and the mechanical properties of biological tissues under large deformations.

Research Facilities

In addition to the regular facilities of the Division of Engineering and Applied Science, such as the extensive digital computing facilities of the Computing Center, and the special facilities for studies in solid and fluid mechanics of the Graduate Aeronautical Laboratories, certain special facilities have grown up in connection with applied mechanics activities. The Dynamics Laboratory is equipped with a good selection of modern laboratory apparatus and instrumentation for experimental research in shock and vibration, and the Earthquake Engineering Research Laboratory contains specialized equipment for the analysis of complex transient loading problems, and for the recording and analysis of strong-motion earthquakes. Other specialized laboratories include the Heat Transfer Laboratory, which contains a forced convection heat transfer loop, and the Hemorheology Laboratory with equipment for quantitative study of blood flow in living microvessels and related model systems and of the mechanical properties of biological tissues.

APPLIED PHYSICS

An interdivisional program in applied physics for both undergraduate and graduate study was initiated in 1970. Like applied mathematics, applied physics at Caltech is in a fortunate position: The comparatively small size of Caltech coupled with great strength in both the pure sciences and engineering make it possible to draw on a faculty having wide interest in the application of modern physics to technology, without losing close interaction with "pure subjects." At present, members of four divisions, Engineering and Applied Science, Physics, Mathematics and Astronomy, Chemistry and Chemical Engineering, and Geological and Planetary Sciences, participate in instruction and research in applied physics leading to a B.S. degree as well as to M.S. and Ph.D. degrees.

The program is designed for students who are deeply interested in physics but at the same time are fascinated by the interrelation of physical problems and technological development, i.e., students who like to work with problems in physics which originate from or result in applications. A sharp division between "pure" and "applied" physics or between applied physics and engineeering cannot be drawn, and the option of applied physics should be considered a bridge rather than a divider. A student is expected to have a thorough background in physics, as well as a broad background in related fields of technology.

Members of the faculty involved with the educational and research activities in applied physics remain members of their respective divisions. Graduate students who choose the applied physics option similarly are admitted to one of the cooperating divisions.

In setting up the undergraduate curriculum every effort has been made to facilitate the transition into and out of the option. In general an undergraduate student in applied physics will devote somewhat more time on the study of matter in bulk than the "pure" physicist. Since it is expected that a comparatively large portion of the student body will be interested in experimental research, a special effort has been made to set up challenging laboratory courses.

For first-year graduate students and adventurous seniors, a set of basic courses covering broad areas in applied physics is available, supplemented by a set of more specialized courses often closely related to a specific research effort.

Areas of Research

Research activities cover a broad spectrum, ranging from cryogenics to plasmas, from rarefied gas flow to high pressures and shock waves in solids, from neutron transport to planetary science. There is research in progress in the physics of solids, including solid-state electronics, ferromagnetic materials, quantum electronics, and superconductivity; in the physics of fluids, including plasmas and magnetohydrodynamics, liquids and superfluids; and in the physics of electromagnetic radiation, including linear and nonlinear laser optics and electromagnetic theory.

ASTRONOMY

The astronomical observatories at Palomar, Mount Wilson, Big Bear, and the Owens Valley Radio Observatory together constitute a unique and unprecedented concentration of scientific facilities in astronomy. Outstanding scientific talent is present in various fields of astronomy and in the related fields of physics. The California Institute of Technology recognized the advantages in the creation of a great astronomical center in which a scientific program could be pursued under favorable circumstances with a variety of instruments which would also draw young men and women of ability to graduate studies, where they might familiarize themselves with powerful tools of exploration. The joint scientific staff of astronomers at Caltech and at the Carnegie Institution of Washington comprise the Hale Observatories. Caltech owns the Palomar and Big Bear Solar Observatories, and the Carnegie Institution the Mount Wilson Observatory, but the equipment and facilities of both observatories are made available for the astronomical investigations of the combined staff and students. The research program is paralleled by undergraduate and graduate training in astronomy and astrophysics by members of the Institute faculty and Hale Observatories, the Radio Observatory, and the Solar Observatory at Big Bear Lake.

The radio astronomy group works in close collaboration with the optical astronomers in Pasadena; the program of graduate study in the two fields is essentially the same, except for specialized advanced courses. Work in physics and geology is expanding in the field of astronomical research in space and in the ground-based study of the planetary system.

During a ten-day period starting August 2, 1972, a series of gigantic eruptions took place on the sun. Photographs taken at the Big Bear Solar Observatory revealed a great flare cloud about 100,000 miles long.

There will be close cooperation between these groups and the students and astronomers interested in planetary physics and space science.

As a result of the cooperation possible over a broad range of astronomy, astrophysics, and radio astronomy, unsurpassed opportunities exist at the California Institute for advanced study and research. The instructional program is connected with a broad and thorough preparation in physics, mathematics, and other relevant subjects, as well as instruction in astronomy, solar physics, space and planetary physics, radio astronomy, astrophysics, and observations with large telescopes.

Areas of Research

Both observational and theoretical astrophysics are actively pursued at Caltech. Topics of current interest in optical astronomy include chemical abundances in normal and peculiar stars, spectroscopic and spectrophotometric studies of quasars, compact and Seyfert galaxies and related objects; studies of white dwarfs and other stars near the end-point of evolution; studies of the dynamics and composition of galaxies and clusters, nebulae and interstellar matter, statistical studies pertinent to the structure of the galaxy, and the physics of solar phenomena.

In addition, active research in infrared and planetary astronomy is done in cooperation with groups in physics and geology.

The research in radio astronomy covers the physical properties of galactic and extragalactic radio sources including quasars, radio galaxies, supernova remnants, pulsars, and the planets. The properties of the interstellar medium in our own and other nearby galaxies are investigated in spectroscopic studies of the 21-cm hydrogen line and various molecular spectral lines.

Theoretical astrophysics is pursued not only in the astronomy department, but in physics and geology as well, and at Caltech includes work on supernovae, pulsars, stellar structure and evolution, stellar atmospheres, interstellar and intergalactic matter, the physics of radio sources, nucleosynthesis, relativity, and cosmology.

Physical Facilities

The Rockefeller Boards provided in 1928 for the construction by the Institute of an astronomical observatory on Palomar Mountain, equipped with a 200-inch reflecting telescope, 48-inch and 18-inch schmidt wide-angle telescopes, and other auxiliary instruments, together with an astrophysical laboratory on the Institute campus. This observatory is supplemented by the facilities of the Mount Wilson Observatory of the Carnegie Institution of Washington, which, while not a part of Caltech, is located even closer to Pasadena than is Palomar Mountain. Some graduate student thesis research is carried out at Mount Wilson. The increased light-collecting power of the 200-inch telescope permits further studies of the size, structure, and motion of the galactic system; of the distance, motion, radiation, composition, and evolution of the stars; the interstellar gas; the distance, motion, and nature of remote galaxies and quasi-stellar radio sources; and of many phenomena bearing directly on the constitution of matter. The 48-inch schmidt has made possible a complete survey of the sky, as well as an attack upon such problems as the structure of clusters of galaxies, the luminosity function of galaxies, extended gaseous nebulae, and the stellar content of the Milky Way. These two unique instruments at Palomar supplement each other as well as the telescopes on Mount Wilson; the one reaches as far as possible into space in a given direction, while the other photographs upon a single plate an entire cluster of distant galaxies, or a star cloud in our own galaxy.

A new multi-purpose solar equatorial telescope has been installed at a new observing station at Big Bear Lake. The work of this facility is coordinated with work with the two solar coelostats in Pasadena (20-inch and 36-inch apertures) and the 60-foot and 150-foot towers on Mount Wilson. The unique atmospheric conditions in this area make possible investigations of the fine structure of the solar atmosphere. Emphasis is on high-resolution spectroscopy, magnetography, and cinematography.

A new 60-inch telescope has been completed for photoelectric observations, image-tube spectroscopy and photography at Palomar. An astroelectronics laboratory is continuously developing sophisticated data-handling systems.

Special apparatus for the far infrared has been fitted to various telescopes to study very cool stars and planets.

Work in radio astronomy was begun at the Institute in 1956 with the founding of the Owens Valley Radio Observatory, near Big Pine, 250 miles north of Pasadena. Research instruments include a 32-foot paraboloid and a pair of very accurate 90-foot paraboloids. The two 90-foot radio telescopes are used together as a variable-spacing interferometer for studies of all aspects of discrete radio sources, including the planets, at centimeter and decimeter wavelengths. Construction of a 130-foot radio telescope has been completed; this instrument is the prototype unit for a three-element, variable-spacing interferometer array which has been proposed for construction at the radio observatory. The 130-foot telescope is used in interferometric combinations with the two 90-foot telescopes and by itself for high-resolution, pencil-beam studies at centimeter wavelengths. Very long baseline interferometric measurements have been made in combination with observers in Australia, Sweden, the U.S.S.R., and across the United States.

The Owens Valley Radio Observatory constitutes one of the most advanced facilities for research in this rapidly growing field. Sensitive receivers, maser amplifiers and sophisticated techniques for digital recording and analysis of data permit study of the positions, spatial distribution, polarization, and other physical properties of the most distant radio galaxies and quasi-stellar sources. Similar studies may be made of the radio emission from most of the planets. Multi-channel filter banks permit work on radio spectral lines – work which recently has been considerably expanded.

BIOLOGY

The recent, dramatic progress in our understanding of the nature of life has revolutionized the science of biology. Applications of the methods, concepts and approaches of modern mathematics, physics, chemistry, and information science are providing deep insight into basic biological problems such as the manner in which genes and viruses multiply themselves; the nature of enzyme action and of enzymatic pathways; the organization of cellular activity; the mechanisms of growth and development; and the nature and interactions of nerve activity, brain function, and behavior. Qualified experimental biologists will find opportunities for challenging work in basic research as well as in medicine, agriculture, and the chemical or pharmaceutical industries.

Because of the eminent position of the California Institute of Technology in both the physical and biological sciences and the current expansion of our programs in the study of behavior and experimental psychology, students at the Institute have an unusual opportunity to be introduced to modern biology.

Areas of Research

Research (and graduate work leading to the Ph.D. degree) is chiefly in the following fields: biochemistry, biophysics, cell biology, developmental biology, experimental psychology, genetics, immunology, neurophysiology, psychobiology, and virology. Most of these fields are approached at the molecular as well as higher levels of organization. The disciplines of biochemistry and biophysics encompass the area of molecular biology. There is extensive interaction with related programs in chemical biology within the Division of Chemistry and Chemical Engineering.

The programs in cell and developmental biology are based upon approaches derived from biochemistry, biophysics, and genetics which offer new possibilities for expanded insight into long-standing problems.

Neurobiology, experimental psychology, and behavioral biology are receiving increasing emphasis within the Division. A comprehensive program of research and instruction has been formulated to span the disciplines from neuron physiology to the study of animal and human behavior. Expansion and development of this program are in process. Related developments in the Divisions of Engineering and Applied Science and the Humanities and Social Sciences serve to fortify doctoral programs concerned with the study of brain and behavior.

Physical Facilities

The campus biological laboratories are housed in three interconnected buildings, the William G. Kerckhoff Laboratories of the Biological Sciences, the Gordon A. Alles Laboratory for Molecular Biology, and the Norman W. Church Laboratory for Chemical Biology. The three laboratories contain classrooms and undergraduate laboratories, an annex housing experimental animals, and numerous laboratories equipped for biological, biochemical, biophysical, physiological, and psychological research at the graduate and doctoral level. The constant-temperature equipment includes rooms for the culturing of the Institute's valuable collection of mutant types of Drosophila and Neurospora and complete facilities for plant and animal tissue culture. A new Laboratory for Behavioral Biology is now under construction.

Adjacent to these laboratories is the Campbell Plant Research Laboratory for botanical investigations.

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 physiology and developmental biology. It is equipped with its own shop, has boats and tackle for collecting marine animals, and running seawater aquaria for keeping them. The proximity of the marine station to Pasadena makes it possible to supply the biological laboratories with living material for research and teaching. The fauna at Corona del Mar and at nearby Laguna Beach is exceptionally rich and varied, and is easily accessible. The laboratory has been extensively rehabilitated and re-equipped for work in modern biology.

The Biological Systems Laboratory in the Booth Computing Center houses the joint research program of the biology and engineering divisions dealing with data processing systems and systems theory as they relate to the nervous system and sensory perception.

CHEMICAL ENGINEERING

The research and teaching interests of the chemical engineering faculty are directed towards broad applications of chemical principles, and to the design, understanding, and improvement of large-scale chemical systems. This leads the faculty and students into problems as diverse as the chemical processes carried out in various organs of the body, the chemistry of polluted atmospheres, synthesis and behavior of materials under conditions of unusual temperature and pressure, etc. At the same time, chemical engineers retain significant interest in the engineering of processes involved in chemical manufacturing and petroleum refining; however, research and teaching in these traditional areas of the chemical process industry are now regarded as only a part of the very broad natural field of study in chemical engineering.

Areas of Research

The chemical engineering program is well equipped for instruction and research programs leading to the degrees of Master of Science and Doctor of Philosophy in Chemical Engineering. The major areas in which graduate research is currently concentrated are:

1. Biomedical problems, especially involving transport in tissues, artificial organs, the vascular system, and gas sterilization.
2. Air pollution studies, including simulation and control; atmospheric chemical reactions; atmospheric fluid mechanics; computer simulation of the urban atmosphere; application of tracer techniques to environmental problems.
3. Chemistry and physics of aerosols.
4. Theoretical and experimental fluid mechanics; rheology and transport properties of suspensions and emulsions; mechanics of non-Newtonian fluids; mass transfer from bubbles and drops; numerical simulation of fluid motion.
5. Liquid-state physics involving studies of forces and configurations at the molecular level in simple systems; determination of structure by x-ray diffraction; other studies of local order by optical, magnetic, and ultrasonic experiments; statistical mechanics.
6. Mechanical and ultimate properties of polymers, particularly filled elastomers and block copolymers. Mechanical properties of dialysis membranes; behavior of elastomers under pressure; physics of elastomer networks.

7. Plasma chemistry and engineering, including diffusion and homogeneous and heterogeneous reactions.
8. Reaction kinetics and combustion, including both homogeneous and catalytic oxidation reactions and reactions involving oxides of nitrogen and hydrocarbons in parts-per-million concentrations.
9. Heterogeneous catalysis and surface chemistry; adsorption and catalytic reactions on well-characterized surfaces; theoretical modeling of solids, solid surfaces, and gas-surface interactions; kinetics of industrially important catalytic reactions, including studies of poisons and moderators.
10. Solid-state and surface chemistry: investigations using multiple pulsed nuclear magnetic resonance techniques, and studies of effects of high pressure on chemical and electronic properties.
11. Optimal control and estimation theory with applications to mathematical modeling and design of chemical engineering systems.

Physical Facilities

Chemical engineering is housed in the Eudora Hull Spalding Laboratory of Engineering. The laboratories are well equipped both for instruction and for research and include the following major subdivisions:

The Kinetics Laboratory contains several research-scale chemical reactors, chiefly of the flow type, and appropriate equipment for the measurement of pressures, temperatures, and flow rates. Extensive use is made of gas chromatography for analysis.

The Liquid-State Physics Laboratory is equipped for x-ray diffraction measurements on cryogenic fluids at moderate pressures. Apparatus is also available for refractive index, ultrasonic velocity and absorption, light scattering, and magnetic experiments over a range of temperatures and pressures.

The Plasma Chemistry Laboratory includes equipment for the generation of various equilibrium and non-equilibrium plasmas. Associated diagnostic equipment includes spectrometers, microwave cavities, and Langmuir probes.

The Polymer Laboratory has extensive apparatus for the study of the mechanical behavior and the failure properties of polymeric materials under both uniaxial and multiaxial loads. Apparatus for polymer synthesis and characterization as well as molding and casting equipment for specimen preparation is also available.

The Solid State Chemistry Laboratory is equipped to make both conventional and multiple pulse nuclear magnetic resonance measurements for the study of solid state and surface chemistry. Facilities for making a variety of measurements of solids as a function of pressure to several million psi are available, and are directed toward obtaining a better understanding of the nature of chemical bonding, or electronic structure, in solids.

The Surface Chemistry and Catalysis Laboratory contains the facilities for studying the interaction of gases with well-characterized solid surfaces.

Investigations are conducted which are aimed at elucidating both chemical adsorption and heterogeneously catalyzed surface reactions. The surface probes include low-energy electron diffraction, Auger electron spectroscopy, inelastic electron tunneling spectroscopy, and mass spectrometry.

The Fluid Mechanics Laboratory contains facilities for investigations of fluid motion and heat or mass transfer, particularly as they pertain to small particles, drops, or bubbles. Various equipment is available for flow visualization, for velocity or pressure measurements, and for other associated determinations.

The Environmental Tracer Laboratory is equipped with an electron capture gas chromatograph used in monitoring tracers in concentrations down to 1 part in 10^{12} parts of air, ozone detectors for measuring ozone in the range 0.1 to 10 ppm, carbon monoxide detectors for measuring carbon monoxide in the range 1 to 100 ppm, a quadrupole mass spectrometer, and various thermal conductivity and flame ionization gas chromatographs.

CHEMISTRY

Caltech has long had a reputation for excellence in chemistry in the areas of molecular structure and the nature of chemical bonding. It has benefited from the close cooperative relationships it shares with biology. More recent is the development of programs aimed at understanding the nature of chemical reactions: chemical kinetics and dynamics. These interests are reflected in a broad range of research, from molecular beam kinetics and ion cyclotron resonance spectroscopy to DNA binding studies and protein crystal structure analysis. Both structure and dynamics are combined in a young but promising program in theoretical chemistry and chemical physics.

Chemistry now has the pivotal role of making any number of neighboring disciplines work, and exciting chemistry will be found in circumstances where it is called molecular biology, lunar geology, solid-state physics, and cosmology. For this reason, cooperative programs have been set up between chemistry, biology, and geology. Graduate students in chemistry with reasonable proposals can cross divisional lines to work for non-chemistry faculty.

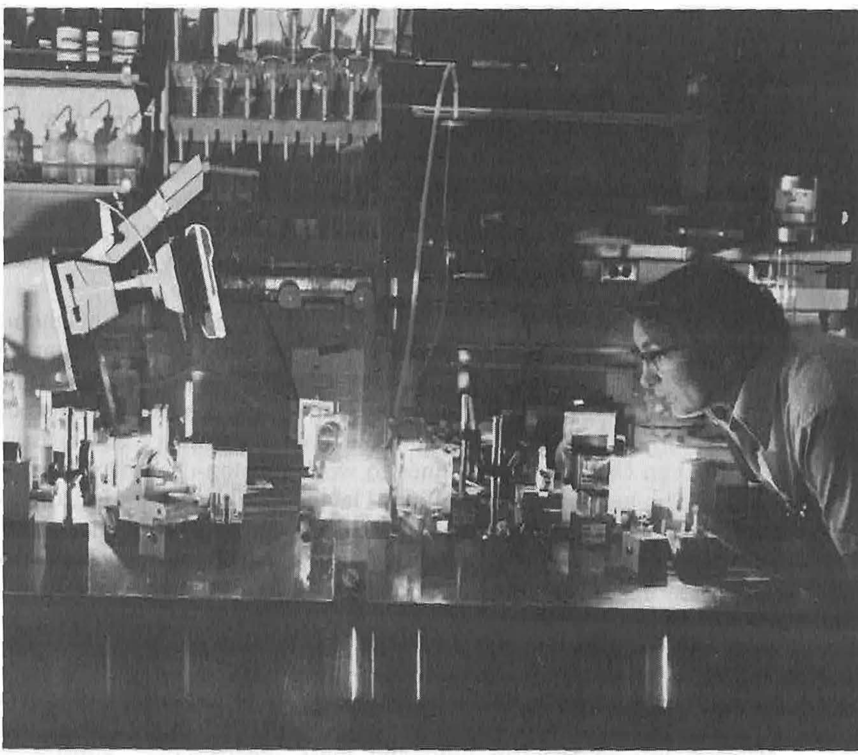
Chemistry also has the responsibility of laying the foundation for tomorrow's advances in other fields. For this reason, we have fundamental research efforts, among others, in synthetic and physical organic chemistry, electronic energy transfer and spectroscopy, and fundamental reaction dynamics.

Areas of Research

1. Structural chemistry, including x-ray diffraction, nuclear magnetic resonance and electron-spin resonance spectroscopy, optical and electron impact spectroscopy, and mass spectroscopy. Substances under study include crystalline enzymes, nucleic acids and nucleo-

tides, intermetallic compounds, inorganic chelates, antibiotics, and liquids.

2. Chemical dynamics, including studies of organic, inorganic, and biochemical reaction mechanisms, the mechanisms of electrochemical and photochemical processes, and molecular beam kinetics.
3. Theoretical chemistry, involving the application of quantum mechanics to the electronic states of molecules and solids, computer experiments in chemical kinetics, and the theory of relaxation processes. The emphasis of the work in molecular quantum mechanics is upon excited states and reactions of molecules.
4. Biochemistry and molecular biology, including studies of oxidative and proteolytic enzymes, the determination of amino acid sequences and three-dimensional structures of proteins, the systematic modification of proteins, the study of nucleic acids by biological, chemical and physico-chemical methods, immunochemistry, and the fundamental processes of photosynthesis.



In a physical chemistry laboratory, pulsed laser techniques are used to follow chemical changes on a picosecond time scale.

5. Synthetic chemistry, with recently increased emphasis on the synthesis of natural products and also including synthesis of theoretically interesting small molecules. In addition, research on the synthesis of new transition-metal and rare-earth complexes is under way.

Physical Facilities

The laboratories of chemistry consist of four units. Crellin Laboratory and an adjoining annex house part or all of six research groups and the divisional administrative offices. The Norman W. Church Laboratory for Chemical Biology is shared with the Division of Biology. The Arthur Amos Noyes Laboratory of Chemical Physics is the largest of the chemical laboratories.

A new temporary building has been constructed for use in undergraduate laboratory instruction. These laboratories provide space for about 225 graduate students and postdoctoral fellows.

CIVIL ENGINEERING

Civil engineering includes the research, development, planning, design, and construction associated with urban development, water and energy supply, waste treatment and disposal, and transportation. It deals with the function and safety of such public facilities as buildings, bridges, pipelines, dams, rivers, power plants, and harbors; and is concerned with the protection of the public against natural hazards of earthquakes, winds, floods, landslides, water waves, and fires.

Advances of recent years in technology and the escalation of urban problems have broadened the applications of civil engineering and increased the scope of research in that field. New problems have presented special challenges to the civil engineer well trained in the fundamentals of his profession. For this reason, in the advanced study of civil engineering at the Institute, emphasis is placed on the application of basic scientific principles and mathematics to the solution of engineering problems.

Areas of Research

Graduate work leading to advanced degrees is chiefly in the following fields: structural engineering and applied mechanics; earthquake engineering; soil mechanics and foundation engineering; hydraulics, which includes hydrodynamics, hydraulic engineering, hydrology and coastal engineering; and environmental engineering (see also Environmental Engineering Science). In recent years, graduate students and members of the staff have pursued a variety of research programs including analysis of structures subjected to earthquakes and other dynamic loadings; the use of digital computers for structural analysis; soil deformation under stress; lunar soils studies; permafrost; investigation of laws of sediment transportation and dispersion in bodies of water; turbulent mixing in density stratified flows;

wave-induced harbor oscillations; tsunamis; design criteria for various hydraulic structures; aerosol filtration; radioactive waste disposal; water reclamation; and ocean outfalls for thermal discharges or sewage effluents.

Students whose interests are in environmental problems may enroll for graduate degrees in either civil engineering or environmental engineering science.

Physical Facilities

Civil engineering activities are housed in two buildings, the Franklin Thomas Laboratory which contains the soil mechanics laboratory, the earthquake engineering laboratory, and an analog computer laboratory, and the W. M. Keck Engineering Laboratories which contain the laboratory of hydraulics and water resources and the environmental engineering laboratory.

Excellent digital computing facilities are housed in the Booth Computing Center.

ELECTRICAL ENGINEERING

Electrical engineering at the Institute comprises the dynamic field of physical electronics and electronic circuits. Closely allied with the applied physics option, it offers students the opportunity for study in the more technological aspects of a wide variety of subjects including plasma dynamics, electromagnetic radiation, quantum electronics, modern optics, new solid-state materials and devices. This broad spectrum of subjects complementing the program in electronic circuits and circuits function design provides exceptional and challenging opportunities for both theoretical and experimental work.

Areas of Research and Physical Facilities

Laboratory facilities are available for a wide variety of research activities. At present electrical engineering activities are housed mainly in one building, the Harry G. Steele Laboratory of Electrical Sciences. This is a modern, 55,000-square-foot laboratory building designed specifically for the research needs of the electrical engineering faculty and students.

Research in the Solid-State Electronics Laboratories extends over a variety of subjects. The transport of charge carried in semiconductors is studied by experiments on single injection, double injection, Hall effect and noise, with particular attention given to very high purity germanium and silicon. Another field of study is the formation of contacts to semiconductors. When viewed by electron microscope and electron microprobe, contact formation can often be seen to involve solid-phase crystal growth and/or junction formation. Closely related to this effort are investigations on the metallurgy of thin evaporated layers, using conventional tools and experimentation as well as ion implantation and ion backscattering. The properties, limitations, and ranges of application of these two techniques are the subject of additional investigations performed in part at the 3 MeV van de Graaff accelerator in the Kellogg Radiation Laboratory.

The Quantum Electronics Laboratory is engaged in research in the area of generation and control of coherent radiation and in the study of related physical phenomena. Research projects now in progress include: superradiance in extremely high gain lasers, generation and control of ultrashort pulses, tunable optical parametric oscillation, integrated optical circuits, injection lasers, nonlinear optics, infrared fluorescence applied to pollution monitoring, speckle, optical data processing, pattern recognition, and holography. Up-to-date facilities for carrying out these experiments are available.

Research in the Magnetics Laboratory centers around the investigation of ferromagnetic anisotropy and flux reversal, the two effects which are the basis of modern digital magnetic devices. Anisotropy studies in thin films of nickel, iron, cobalt, and gadolinium alloys are concerned with both field-induced and magneto-crystalline anisotropy, with a goal of understanding both the origin and consequences of the anisotropy. Studies of the flux-reversal mechanism in films and toroids and ferromagnetic resonance experiments are used to investigate the loss mechanism in ferromagnetically ordered atomic structures.

The Plasma Laboratory is involved in studying wave phenomena in plasmas and methods of producing laboratory plasmas. Facilities are available for the generation and diagnosis of a variety of plasmas. Current studies involve theoretical and experimental investigations of microwave radiation from plasmas, echoes in plasmas, and wave propagation.

The Antenna Laboratory is a center for the mathematical study of problems in electromagnetic theory. Its activities include problems in antenna theory, scattering theory, the propagation of waves in continuous moving media, boundary-value theory for moving boundaries, shielding theory, and problems in cosmical electrodynamics.

The Electronic Circuits Laboratory deals with modern problems in analysis, design, and synthesis of electronic circuits. Applications of new and current devices and analysis techniques for a better understanding of existing devices are emphasized. Facilities are available for experimental confirmation of theoretical results over a wide frequency range. Projects now in progress include analysis and design of multiple-loop feedback systems, and optimization of pulse-width controlled regulators.

The Communication Laboratory conducts experimental and theoretical work in a wide range of communication problems, including communication systems, information theory, noise and modulation problems, data communication, optical communication, and other areas.

ENGINEERING SCIENCE

Advanced programs of study leading to the degree of Master of Science and Doctor of Philosophy in Engineering Science are offered by the Division of Engineering and Applied Science. The need for these programs has developed as the traditional barriers between engineering and what was once called "pure science" have disappeared. Engineers are quick to learn of new research in plasma dynamics or the kinetic theory of gases, while designers of nuclear reactors may find it worthwhile to look into the distribution of nuclear energy levels, the theory of dynamical stability, or the motion of charged particles in solids. In the past these subjects lay exclusively in the domain of university departments of physics and mathematics.

Areas of Research

The study program of the engineering science student at Caltech emphasizes physics, applied mathematics, and those scientific disciplines which underlie the current development of technology. Its scope contains a broad range of subjects. Fields of study may include such topics as fluid mechanics with applications to geophysical and biomechanical problems, physics of fluids, structure and properties of solids, dynamics of deformable solids, rheology of biological fluids, plasma physics, the physics underlying nuclear reactors, fission and fusion engineering.

BIOLOGICAL ENGINEERING SCIENCES

Graduate study and research in areas involving the application of the engineering sciences to problems of health and biology are of continually increasing importance at the California Institute of Technology.

Areas of Research and Physical Facilities

The primary areas of interest at present are in the fields of biosystems, environmental health engineering, transport processes, and circulatory dynamics and hydromechanics of exterior and interior flows involving protozoa and bacteria. Close cooperation exists among the different groups, and joint seminars are held frequently.

Environmental Health Engineering. The environmental health group is concerned with the protection and control of our air environment and water supplies, now under increasing strain because of population growth and industrial expansion. Several of the research projects under way in this program have significant biological components.

Biomedical Transport Processes. Research in this field in chemical engineering and environmental engineering science has application to the design of artificial organs and to other problems involving the handling of biological fluids, and to certain aspects of respiratory physiology. A recent study of gas exchange with flowing blood has immediate application to the design of membrane oxygenators (artificial lungs) employed in heart surgery. Other studies have been initiated on the development of mathematical models for the prediction of particle and gas transport in the lungs. A collaborative effort between the chemical engineering group and local medical institutions on some aspects of the design of the artificial kidney is also under way. Blood gas instruments are available as well as the other facilities of the Environmental Health Engineering Laboratory.

BIOLOGICAL FLUID MECHANICS

Circulatory Dynamics. Studies on the effects of the rheological properties of blood and the vascular structures on flow, particularly in the microcirculation and the relationship of the flow pattern to the dynamics of gas and metabolite exchange, are being carried on in collaboration with the L. A. County Heart Association-University of Southern California Cardiovascular Research Laboratory. Research is in progress at Caltech on the flow of blood in tubes of diameters in the size range of interest in microcirculatory studies (5 to 200 micra) and in living microbeds in small animals.

The Hemorheology and Microcirculation Laboratory, located in the sub-basement of the Thomas Engineering Laboratories, is equipped with an unusually versatile precision animal table and intravital microscope system for quantitative measurements in living microbeds of velocity, vessel dimensions, and pressure drop and transmural exchange, particularly of the micromolecular components of blood plasma. Additional facilities for still and cine photomicrography permit the study of blood rheology in flow in small tubes. Methods have also been developed for measuring the mechanical response of biological tissues and of small blood vessels.

Micro-Organism. Graduate studies and research are being actively developed in the subject of locomotion of micro-organisms, involving the flagellated propulsion, swimming of ciliates, spirilla and spirochaetes, geotaxis and phototaxis phenomena, bioconvections in cell suspensions, as well as other fluid physical phenomena within cells, such as protoplasmic and cytoplasmic streamings. The research interests in this program also extend to cover the swimming of fish and cetaceans, and flapping flights of birds and insects.

In the fluid mechanical area, the basic research program emphasizes the development of effective methods for solving flow problems at low Reynolds numbers as well as problems at high Reynolds numbers arising from unsteady lifting surfaces. These studies are pursued in collaboration with physiologists.

ENVIRONMENTAL ENGINEERING SCIENCE

This interdisciplinary graduate program is concerned with the protection and control of man's environment; historically, it has grown from activities in air and water pollution control which have been in existence at Caltech for many years.

Research and education in the environmental field stress basic studies which can help answer such questions as: How can we improve the quality of the air in the great basin areas in which lie our urban and industrial centers? How can we insure the availability of water of adequate quality and quantity for population centers and industry? How can we protect our offshore waters from pollution? How can thermal pollution from power plants be controlled? How does a polluted environment affect man's health? How does society make decisions about environmental control measures, and allocate the costs?

The academic disciplines of importance include the chemistry of natural waters and of the atmosphere; the physics and physical chemistry of disperse systems; biological fluid mechanics; biomedical transport processes; marine biology and ecology; fluid mechanics of the natural environment; hydrology; sedimentation and erosion; the theory and design of complex environmental control systems; combustion; environmental modeling and information systems; and environmental economics. Courses in these fields are offered in the environmental engineering science program and in other departments of the Institute.

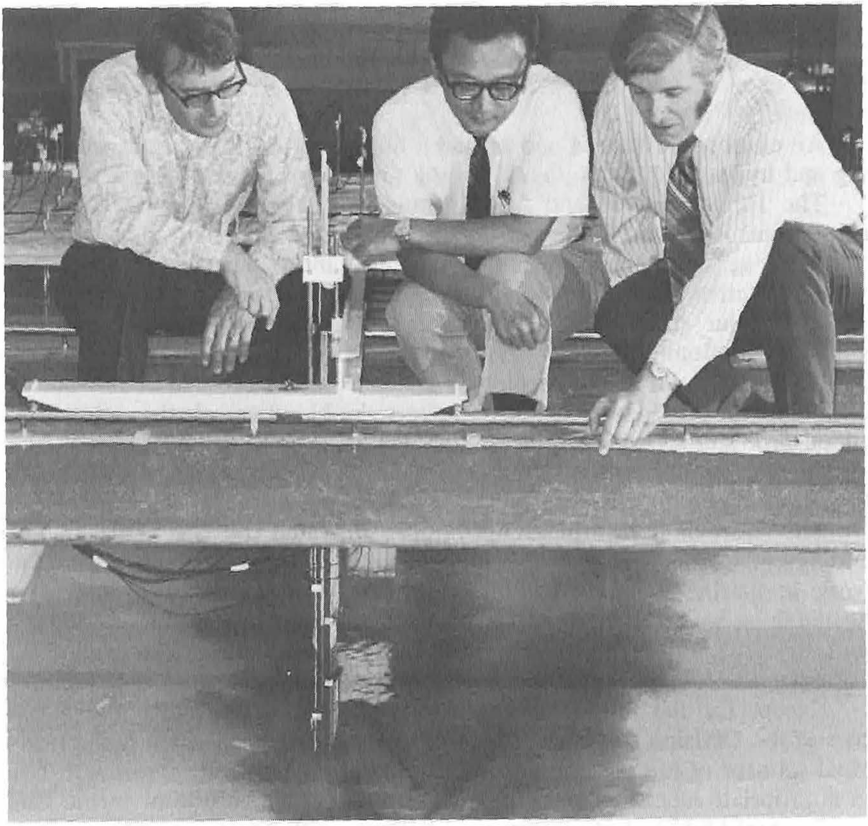
The majority of the faculty members in this interdisciplinary program are from the Division of Engineering and Applied Science. There is also participation from the Divisions of Chemistry and Chemical Engineering, the Humanities and Social Sciences, Geological and Planetary Sciences, and Biology.

Areas of Research

Examples of recent and current research are: the flow of trace metals through urban basin environments; the search for causes of urban basin hazes; regional studies on the fate of pollutants; chemical speciation of metals in wastewaters and ocean waters; dispersion of contaminants in rivers and estuaries; mixing of buoyant jets in lakes and oceans; thermal pollution control; generation and propagation of tsunamis; the effects of pollution on the ecology of nearshore waters; kelp restoration; the development of economic methods for wastewater reclamation; the investigation of the interaction of beams of small particles with surfaces at reduced pressures; particle deposition in lung models; gas exchange with blood; rheology of blood in small tubes and microcirculation; low-pollution vehicles; and power-plant siting.

Physical Facilities

The facilities in the W. M. Keck Laboratory of Environmental Health Engineering include some of the modern instrumentation used in the air and water pollution analyses. The air pollution and aerosol physics laboratory is equipped with a computer-interfaced aerosol size distribution measuring system consisting of optical single-particle counters, multichannel analyzer, a condensation nuclei counter, quartz crystal aerosol mass monitor and various aerosol generators. For gas-phase chemical analyses a sulphur-dioxide monitor and chemiluminescence ozone and nitrogen oxide monitors are available, as well as gas chromatographic equipment for organic anal-



Hydraulic engineers in the Keck Laboratory of Hydraulics and Water Resources use dynamic modeling to predict the performance of thermal outfall systems to be built for a coastal nuclear power plant.

ysis. For water chemistry studies a well-equipped chemical instrumentation laboratory is maintained with facilities for tracer studies including an atomic absorption spectrometer, total carbon analyzer, fluorometer, anodic stripping apparatus, a liquid scintillation detector and a portable water-quality monitor. Also available is a Coulter particle-size analyzer and an ultracentrifuge. Facilities for the microbiological work include incubators, constant-temperature rooms, autoclave, microscopes, and accessory equipment. A Zeiss electron microscope with x-ray diffraction attachment and associated equipment for sample preparation is available for air and water pollution and microbiological studies.

The W. M. Keck Laboratory of Hydraulics and Water Resources is well equipped for research into a wide variety of fluid flows which are important in environmental control. The facilities include large flumes for studies in diffusion, turbulence, sediment transport, and stratified flow; a wave tank and wave basin; a water tunnel; and specialized instrumentation, such as a laser-doppler velocimeter and a digital data-processing system to record experimental analog data directly on digital tapes for high-speed computing.

An excellent reference and research library for environmental engineering and hydraulics is maintained on the first floor of the Keck Laboratory.

The Hemorheology and Microcirculation Laboratory, located in the sub-basement of the Thomas Engineering Laboratories, is equipped with an unusually versatile precision animal table and intravital microscope system for quantitative measurements of velocity, vessel dimensions, pressure drop and molecular exchange in living microbeds. Additional facilities for still and cine photomicrography and high sensitivity closed-circuit television permit the study of blood rheology flow and the time-course of movement of fluorescent tagged macromolecules from the blood vessels through tissue. Blood-flow studies with larger animals are done in collaboration with the Cardiovascular Laboratory located at the L.A. County-USC Medical Center, about nine miles from Caltech.

The Kerckhoff Marine Laboratory, operated by the Division of Biology at Corona del Mar (50 miles from Pasadena), is the base for the work in marine ecology. Running seawater with temperature control is available, as well as diving vessels, scuba gear, workshop, darkroom, aquarium, dry labs, and a small library and reference collection. The marine laboratory has four apartments for visiting researchers.

Except for the marine laboratory, the facilities described above are part of the Division of Engineering and Applied Science, which is the principal sponsor of the program. Students may also elect to do thesis research in appropriate laboratories in other divisions of the Institute or in the Environmental Quality Laboratory (see below), with professors who participate in this interdisciplinary program.

ENVIRONMENTAL QUALITY LABORATORY

The Environmental Quality Laboratory (EQL), organized by Caltech with the cooperation of the Jet Propulsion Laboratory (JPL), the Rand Corporation, and the Aerospace Corporation, was created to deal with broad, strategic questions of environmental control. EQL consists of a small, informally organized group of strongly interacting faculty and staff members of Caltech, JPL, Rand, and Aerospace Corporation from various disciplines, including engineers, natural and social scientists, lawyers, and systems analysts, plus several undergraduate and graduate students and postdoctoral fellows from Caltech.

The charter of the EQL is defined broadly enough to encompass six closely related activities:

(1) development of a conceptual framework for dealing with large-scale environmental problems, emphasizing the relationship between en-

vironmental quality and the quality of life (including people's freedom of choice);

(2) development of a long-range strategy for environmental control, including the following elements:
   (a) analysis of trends in environmental problems incorporating flexible planning to cope with uncertainties about the future, and providing for continuous feedback from the changing environment in order to adjust to new information as much as possible;
   (b) combinations of incentives and regulations that will help industry to develop the least costly (or most efficient) pollution abatement and materials-recycling technologies;
   (c) encouragement of consumption and growth patterns that put the least pressure on the environment in critical areas;
   (d) extending to problems of environmental quality the notion of shared risks, responsibilities, costs, and benefits among different groups.

(3) application of the general principles and methods developed in (1) and (2) to a few specific, long-range problem areas; for example, (a) energy use and thermal power plant siting; (b) economics of air pollution control in the Los Angeles Basin;

(4) involvement of undergraduate and graduate students and postdoctoral fellows in the work of the EQL in order to develop professional people who understand how to employ both technical and non-technical disciplines in the solution of large-scale environmental problems;

(5) development of effective lines of communication between the EQL and environmental decision makers in business, industry, and government;

(6) utilization of the considerable human and technical resources of the Caltech campus, the Jet Propulsion Laboratory, the Rand Corporation, and the Aerospace Corporation in the work of the EQL and in a few, carefully selected demonstration projects that grow out of this work.

Faculty and students who participate in EQL activities are associated with one of the divisions of the Institute, so that students who desire to work in EQL apply through an appropriate degree program, such as Environmental Engineering Science or Social Science.

GEOLOGICAL AND PLANETARY SCIENCES

In the Division of Geological and Planetary Sciences, study of the earth and planets is pursued with the aim of understanding their origin, constitution, and development, and the impact of the resulting physical and chemical environments on the history of life, and on man. The approach to these problems is made with strong reliance on the basic sciences; close contact and interaction with the other divisions of the Institute is cultivated. Programs of study and research are pursued in geology, geobiology, geochemistry, geophysics, and planetary science.

The geographical position and geologic setting of the Institute are favorable for year-round field access to a wide variety of earth problems and materials. Current advances in understanding the dynamic motions of the earth's crust and the structure of the interior have opened up new opportunities for research into the processes responsible for the earth's development and activity. Seismic activity in the southern California area presents stimulus and research material for the study of earthquakes, which are of great practical concern and are intimately related to the earth's development on a global scale. Human records of seismic activity are put into long-term perspective by studies of surface and bedrock geology, which reveal the history of motion on fault systems. Major events in the chemical and physical evolution of the earth can be identified by studying the structure and chemistry of rocks formed or modified in these events, and their absolute chronology can be established by measurements of radioactive isotopes. Stable isotopes can indicate the temperature conditions both of deep-seated events and of the habitat of ancient life, whose chemical and structural evolution responded to the changing environment provided by the developing earth. The earliest history of the earth can be approached via the history of the moon, which is being revealed by studies of lunar samples obtained in the Apollo missions. Further breadth in our understanding of the earth and its place in the cosmos is being gained by comparative study of the other planets – their atmospheres, surfaces, and internal structures.

Physical Facilities

The Arms and Mudd Laboratories are modern, five-story buildings specifically designed for instruction and laboratory research in geology and geochemistry. They also house the division library; paleontologic, rock, and mineral collections; a laboratory for planetary studies; spectrographic, x-ray diffraction and x-ray fluorescent equipment; wet chemical laboratories; an electron microprobe facility; and facilities for rock and mineral analysis, thin- and polished-section work, and other requirements for comprehensive studies in the earth sciences.

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

Extensive facilities are available for the application of techniques of nuclear chemistry to problems in the earth sciences. These facilities include chemical laboratories for trace-element studies and mass spectrometric and counting facilities for isotopic work. Available equipment includes mass spectrometers, emission counters, and extensive mineral separation facilities, in addition to the usual geological and chemical items.

Favorable opportunity for study of dynamic aspects of paleontology and evolution as revealed by morphology, ecology, and biogeochemistry is provided by the combination of personnel, reference collections, and modern geochemical tools and techniques. Biologic principles and processes, past and present, of significance to geology may be interpreted from experimentation and studies at the Kerckhoff Marine Laboratory at Corona del Mar, operated under the auspices of the Division of Biology.

The Seismological Laboratory of the Institute, with ample space and excellent facilities, including computers and extensive shops in the Donnelley and Kresge laboratories, is located about three miles west of the campus on crystalline bedrock affording firm foundation for the instrument piers and tunnels. The central laboratory together with a dozen portable and seventeen permanent outlying auxiliary stations in southern California – built and maintained with the aid of cooperating companies and organizations – constitute an outstanding center for education and research in seismology. In addition, special facilities are available at the Seismological Laboratory for both the study of heat flow in geological materials and the behavior of rocks and minerals in the pressure and temperature

Caltech geologists collect samples in the Grand Canyon.

environments of planetary interiors. These facilities include laboratories for performing ultrasonic and Brillouin scattering measurements of elastic constants of rocks and minerals at high pressures and temperatures. Ultra-high-pressure equations of state and shock effects in minerals are being studied in a shock-wave laboratory.

The Seeley G. Mudd Building of Geophysics and Planetary Science is under construction on the campus adjacent to the Arms and Mudd Laboratories. It will provide additional research and teaching facilities for seismology, experimental geophysics, and planetary science.

Optical and infrared observations of the moon and planets are being carried out at the Hale Observatories; special, moderate-sized telescopes designed specifically for planetary work are available. A wealth of photographic information on the surface of Mars is available from the Mariner flyby and orbiter missions. Radio and radar observations of the planets are made at the Owens Valley Radio Observatory and the JPL radar facility.

THE HUMANITIES AND SOCIAL SCIENCES

Throughout its history the Institute has placed a strong emphasis upon the humanities as an important and necessary part of the education of scientists and engineers. In recent years increased attention has been paid to the social sciences. At the undergraduate level all students are required to devote a substantial portion (between one-fifth and one-fourth) of their curriculum to humanistic and social science studies. These studies are normally undertaken in regular courses, but a limited number of interested students may be permitted after their freshman year to enter a tutorial program involving instruction on a one-to-one basis. At the graduate level, the Division of the Humanities and Social Sciences offers a Ph.D. and M.S. program in social science. Humanities courses are required for the Master of Science degree in civil engineering and astronomy, and are recommended in other options. At the doctoral level, a Ph.D. minor may be taken in economics, philosophy, history, or English, with a Ph.D. major in any branch of science or engineering.

Since the academic year 1965-66, the Institute has offered undergraduate options in English, history, economics, and social science leading to the B.S. degree. Students electing one of these options will take the regular courses prescribed for all freshmen in their first year and the required courses in mathematics and physics in the sophomore year. In the last two years, students in these options will take further work in science, mathematics, or engineering courses as well as the advanced work in their humanities or social science option. The purpose of the humanities and social science options at Caltech is to produce a special kind of student – one who has an exceptionally strong background in science or engineering, yet who is well prepared for graduate work in humanities and social science, professional schools, business, or government service.

Dabney Hall of the Humanities was given to the Institute in 1928 by Mr. and Mrs. Joseph B. Dabney. At the same time a special fund of $400,-000 for the support of instruction in humanistic fields was subscribed by several friends of the Institute. In 1937 Mr. Edward S. Harkness gave the Institute an additional endowment of $750,000 for the same purpose.

In April 1971, the division moved most of its activities to the Donald E. Baxter, M.D., Hall of the Humanities and Social Sciences, a gift of Mrs. Donald E. Baxter.

The proximity of the Henry E. Huntington Library and Art Gallery, one of the great research libraries in the world, offers rich opportunities for the humanities staff, especially in history and literature, and a close but informal relationship is maintained between the Institute and visiting scholars at the Library.

INDEPENDENT STUDIES PROGRAM

An Independent Studies Program will be offered as an option during the 1973-74 academic year. The course is intended to accommodate individual programs of study or special research that fall outside ordinary course offerings.

(For complete description see page 215)

MATERIALS SCIENCE

The field of materials science is concerned with the properties and behavior of materials of every kind. This field at the California Institute of Technology is largely restricted to metallic and polymer materials, essentially in the solid state. Faculty specifically in the field of materials science are concerned with the mechanical, physical, and chemical properties of solids. Some members of the faculty in electrical engineering are concerned with the behavior of electric and magnetic materials. Work in the general fields of polymers is carried on by faculty in chemical engineering and aeronautics.

Areas of Research

Current areas of research by the faculty and graduate students in materials science include:

A. Mechanical Properties
   1. Dislocation dynamics
   2. Theoretical and experimental deformation studies
   3. Behavior of metals under dynamic loading
   4. Fracture mechanics

B. Physical Properties
   1. Magnetic properties
   2. Electrical properties
   3. Electron transport properties
   4. Radiation effects

C. Chemical Properties
   1. Kinetics of phase transformations
   2. Diffusion in solids
   3. Metastable phases
   4. Catalysis on metal surfaces
   5. Corrosion

D. Structure
   1. Theoretical and experimental transmission electron microscopy and diffraction studies of crystal defects and alloy phases
   2. Direct crystal lattice resolution by transmission electron microscopy
   3. X-ray studies of crystal defects and alloy phases.

Research Facilities

Research by the faculty and graduate students in materials science is conducted in the W. M. Keck Laboratory of Engineering Materials. Facilities are provided for crystal growth and alloy preparation, strain-free machining, annealing with atmosphere control, rapid quenching, optical metallography, x-ray diffraction, electron microscopy (including modifications for direct lattice resolution), and systems to control the application of stress (from load pulses of a few microseconds duration to static loading). Specialized equipment is available for measuring low- and high-temperature specific heat, thermoelectric power, superconductivity, magnetic susceptibility, ferromagnetic resonance, Mössbauer effect, and mechanical properties. Computing facilities are available in the Computing Center as well as by remote console in the laboratories.

Other facilities in the field of materials science are available in the Spalding Laboratory of Engineering, the Firestone Flight Sciences Laboratory, and the Steele Laboratory of Electrical Sciences.

MATHEMATICS

"'Mathematics is Queen of the Sciences and Arithmetic the Queen of Mathematics. She often condescends to render service to astronomy and other natural sciences, but under all circumstances the first place is her due.'

"So said the master mathematician, astronomer, and physicist K. F. Gauss (1777-1855). Whether as history or prophecy, Gauss's declaration is far from an overstatement. Time after time in the nineteenth and twentieth centuries, major scientific theories have come into being only because the very ideas in terms of which the theories have meaning were created by mathematicians years, or decades, or even centuries before anyone foresaw possible applications to science." (from *Mathematics, Queen and Servant of Science* by E. T. Bell)

The development of mathematics at the Institute has been significantly influenced by two outstanding mathematicians, Eric Temple Bell and Harry Bateman, who were appointed to the staff shortly after the institution became known as the California Institute of Technology. Both of these men made major contributions to their respective fields of interest: Bell to algebra and number theory, Bateman to analysis and applied mathematics; yet both had a profound and lasting interest in the development of mathematics as a whole and in the interplay between mathematics and the sciences. Through the years the mathematics program at Caltech has reflected the dual philosophies of these two mathematicians.

Today mathematics is a rapidly developing and expanding field whose range of application is continually extending into new areas of knowledge. Subject areas such as algebraic topology which were relatively unknown a few decades ago have become major research areas in mathematics. New developments, such as that of the modern computer, have given rise to new and flourishing mathematical disciplines such as theory of algorithms, recursive function theory, and modern numerical analysis. Older areas of mathematics have been revitalized and significantly advanced through the use of concepts and techniques from more recent mathematical fields. One may say that most of the current research in mathematics is characterized by the development of powerful abstract methods which are applicable to broad areas of mathematics and its applications.

Areas of Research

Areas of current research interest of the mathematics faculty include the following: algebraic number fields; analytic number theory; approximation theory; combinatorial theory; complex function theory; finite group theory; fixed point and coincidence theory; harmonic analysis; universal algebra; lattice theory; matrix theory; measure and integration theory; interpolation theory; non-standard analysis and model theory; infinitary logic and admissable sets; number theory in orders; numerical analysis; operator theory; Banach algebras; partial differential equations and pseudo-differential operators; ordinary differential equations on manifolds; mathematical statistics.

Physical Facilities

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

The Willis H. Booth Computing Center central computing facility described on page 117 serves the entire campus. Students are encouraged to use the computer as a research tool; a remote console is located in Sloan Laboratory.

MECHANICAL ENGINEERING

The way in which the term "mechanical engineering" is being used today embraces essentially all of those engineering aspects of a project which have to do with fluid flow, heat and mass transport, combustion, power, propulsion, structural integrity, mechanical design, optimization, and systems analysis. Projects in which mechanical engineers play a large role include the space missions, nuclear and fossil-fuel power plants, transportation systems, airplane propulsion engines, and low-pollution vehicles. At the Institute, many of the basic disciplines are offered which are required for applications such as the above. They are described in the following paragraphs under the headings of Design, Mechanics, Thermal and Fluids Engineering, Nuclear Energy, and Jet Propulsion.

DESIGN

Engineering design is regarded as an interdisciplinary activity providing an opportunity for putting theory into practice and bringing together on a common ground some of the more specialized branches of engineering. It serves to emphasize the importance of a sound, broad, theoretical background and its relevance to actual engineering practice. Emphasis is placed on the imaginative practical approach in the solution of real problems involving various disciplines. The human, sociological, and economic aspects as related to a particular design project are carefully considered in their proper perspective. System design in the broad sense, automatic control, problem modeling, and the appropriate use of analog and digital techniques in optimization are general areas of interest. Projects have included the design and development of apparatus for scientific investigation in different areas of research such as earthquake engineering, hydraulics, heat transfer, etc. Faculty members from other disciplines are invited to participate in the design activity offering specific design problems involved in their current investigations. A close relationship with those working in the design area at the Jet Propulsion Laboratory, as well as those in industry, is maintained through seminars, visits, and a free exchange of ideas on current design problems.

MECHANICS

Studies in the broad field of mechanics may be undertaken in either the Applied Mechanics option or the Mechanical Engineering option. In general, work pursued within the Mechanical Engineering option will have a more physical orientation. The specific areas available for advanced study closely parallel the research interests of the faculty and presently include: linear and nonlinear problems in static and dynamic elasticity, plasticity and viscoelasticity, wave propagation in solids, load transfer problems, modeling of dynamic systems, linear and nonlinear vibrations, random vibrations, stability, structural dynamics, and design for earthquake loads.

Physical Facilities

The *Dynamics and Vibrations Laboratories* provide for the study of a wide range of problems relating to the dynamics of mechanical systems. These two laboratories contain a variety of specialized equipment including: electrodynamic shakers, shock generators, optical followers, and various electromechanical transducers.

The *Analog Computer Laboratory* is equipped with specially designed equipment for the direct simulation and analysis of both linear and nonlinear systems, with stochastic as well as deterministic excitation. Input-output systems are available for various types of signal analysis.

The *Earthquake Engineering Research Laboratory* contains specialized recording and data processing equipment for the study of complex transient loading problems. This equipment has been used extensively in the analysis of strong-motion earthquakes.

THERMAL AND FLUIDS ENGINEERING

Instruction and research are offered in these fields of mechanical engineering. Typical areas of research include free and forced convection heat transfer, friction and heat transfer in dilute polymer solutions, granular media, fluids near the critical point and other unusual media, cavitation, fluid machines, and some related areas of hydrodynamics.

Physical Facilities

Several facilities are available for heat transfer studies, including free convection equipment, a forced convection loop, a blowdown facility for polymer solutions, and a liquid carbon dioxide heat transfer facility. An internal combustion engine laboratory, containing a variable compression fuel research engine, together with a conventional automotive engine dynamometer, is also available. In addition, hydrodynamic research facilities of the division are available for work in this field. These include the low-speed flumes of the Keck Laboratory and the two water tunnels of the Karman Laboratory. The latter are particularly useful for studies of cavitation, ventilation, steady and nonsteady characteristics of hydrofoils, planing surfaces, and flow visualization.

NUCLEAR ENERGY

Opportunities for study and research in nuclear energy are available in mechanical engineering, engineering science, and applied physics. The central area of interest involves the solutions of those problems arising from the unique nature of nuclear energy. Thus, the program specializes in reactor physics – the study of the behavior of neutrons in nuclear reactors. The program is essentially that of applied physics rather than engineering. Undergraduate preparation should include a good background in mathematics and, if possible, a course in modern physics. Nuclear specialization at the undergraduate level is not required.

JET PROPULSION

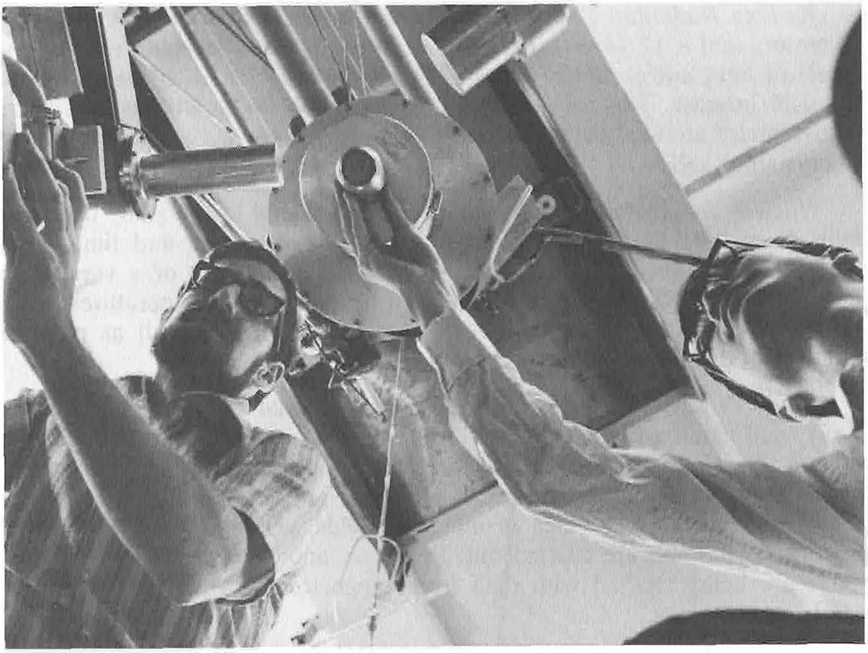
The Daniel and Florence Guggenheim Jet Propulsion Center was established at the California Institute of Technology in 1948. This center was created specifically to provide facilities for postgraduate education and research in jet propulsion and rocket engineering, with particular emphasis on peacetime uses: to provide training in jet propulsion principles, to promote research and advanced thinking on rocket and jet propulsion problems, and to be a center for peacetime commercial and scientific uses of rockets and jet propulsion. The Guggenheim Jet Propulsion Center is a part of the Division of Engineering and Applied Science. All instruction in the Guggenheim Center is on the graduate level. Students wishing to pursue courses of study and research in jet propulsion take degrees in aeronautics or mechanical engineering.

The solution of the engineering problems in jet propulsion requires new techniques as well as drawing on the knowledge and practice of the older branches of engineering, in particular, mechanical engineering and aeronautics. Thus, it is appropriate that the program of instruction includes material from both of these engineering fields. In general, students entering the course work in jet propulsion will have had their undergraduate preparation in mechanical engineering or aeronautics, but the courses are also available to students whose preparation has been in applied mechanics, engineering science, or physics.

Areas of Research and Physical Facilities

The experimental facilities of the Jet Propulsion Center are located in a gasdynamics laboratory and a combustion laboratory, housed in the Karman Laboratory of Fluid Mechanics and Jet Propulsion, and an acoustics laboratory housed in the Guggenheim Aeronautical Laboratory. Specialized equipment includes special-purpose wind tunnels, a shock tube for reaction-rate studies, a convective-flow facility for fire research, and an acoustic-flow facility with an echoic chamber. Certain facilities of the Jet Propulsion Laboratory may also be utilized under special arrangement.

Some of the research topics currently under investigation are: the aerodynamics of turbomachine components in air-breathing engines, the combustion instability of rocket motors, the mechanics of multi-phase flow in propulsion systems, and acoustical problems and noise reduction of jet engines.



Caltech physicists set up a supercold "dilution refrigerator" in the nuclear spectroscopy laboratory.

PHYSICS

Areas of Research

Graduate students in physics will find opportunities for research in the following areas where members of the staff are currently active.

High-Energy Physics: An active group performs various types of elementary particle experiments at the major accelerator centers, with the focus shifting strongly toward the new National Accelerator Laboratory. Experiments on neutrino interactions, charge-exchange scattering, and quasi-two-body reactions are presently being prepared and carried out at NAL. The group has been involved in the design and use of large-magnet spectrometer systems, and is presently involved in hybrid experiments which combine bubble chamber and counter techniques. A phenomenology group is studying the systematics of elementary particle reactions and their theoretical interpretation.

Kellogg Radiation Laboratory: Three conventional Van de Graaff accelerators and a 12 MeV tandem accelerator are used to study the energy levels of light nuclei and to measure cross sections for reactions of astrophysical interest. The accelerators are also used for atomic studies with high-velocity atomic beams and channeling investigations of the properties of crystalline solids.

Nuclear Spectroscopy: This laboratory is engaged in the study of problems in nuclear and atomic structure. Tests of the space and time symmetries of the nuclear forces are conducted with the use of a variety of techniques, including nuclear orientation at cryogenic temperatures. Nuclear charge distributions are investigated in ordinary as well as muonic atoms with the aid of bent crystal x-ray spectrometers.

Space Physics: There is an active observational program in infrared, x-ray, and gamma-ray astronomy. The astrophysical aspects of cosmic radiation are investigated with detectors flown in balloons and in spacecraft, and a variety of related theoretical problems are being studied. Observational and theoretical studies of magnetic fields, velocity fields, and active regions on the sun are carried out. Planetary and interplanetary magnetic fields are being studied with data from magnetometers carried by spacecraft.

Low Temperature: Cryogenic techniques form the basis for studies ranging from investigations of the fundamental nature of superfluidity and examinations of two-dimensional systems to the development of unique electronic systems from quantum superconductivity.

Radio Astronomy: One 40-meter and two 30-meter antennas are used either individually or in various interferometric combinations to investigate the properties of galactic and extragalactic radio sources, of the planets, and of gas clouds in the interstellar medium. Receiving equipment includes multiple narrow-band correlators for interferometric spectrometry, an autocorrelation spectrograph, and a recording terminal for very-long-baseline interferometry.

Theoretical Physics: The principal areas under theoretical investigation are the nature of elementary particles and their high-energy interactions, various problems in the area of general relativity and cosmology, the physics of the interplanetary and interstellar media, the origin and transport of cosmic rays, problems of stellar structure and stellar evolution, the synthesis of elements in stars, and the nature of quasi-stellar radio sources and pulsars.

Physical Facilities

The physics department is housed in six buildings grouped together on the south side of the campus: Norman Bridge Laboratory, Alfred P. Sloan Laboratory of Mathematics and Physics, W. K. Kellogg Radiation Laboratory, George W. Downs Laboratory of Physics, C. C. Lauritsen Laboratory of High Energy Physics, and the Synchrotron Laboratory. Members of the staff also carry out research with the Mt. Wilson and Palomar Mountain facilities of the Hale Observatories, and at the Owens Valley Radio Observatory.

UNDERGRADUATE RESEARCH

Each division offers the opportunity for qualified students early in their careers to engage in research under the supervision of a faculty member. Most options offer undergraduate research courses in order to encourage participation in research, and students should consult listings and descriptions of research opportunities given by the various options. Students should be encouraged to undertake research of such scope and caliber as to merit the preparation of a Bachelor's Thesis. In most cases, a minimum of 54 units, distributed over at least four terms, counting the summer months as a term, should be required of students preparing a Bachelor's Thesis. With the approval of the faculty, graduation "with honor" may be granted a student on the basis of a meritorious Bachelor's Thesis or its equivalent.

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 Lloyd, Page, and Ruddock. Each of the seven is a separate unit with its own dining room and lounge, providing accommodations for about seventy-five students.

Each house has its own elective officers, and has wide power to arrange its own social events and preserve its own traditions. The immediate supervision of the activities of each house is the responsibility of the house Resident Associate, generally a graduate student or younger faculty member. All houses are under the general supervision and control of a member of the faculty known as the Master of Student Houses.

Mail is delivered daily to the student houses except on Sunday. Students living in student houses should use their house name and mail code, California Institute of Technology, Pasadena, Calif. 91109, to facilitate the handling of their mail at the campus post office.

Since the demand for rooms may exceed the supply, newly entering students are advised to file room applications with the Master of Student Houses immediately upon being notified by the Director of Admissions of admittance to the Institute.

Interhouse Activities. There is representation of each of the undergraduate houses on the Interhouse Committee, which determines matters of general policy for all seven houses. While each sponsors independent activities, there is at least one joint dance held each year. The program of intramural sports is also carried on jointly. At present it includes football, softball, swimming, basketball, tennis, track, and volleyball.

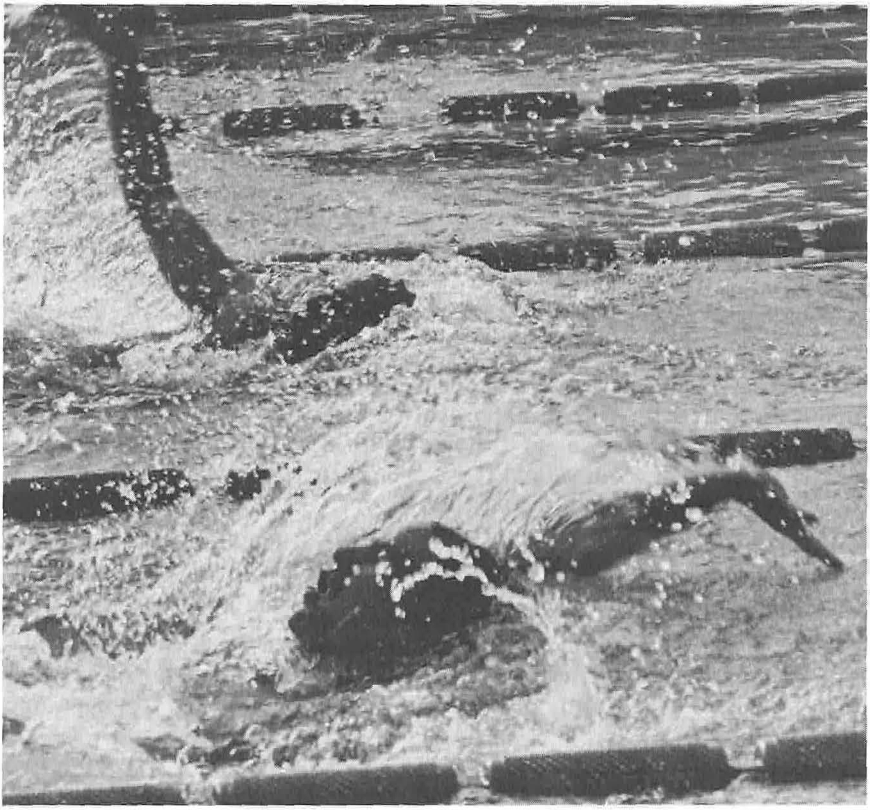
Interhouse Scholarship Trophy. A trophy for annual competition in scholarship among the seven student houses has been provided by an anonymous donor. With the approval of the donor the trophy has been designated as a memorial to the late Colonel E. Goldsworthy, who was Master of Student Houses, and it commemorates his interest and efforts in the field of undergraduate scholarship.

Faculty-Student Relations. Faculty-student coordination and cooperation with regard to campus affairs is secured through the presence of students on faculty committees and by means of other less formal mechanisms.

Freshman Advisers. Each member of the freshman class is assigned to a faculty adviser. The adviser interests himself in the freshman's progress and provides advice on any questions or problems which the freshman may have.

Option Advisers. Each member of the three undergraduate upper classes is assigned to an option adviser, a faculty member in the option in which the student is enrolled. The adviser interests himself in the student's selection of optional courses, progress toward his degree, and, eventually, in assisting the student toward satisfactory placement in industry, or in graduate school. Normally, the association between student and adviser, which is primarily professional, is established before the beginning of the sophomore year and continues through graduation.

Athletics. The California Institute maintains a well-rounded program of athletics and, as a member of the Southern California Intercollegiate Athletic Conference, schedules contests in nine sports with the other members of the Conference – Occidental, Pomona, Redlands, Whittier, and Claremont-Harvey Mudd – as well as many other neighboring colleges. In addition, the Caltech Sailing Club sails a fleet of Institute dinghies based at Los Angeles Harbor.



The California Institute Athletic Field of approximately 23 acres includes a football field, a standard track, a baseball stadium, and championship tennis courts. The Scott Brown Gymnasium and the Alumni Swimming Pool, completed in 1954, provide attractive modern facilities for intercollegiate, intramural, or recreational competition in badminton, basketball, volleyball, swimming, and water polo. Funds for the pool were contributed by the alumni of the California Institute; construction of the gymnasium was made possible through a bequest of Scott Brown.

The Institute sponsors an increasingly important program of intramural athletics. There is spirited competition among the seven houses for the possession of the three trophies. The Interhouse Trophy is awarded annually to the group securing the greatest number of points in intramural competition during the year. The Varsity and Freshman Rating Trophy is presented to the group having the greatest number of men participating in intercollegiate athletics. The third trophy, "Discobolus," is a bronze replica of Myron's famous statue of the discus thrower. It is a challenge trophy, subject to competition in any sport, and it remains in the possession of one group only so long as that group can defeat the challengers from other groups.

ASCIT. Despite the outward appearance on campus of political quiescence, the student body government (officially known as the "Associated Students of the California Institute of Technology, Inc.," or "ASCIT") plays a significant role in bringing change to campus life. Some of ASCIT's more notable and recent efforts brought about the student-directed (and smog-oriented) ASCIT Research Project, the student-run coffeehouse (which provides a respite from the pressures of Caltech), and student representation on faculty committees. It should be noted that few student governments are superior to ASCIT in their working relationship with faculty and administration.

A member of the corporation (i.e., a dues-paying student-body member) is entitled to participate fully in campus politics: to vote, to lobby, and to hold corporate office.

Graduate Student Council. The Graduate Student Council performs essentially the same functions for the graduate students as the Board of Directors of ASCIT does for the undergraduates.

Board of Control. The Honor System is the fundamental principle of conduct for all students. More than merely a code applying to conduct in examinations, it extends to all phases of campus life. It is the code of behavior governing all scholastic and many extracurricular activities, relations among students, and relations between students and faculty. The Honor System is the outstanding tradition of the student body, which accepts full responsibility for its operation. The Board of Control, which is composed of elected representatives from each of the seven houses, is charged with interpreting the Honor System for undergraduates, while the Graduate

Review Board performs the same function for graduate students. If any violations should occur, the appropriate board investigates them and recommends disciplinary measures to the deans.

Student Body Publications. The publications of the student body include a weekly paper, the *California Tech;* an annual; a literary magazine; and a student handbook, which gives a survey of student activities and organizations and serves as a campus directory. These publications are staffed entirely by students. Through them ample opportunity is provided for any student who is interested in obtaining valuable experience not only in creative writing, art work, and in the journalistic fields of reporting and editing, but in the fields of advertising and business management as well.

Musical Activities. The Institute provides qualified directors and facilities for a band, several choral music groups including a glee club, and a chamber orchestra. The glee club is reputed to be among the best collegiate male choruses in the country and annually enhances its reputation with extensive touring. A series of chamber music concerts is given on Sunday evenings in the lounge of Dabney Hall. There are other musical programs in Beckman and Ramo Auditoriums. The Musicale is an organization which encourages interest in and appreciation for classical recordings. The extensive record library of the Institute provides opportunity for cultivation of this interest and for the presentation of public programs. The Winnett Center Record Library has over 200 popular albums which may be rented for a nominal charge.

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.

Special interests and hobbies are provided for by a broad and constantly changing spectrum of clubs, some informal but most formally recognized by either ASCIT or the Graduate Student Council.

Student Shop. The Student Shop is housed in the Winnett Student Center. It is equipped by the Institute, largely through donations, and is operated by the students under faculty supervision. It is 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.

The Caltech Y. The Caltech Y is one of the major centers of campus activities. The Y is a place where a student can bring an idea or need and find help in organizing a program in response to his concern. The range of programs planned by students and faculty through the Y includes discussion and action programs on social and political issues, educational programs on international problems, personal growth experiences, community services projects, and social events. These programs take the form of guest speakers, Olive Walk talks, retreats and conferences, student house discussions, courses and study groups, dinner in faculty homes, trips, workshops, and work projects. In addition, the Y provides several campus services including a used-book exchange, an emergency loan fund, a record library, current issues libraries, and individual and group support services to students and student organizations.

Beckman Auditorium. Beckman Auditorium serves as the center of the performing arts program on the Caltech campus. Each year, the Auditorium hosts over 125 public events, ranging from the traditional Monday night lecture series to professional dramatic, dance, film, and concert presentations, featuring world renowned artists. It is the site of the annual Caltech student musical show, the Caltech Glee Club Home Concert, and the Caltech Band Hunter Mead Memorial Concert. Located in the Auditorium offices are a Ticket Agency and the campus Audio-Visual Services Unit.

Bookstore. The student store serving students, faculty, and staff is located on the ground floor of the Winnett Student Center. The store, which is owned and operated by the Institute, carries a complete stock of required books and supplies, reference books, and such extracurricular items as athletic supplies, stationery, and fountain pens. There is, on open shelves, an extensive collection of paperbacks and other books of general interest.

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 co-educational; there is no set ratio of men to women. 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.

Individuals are considered for admission to student status — and all student services, facilities, programs, and activities are administered — in a nondiscriminatory manner without regard to race, religion, color, sex, or national origin, and fully in accordance with all existing laws and regulations.

Admission to the Freshman Class

The freshman class of approximately 225 is selected 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. A personal interview with an applicant and two or three of his teachers is held at his school whenever 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 register in September.

APPLICATION FOR ADMISSION

An application form may be obtained by writing to the Office of Admissions, California Institute of Technology, Pasadena, California 91109. It is to be returned directly to the Institute.

Completed admission application blanks and the $10 application fee must reach the Admissions Office not later than February 1. (Application to take entrance examinations must be made directly to the College Board at an earlier date, for which see page 163.)

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. Students 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.

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
	Chemistry	1
	Mathematics	4
	Physics	1
	United States History and Government	1
Group B:	Foreign Language, Shop, additional English, Geology, Biology or other Laboratory Science, additional History, Drawing, Commercial subjects, etc.	5

The three units of English are a minimum and four units are strongly recommended.

The four-year program in mathematics should include the principal topics of algebra, geometry, analytic trigonometry, and the elementary concepts of analytic geometry and probability. The program should emphasize the principles of logical analysis and deductive reasoning and provide applications of mathematics to concrete problems.

ENTRANCE EXAMINATIONS

In addition to the above credentials, all applicants for admission to the freshman class are required to take the following College Entrance Examination Board examinations: the Scholastic Aptitude Test and the Level II Achievement Test in Mathematics, plus any two of the following achievement tests: Physics, Chemistry, Biology, English Composition. The Level II Mathematics Test is designed for students who have completed three and one-half years of a mathematics program of the type outlined above. The Level II test does not presuppose an advanced placement course in mathematics. Note that the Scholastic Aptitude and the Level II Mathematics Test must be taken,* and that the choice lies only among Physics, Chemistry, Biology, and English — of which two must be taken. No substitution of other tests can be permitted.

The Scholastic Aptitude Test and achievement tests must be taken no later than the January College Board Series. *It is important to note that no applicant can be considered who has not taken the required tests by January, but tests taken on any prior date are acceptable.* No exception can be made to the rule that all applicants must take these tests.

Full information regarding the examinations of the College Entrance Examination Board is contained in the *Bulletin of Information* which may be obtained without charge at most high schools, or by writing to the appropriate address given below. The tests are given at a large number of centers, but if any applicant is located more than 75 miles from a test center, he can make special arrangements to take the tests nearer home.

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*Very occasionally the applications of those who have taken the Level I instead of the Level II Mathematics Test will be considered. It should be pointed out, however, that the Institute feels it can better judge the qualifications of an applicant who has taken the Level II test, and those who have not done so will be handicapped in the competition for admission.

Applicants who wish to take the examinations in the western United States or Canada, or in Mexico, Australia, or the Pacific Islands should address their inquiries by mail to College Entrance Examination Board, P.O. Box 1025, Berkeley, California 94701. Check the *Bulletin of Information* for the exact dividing line.

Candidates applying for examination in other areas should write to College Entrance Examination Board, P.O. Box 592, Princeton, New Jersey 08540.

All applications to take examinations in the United States should reach the appropriate office of the Board at least four weeks in advance of the test date. Examinations to be taken abroad need to arrive at least six weeks in advance. 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. These forms are sent directly to the school which the applicant is attending, with the request that they be filled out and returned directly to the California Institute. These recommendation forms provide valuable information on candidates. The College Board scores, the last of which will be received by about February 15, provide further important data. Since, however, there are many more applicants to the California Institute than our facilities can accommodate, as much information as possible is desired on each candidate for admission. Wherever preliminary information shows that an applicant has a chance of gaining admission, the Institute will attempt to hold a personal interview with him at the school he is attending. It is not possible to visit all of the schools involved; but if a personal interview cannot be held, this in no way prejudices an applicant's chances of admission. The applicant has no responsibility with regard to the personal interview unless and until he receives a notice giving the time and date when a representative will visit his school. These visits occur generally between March 1 and April 6.

NOTIFICATION OF ADMISSION

Final selections will ordinarily be made and the applicants notified of their admission or rejection well before May 1. Most College Board member colleges have agreed that they will not require any candidate to give final notice of acceptance of admission or of a scholarship before this date. Upon receipt of a notice of admission an applicant should immediately send in the registration fee of $10. In the event he subsequently cancels his acceptance, the registration fee is *not* refundable. Places in the entering class will not be held after May 1, if the applicant could reasonably be expected to have received notice at least ten days before that date. Otherwise, places will be held not more than ten days after notification. When the registration fee has been received, each accepted applicant will be sent a registration card which will entitle him to register, provided his physical examination is satisfactory.

Checks or money orders should be made payable to the California Institute of Technology.

DEFERRAL OF ENTRANCE

The Institute will consider requests from newly admitted freshmen for a year's deferral of entrance for such purposes as studying abroad, working, or maturing. It is possible that not all requests will be granted: the seriousness and appropriateness of the purpose and the number of requests received will be determining factors.

Students who wish to request a year's deferral of entrance must (1) pay the registration fee by May 1 in the normal manner; (2) make a written request stating the purpose of postponement and the plans for using the extra year.

EARLY DECISION PLAN

The Institute will consider a few outstanding candidates who wish to make the California Institute their first choice under an early decision plan. Such candidates must have taken the required College Board tests by the end of their junior year or at the following July administration,* must have an excellent school record, and must have the thorough backing of their high school.

An applicant for admission under the early decision plan must have his credentials on file by October 15 of his senior year. (If he is applying for a scholarship, his application should be filed with the College Scholarship Service [see p. 182] by the same date.) He will be notified by December 1 whether he has been accepted. An accepted applicant is then expected to withdraw all applications to other colleges. An applicant who is not accepted under the early decision plan will be considered without prejudice for admission at the regular time in April, unless he receives final rejection in December.

ADVANCED PLACEMENT PROGRAM

A number of high schools and preparatory schools offer selected students the opportunity to accelerate and to take in the senior year one or more subjects which are taught at the college level and cover the material of a college course. The College Entrance Examination Board gives each year in May a set of Advanced Placement examinations covering this advanced work. The regulations governing Advanced Placement at the California Institute in the subjects concerned are as follows:

Chemistry. Students with a particularly strong background in chemistry may elect to take Chemistry 2, Advanced Placement in Chemistry, rather than Chemistry 1, General and Quantitative Chemistry. It is assumed that such students have reasonable competence in the following areas: 1) *elementary* theories of atomic structure and electronic theories of valence, 2) chemical stoichiometry, and 3) computations based upon equilibrium relationships. Chemistry 2 differs from Chemistry 1 chiefly in having different lectures and recitation. The required first-term laboratory is the same. There is more emphasis in Chemistry 2 on systematic treatment of reactions and chemical reactivity than in Chemistry 1. Equilibrium relationships, electrochemistry, etc., are discussed directly in terms of thermodynamics and used as examples of variations in chemical reactivity as a function of chemical structure.

Admission to Chemistry 2 is based on an interview with the instructor.

Humanities and Social Sciences. Students will not be admitted to upperclass humanities and social sciences courses until or unless they have successfully completed three terms of freshman humanities and social sciences, been excused therefrom as a consequence of a high score on the appropriate advanced placement examination or by their instructor (through the divisional Freshman Requirements Committee), or obtained (from that committee) an exemption in an particular case.

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*Please note that the Level II Mathematics Test (required) is not given in the July series. It is given only in December, January, and May.

Mathematics. Normally, an entering freshman will take Math 1 abc, Freshman Mathematics. This course will cover the calculus of functions of one variable; an introduction to differential equations; vector algebra; analytic geometry in two and three dimensions; infinite series. The course will be divided into a lecture part, discussing primarily the mathematical notions of the calculus and the other topics listed above; and a recitation part, providing active practice in the applications of corresponding mathematical techniques.

During the summer, entering freshman will be invited to outline their advanced training in mathematics and to have their knowledge tested. They then will be placed in the course which best fits their preparation: Math 1 abc, Math 1.5 abc, or Math 2 abc. Freshmen completing either of the last two courses will have satisfied the Institute requirements for mathematics.

Physics. The required freshman physics course, Ph 1 abc, is quite unlike most advanced placement work, and entering freshmen are encouraged to take Ph 1, whatever their high school preparation. However, students with unusually advanced backgrounds, wishing to receive credit for Ph 1, should take the College Board Advanced Placement Examination in Physics, Version C. Entering freshmen with scores of 4 or 5 on this examination will be considered for possible advanced placement.

NOTE: The Advanced Placement tests are in no way a substitute for the College Board Aptitude and Achievement Tests at the ordinary high school level required for admission. The latter are the only tests considered in granting freshman admission. After admission, those who offer advanced credits and examinations will be considered for credit and advanced placement in the subjects involved.

MEDICAL EXAMINATION

Prior to final acceptance for admission, each applicant is required to submit a report of Medical History and Physical Examination on a form which will be sent him at the time he is notified of admission. It is the applicant's responsibility to have this form filled out by a Doctor of Medicine (M.D.) of his own choosing. Admission is tentative pending such examination, and is subject to cancellation if the report indicates the existence of a condition that the Director of Health Services deems unsatisfactory.

Students who have been on leave of absence for two years or more must submit Medical History and Physical Examination reports under the same conditions as for new students.

SCHOLARSHIPS AND LOANS

For information regarding scholarships for entering freshmen and deadline for application see pages 182-183. In computing need the California Institute includes tuition, board and lodging, books and supplies, incidental fees and dues, and about $400 for personal expenses. A travel allowance, which varies with the distance between Pasadena and the student's home but in no case exceeds $450, is added to this figure. The figure for the expenses of those who live at home or with relatives or friends to whom they pay nothing for board and lodging is approximately $500 less. Further information on tuition and other costs, and on loans and the deferred payment plan is given on pages 180-185.

NEW STUDENT ORIENTATION

All freshmen are required to attend the New Student Orientation as a part of the regular registration procedure. Upperclass transfer students are not required to attend but are welcome to do so if they wish.

The orientation takes place during three days immediately following freshman registration for the fall term. A large number of faculty members and upperclass student leaders participate to help introduce the new student to the Caltech community. The orientation period provides an opportunity for the new student to become acquainted with the campus, the Honor System governing personal conduct, and other aspects of life at Caltech. In addition he can meet his classmates and a number of the upperclass students and faculty. Thus the new student can begin to feel at home at Caltech and share in the common agreement on intellectual and moral standards before the pressure of academic work begins.

Admission to Upper Classes by Transfer from Other Institutions

The Institute admits to its sophomore or junior class a limited number of students who have made satisfactory records at other institutions of collegiate rank and who do satisfactorily on the transfer entrance examinations. Transfer students are not normally admitted to the senior year. In general only students whose grades, especially those in mathematics and science, are above average can be expected to be permitted to take the entrance examinations.

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.

Students will be allowed to apply for transfer admission only if they have completed elsewhere essentially the equivalent of the courses required of students at the Institute. This means that applicants for transfer into the sophomore class must have completed at least one full year of calculus and one full year of physics at the college level. For transfer to the junior class, two years of each of these subjects is required, plus a one-year course in college chemistry. Those who have pursued college work elsewhere but have not had the substantial equivalent of the freshman courses in mathematics and physics — and in addition chemistry for those wishing to major in chemistry or chemical engineering — will be classified as freshmen and should apply according to the instructions on pages 161-164. They may, however, receive credit for pertinent 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 of Technology stating his desire to transfer, his choice of engineering or one of the options in science or humanities, and the number of years of calculus and of physics 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. In his preliminary letter, the applicant must describe the content of the physics, mathematics, and chemistry courses he has completed thus far, and give course numbers, titles, and descriptions for all courses he will complete before transferring to the Institute which are not recorded on his college transcripts. After this letter has been received and 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 preliminary letter and transcripts have been received and evaluated. Transcripts are held in the files until such a letter is received.

Application blanks must be on file in the Admissions 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; information with regard to acceptance or rejection for all candidates is sent before June 20. Candidates who are admitted to the Institute must send a second transcript of their work showing final grades received for any work in progress during the spring.

All transfer applicants must arrange to have sent in their scores on the Scholastic Aptitude Test (SAT) of the College Entrance Examination Board. If they have taken the SAT in previous years, these scores will be acceptable; but applicants must instruct the College Board (see address on page 163) to send the scores to the Institute. If the SAT has not been taken previously, it must be taken by the April series at the latest. College Board Achievement Tests are not required of transfer applicants. Before their admission to the upper classes of the Institute, all students are required to take entrance examinations in mathematics and physics covering the work for which they desire credit. In addition an examination in chemistry is required for those desiring to major in chemistry or chemical engineering.

Two examinations of a comprehensive character are offered in mathematics and physics. One examination in each subject covers the work of the first year, the other examination that of the first and second years. Representative examination papers will be sent to approved applicants upon request. The Institute courses for which those admitted will receive credit will be determined by the Committee on Admission to Upper Classes and the departments concerned, on the basis of the applicants' previous records and the results of their examinations.

It is not possible to give definite assurance that a transfer student entering the sophomore year will graduate in three years or that one entering as a junior will graduate in two years. Much depends on the amount and nature of the credit granted at the time a student registers in September and on the possibility of fitting deficiency make-ups into the regular schedule.

The first-year chemistry course at the California Institute differs from those given at many other colleges because of the inclusion of a substantial amount of quantitive analysis in the laboratory work. A transfer student who has had a one-year college course in inorganic chemistry and qualitative analysis will be considered to have met the first-year chemistry requirements, provided, of course, that his grades have been satisfactory. Those wishing to major in biology, chemistry, or geology will be required to take certain portions of freshman chemistry if they do not have the equivalent laboratory work elsewhere.

The transfer examination in chemistry is required only of those wishing to major in chemistry or chemical engineering. This examination is the same for both sophomore and junior standing and covers general chemistry. Transfer students entering the junior year in chemistry will be able to take the sophomore organic chemistry course during their first year at the Institute.

Examinations for admission to upper classes are given in the first two weeks in May. No other examinations for admission to upper classes will be given.

Applicants residing at a distance may take the examinations under the supervision of their local college authorities, provided definite arrangements are made well in advance.

Students whose native language is not English will be required to take the test of English as a Foreign Language (TOEFL). This test is a College Entrance Examination Board test and is given all over the world, including the United States, four times a year. This test must be taken by the March series at the latest. Full information on how and where to take the test should be obtained from the College Board.

It is not possible to answer general questions regarding the acceptability of courses taken elsewhere. The nature of the work at the Institute is such as to demand that all courses offered for credit be scrutinized individually. In case the standard of the work taken elsewhere is uncertain, additional examinations may be required before the question of credit is finally determined.

The Institute has recently started a pilot program with 12 relatively local public junior colleges, whereby a student at one of the junior colleges may follow a certain pattern of courses, maintain specified grades and grade-point average, receive the recommendation of his science faculty, and be considered for admission to the junior year without the necessity of taking tests. Decisions on such applicants will be made on a rolling basis and will be earlier than decisions under the standard program. Full details can be obtained from the junior-college counselors. The colleges are: El Camino College, Fullerton Junior College, Glendale College, Long Beach City College, Los Angeles City College, Los Angeles Pierce College, Los Angeles Valley College, Pasadena City College, Riverside City College, Santa Ana College, Santa Monica College, Ventura College.

Physical examinations are required for transfer students as in the case of students entering the freshman class (see page 165). Admission is conditional upon a satisfactory report on the physical examination.

Transfer students are required to pay a registration fee of $10 upon notification of admission to the Institute. In the event of subsequent cancellation of application, the registration fee is *not* refundable unless cancellation is initiated by the Institute.

Scholarship grants for transfer students are awarded on the same basis as are those for freshmen. To apply 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 should reach the Admissions Office as soon as possible after the filing of the application.

THE 3-2 PLAN

The California Institute of Technology has an arrangement whereby students enrolled in certain liberal arts colleges may follow a prescribed course for the first three years and then transfer into the third year of the engineering option at the Institute without further formality, provided that they have the unqualified recommendation of the officials at the liberal arts college which they are attending. After two full years' residence at the Institute and after satisfactorily completing all the remaining work required for a bachelor's degree in engineering, they will be awarded a Bachelor of Arts degree by the college from which they transferred and a Bachelor of Science degree by the California Institute. Application for admission at the freshman level under this plan should be made to the liberal arts college.

The colleges with which these arrangements exist are:

Bowdoin College, Brunswick, Maine
Grinnell College, Grinnell, Iowa
Occidental College, Los Angeles, California

Ohio Wesleyan University, Delaware, Ohio
Pomona College, Claremont, California
Reed College, Portland, Oregon
Wesleyan University, Middletown, Connecticut
Whitman College, Walla Walla, Washington

EXCHANGE PROGRAMS

Exchange programs exist with Occidental College and Scripps College permitting California Institute students to receive credit for courses taken at these two colleges. Occidental College students and Scripps College students also may receive credit for courses taken at the Institute. Tuition payments are not required but the student may have to pay any special fees. The student must obtain approval from the instructor of the exchange course. Exchange courses taken by Caltech students must have prior approval by the student's option, by the division providing courses most similar to the proposed course, and by the Registrar. Freshmen at the California Institute ordinarily cannot participate in this exchange.

In addition, through the office of the Dean of Students, informal exchange programs are conducted with several colleges and universities throughout the country. Under this scheme, a student can visit another campus for a period ranging from one term to a full academic year, without the formalities of transfer proceedings or written applications. Any student interested in the informal program should check with the Dean of Students for details.

Air Force ROTC

Established at Caltech in 1951-52, this department has continued since that time to offer interested Caltech students a program leading to an Air Force commission as a second lieutenant upon their graduation. AFROTC graduates from Caltech are generally assigned to scientific/engineering positions within the Air Force R&D complex. Those electing pilot or navigator duty can look toward assignments leading to experimental research as well as operational flying duties.

Under the present two-year program, students apply at the department during the first and second terms of their freshman or sophomore years. Graduate students who are assured of at least two years remaining towards their degrees are also eligible to apply. Applicants are given aptitude and medical examinations, and final selection of qualified applicants is made in the third term. Until the time of formal enrollment in the fall, neither the student nor the Air Force is under any contractual obligation.

When the student formally enrolls in the program, he begins receiving $100 monthly (up to a maximum of $2,000) as a subsistence allowance to defer incidental costs such as uniform maintenance, etc.

The program offers visits to aerospace scientific and engineering complexes as well as visits by young Air Force officer engineers or scientists assigned to such activities. For cadets who are qualified and interested in becoming Air Force pilots, the program offers the equivalent of $700 worth of flight instruction in the year prior to commissioning, comprising 30 hours of ground school and 35 hours of actual flight training, normally culminating in receipt of a civilian pilot's license.

Many students elect upon commissioning to apply for a delay of their entry upon active duty in order to work toward a graduate degree. Depending upon the needs of the Air Force, many such delays are granted, normally on a year-to-year basis up to a maximum of four years.

Persons desiring more specific information about the program, application procedures, and educational and professional opportunities open to Caltech AFROTC graduates should contact the Department of Air Force Aerospace Studies.

REGISTRATION REGULATIONS

Students are held liable for any careless or willful destruction or waste for which they may be responsible. 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.

The Institute is dedicated to the principle of peer group judgment in cases of misconduct. The honor system prevails in all student affairs, both academic and extracurricular. The Institute officer charged with jurisdiction over student behavior is the Dean of Students. The Board of Control, an elected group of students headed by the vice-president of the Associated Students, will make its recommendations to him and in cases where the Board of Control is unable to assume jurisdiction, he will establish procedures designed to protect the interests of any student accused of improper conduct and the interests of the Institute as a whole.

Registration Procedures

Students must register in person on the dates specified in the academic calendar. Registration material is to be picked up at a location designated by the Registrar and is returned to the Office of the Registrar when completed. A student is not registered until he has both

a. turned in a signed registration card with his approved study list, and
b. made satisfactory arrangements with the Office of Student Accounts for the payment of all fees due the Institute.

Any student who has not completed both phases of registration within one week after registration day will be removed from the Institute rolls.

Changes of Registration

All changes in registration must be reported to the Registrar's Office by the student prior to the published deadlines. A grade of F will be given in any course for which a student registers and which he does not either complete satisfactorily or drop. A course is considered dropped when a drop card is completed and signed by the approving signatures and returned to the Registrar's Office. A student may not drop a course or courses if this results in his being registered for fewer than 36 units, unless he obtains the prior approval of the Undergraduate Academic Standards and Honors Committee. Such approval will not be given to any students other than third-term seniors except in extraordinary circumstances. A student may not at any time withdraw from a course which is required for graduation in his option without permission of the Dean.

A student may not add a course after the last day for adding courses, or withdraw from a course after the last date for dropping courses without, in addition to his instructor's consent, the approval of the Undergraduate Academic Standards and Honors Committee. Registration for added courses is complete when an add card has been filed in the Registrar's Office signed by the instructor and the student's adviser. No credit will be given for a course for which a student has not properly registered. The responsibility that drop cards and add cards are received in the Registrar's Office before the deadlines for dropping or adding courses each term rests entirely with the student. Failure to fulfill the responsibility because of oversight or ignorance is not sufficient grounds to petition for permission to drop or add courses after the deadline. It is the policy of the Undergraduate Academic Standards and Honors Committee that no petitions for the retroactive dropping or adding of courses will be considered except under very extenuating circumstances.

Summer Research

Qualified undergraduate students who are regular students in the Institute are permitted to engage in research during the summer, but in order to receive academic credit the student must have the approval of his division and must file a registration card for such summer work in the Office of the Registrar prior to June 1. Students who are registered for summer research will not be required to pay tuition for the research units.

Auditing of Courses

Persons not regularly enrolled in the Institute may audit courses, if they obtain the consent of the instructor in charge of the course and the chairman of the division concerned, for a fee of $40 per lecture hour, per term. Auditing fees for non-academic staff members may be covered by the Institute Tuition Support Plan. Auditing cards may be obtained in the Registrar's Office.

Regularly enrolled students and faculty members of the Institute staff are not charged for auditing. Auditing cards are not required, but the instructor's consent is necessary in all cases. No grades for auditors are reported to the Registrar's Office, and no official record is kept of the work done.

SCHOLASTIC REQUIREMENTS; GRADING

General Regulation

Every student is expected to satisfy the requirements in each of the courses he is registered for, as the instructor may determine.

Grades

All permanent grades recorded for freshmen will be either "P," indicating passed, or "F," indicating failed. The temporary grade of "I" may be used as it is for upperclassmen. The temporary grade of "E" may be given to freshmen as described below for upperclassmen. It may also be used in a continuing course if the performance of the freshman concerned is not significantly below the current passing level, and in addition the student is maintaining a steady and substantial improvement; an "E" given for this reason will be automatically changed to a "P" if the freshman earns a "P" for the following term, and will be changed to an "F" if the student receives an "F" for the following term. The grade may not be used in this way for two successive terms nor for the last term of the course.

If a freshman is enrolled in a course in which the instructor gives letter grades, the Registrar will record "P" for all passing grades. The grade of "H" is given for satisfactory completion of freshman honor elective courses. No grades given to a freshman will be used in computing the cumulative grade-point average.

For undergraduate students beyond the freshman year, letter grades will ordinarily be used to indicate the character of the student's work: "A" excellent, "B" good, "C" satisfactory, "D" poor, "E" conditioned, "F" failed, "I" incomplete. Exceptions are allowed only where the instructor uses the grade "P" instead of a passing letter grade for all students in the course, or where the student elects to take the course on a Pass-Fail basis as described on page 173. This rule regarding exceptions applies whether the student is repeating a course failed at an earlier time or taking the course for the first time. In addition, grades of A+ and A–, B+ and B–, C+ and C–, and D+ may be used for undergraduates only.

The grade "E" indicates deficiencies that may be made up without actually repeating the subject. If the course has been graded with letter grades, a grade of "D" is given when the work is completed; a grade of "P" is given if the student is a freshman, or if the course was taken on a Pass-Fail basis.

The grade "I" is given only in case of sickness or other emergency which justifies non-completion of the work at the usual time. An incomplete will be recorded only if the reasons for giving it are stated on the instructor's final grade report and only if, in the opinion of the appropriate committee (Undergraduate Academic Standards and Honors 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. The Undergraduate Academic Standards and Honors Committee has authorized the Dean of Students or the Associate Dean of Students to approve the awarding of the grade "I."

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 the instructor of the course recommends otherwise.

"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 completion 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.

Each course in the Institute is assigned a number of *units* corresponding to the total number of hours per week devoted to that subject, including classwork, laboratory, and the normal outside preparation. The units used at the California Institute may be reduced to semester hours by multiplying the Institute units by the fraction 2/9. *Credits* are awarded as shown in the following table.

No. of Units	A+	A	A–	B+	B	B–	C+	C	C–	D+	D	F
1	4	4	4	3	3	3	2	2	2	1	1	0
2	9	8	7	7	6	5	5	4	3	3	2	0
3	13	12	11	10	9	8	7	6	5	4	3	0
4	17	16	15	13	12	11	9	8	7	5	4	0
5	22	20	18	17	15	13	12	10	8	7	5	0
6	26	24	22	20	18	16	14	12	10	8	6	0
7	30	28	26	23	21	19	16	14	12	9	7	0
8	35	32	29	27	24	21	19	16	13	11	8	0
9	39	36	33	30	27	24	21	18	15	12	9	0
10	43	40	37	33	30	27	23	20	17	13	10	0
11	48	44	40	37	33	29	26	22	18	15	11	0
12	52	48	44	40	36	32	28	24	20	16	12	0
13	56	52	48	43	39	35	30	26	22	17	13	0
14	61	56	51	47	42	37	33	28	23	19	14	0
15	65	60	55	50	45	40	35	30	25	20	15	0

Grade-Point Average is computed by dividing the total number of credits earned in a term or an academic year by the total number of units taken in the corresponding period. Units for which a grade of "F" has been received are counted, even though the "F" may have subsequently been removed. Units and credits in military subjects taken by Air Force ROTC students are counted in computing grade-point average. Physical education units and credits, and grades of "P" are not included in computing grade-point average.

Pass-Fail Grading: Grades of "P" may be given for undergraduate research, research conferences, courses numbered 200 or greater, and for other courses which do not lend themselves to more specific grading. All students in a given course are to be graded using the same system (either all P-F, or all letter grades), unless the instructor offers the course on a letter-graded basis and a student chooses to take it on a P-F basis by filing a Pass-Fail Course Selection Card.

Each term a sophomore, junior, or senior may select one elective course, not specifically required for graduation in his option to be graded on a Pass-Fail basis, subject to such requirements as may be imposed by his option. The following additional provisions apply:

(a) Any instructor may, at his discretion, specify prior to pre-registration that his course is not available on a Pass-Fail basis.

(b) Registration may be changed from Pass-Fail to regular grades and vice versa until the last day for dropping courses each term.

(c) The total number of Pass-Fail units in regularly scheduled courses (that is, courses other than research and reading courses) in the sophomore, junior, and senior years, which a student may offer for graduation, may not exceed 81.

To elect to take a course *Pass-Fail,* a student must submit a completely filled-out Pass-Fail Course Selection Card to the Office of the Registrar prior to the last day for dropping classes that term.

Scholastic Requirements

All undergraduates are required to meet certain scholastic standards as outlined below. Students who have been reinstated after having failed to make the required number of credits in the junior year are subject to these requirements in the senior year.

Ineligibility for Registration. 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. Freshmen who receive no grades of "Fail" or "Condition" during the year are academically eligible to register for the sophomore year. Freshmen who have accumulated 42 units or more of "Fail" or "Condition" will automatically be evaluated by the Committee on Undergraduate Academic Standards and Honors at the end of any term. Other freshmen may, at the end of the year, be referred to the Committee by the Associate Dean of Students and the student's adviser. If it is the opinion of the Committee on Undergraduate Academic Standards and Honors that any freshman referred to it is unprepared for the work of the sophomore year, he may be declared ineligible to register for academic reasons.

Freshmen whose records are to be reviewed at any meeting of the Committee will be notified in advance and invited to meet with the Committee to discuss their performance; freshmen so notified should also plan to submit a written statement to the Committee in advance of its meeting.

Any undergraduate student, except a freshman, is ineligible to register for another term:

(a) If he fails during any one term to obtain a grade-point average of at least 1.4.

(b) If he fails to obtain a grade-point average of at least 1.9 for the academic year. A student who has completed at least three full terms of residence at the Institute and has been registered for his senior year shall no longer be subject to the requirement that he make a grade-point average of at least 1.9 for the academic year. Seniors are subject to the requirement, however, that they must receive a grade-point average of at least 1.4 each term to be eligible for subsequent registration.

(c) Any undergraduate student, including a senior, who has been *reinstated* and who fails to make a grade-point average of at least 1.9 on a full load of at least 45 units for the following term is ineligible to register.

A student ineligible for registration because of failure to meet the requirements stated in the preceding paragraphs may submit a petition to the Undergraduate Academic Standards and Honors Committee for reinstatement, giving any reasons that may exist for his previous unsatisfactory work and stating any new conditions that may lead to better results. Each such petition will be considered on its merits. *For the first such ineligibility,* the petition will be acted upon by the appropriate dean, after consultation with the student and examination of his record. At the dean's discretion, such cases may be referred to the Undergraduate Academic Standards and Honors Committee for action. *All subsequent reinstatements must be acted upon by the Committee.* A reinstated student who again fails to fulfill the scholastic requirements for registration must petition the Undergraduate Academic Standards and Honors Committee, and action can only be taken by the Committee. In any case being considered by the Committee, the student may, if he wishes, appear before the Committee or, on request by the Committee, he may be required to appear. A second reinstatement will be granted only under very exceptional conditions.

Departmental and Option Regulations. Any student whose grade-point average is less than 1.9 at the end of an academic year in a specific group of subjects designated by his department or option (see pages 189-221) may, at the discretion of his department, be refused permission to continue the work of that option. Such disbarment 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. *A student without an option will fall under the direct jurisdiction of the Dean of Students. Until he is readmitted to his option, a student may not take courses in that option beyond the level he had reached when he was refused permission to continue work. A student may remain without an option for no more than one year.*

Term Examinations will be held in all subjects unless the instructor in charge of any subject shall arrange otherwise. No student will be exempt from these examinations. Permission to take a term examination at other than the scheduled time will be given only in the case of sickness or other emergency and upon the approval of the instructor in charge and of one of the deans. When conflicts exist in a student's examination schedule, it is the student's responsibility to report the conflict to the instructor in charge of one of the conflicting examinations and make arrangements to take the examination at another time.

Graduation Requirement. To qualify for graduation a student must complete the prescribed work in one of the options with a passing grade in each required subject and with a grade-point average of 1.9. A grade of "F" in an elective course need not be made up, provided the student has received passing grades in enough other accepted units to satisfy the minimum total requirements of his option.

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 90 of the units taken must be in subjects in professional courses. A full year of residence is interpreted as meaning the equivalent of registration for three terms of not less than 36 units each.

Requirement for a Second Bachelor of Science Degree. Students who wish to receive a second degree of Bachelor of Science in another option are required to have one additional year of residence (three terms of study involving at least 36 units per term) beyond the first Bachelor of Science degree.

Honor Standing. At the close of each academic year the Committee on Undergraduate Academic Standards and Honors awards Honor Standing to 20 to 30 students in the sophomore and junior classes, based on the scholastic records of the students.

Graduation with Honor. With the approval of the faculty, graduation *with honor* may be granted a student who has achieved an overall grade-point average of 3.2, including such an average in the senior year. In addition, a student may be graduated with honor under joint recommendation of his division and the Committee on Undergraduate Academic Standards and Honors, with the approval of the faculty.

Excess or Fewer than Normal Units. An undergraduate who wishes to register in any term for more than 58 units must obtain the recommendation of his option adviser and the approval of the Undergraduate Academic Standards and Honors Committee. Petitions to carry excess units will not be accepted later than the last day for adding classes in any term.

Registration for fewer than 36 units must be approved by the Undergraduate Academic Standards and Honors Committee. Petitions to register for fewer than 36 units must be filed with the Registrar one week prior to the last day for adding classes in any term. See page 225 for graduate students.

Miscellany

Freshman Honor Electives. Honor Electives are available, on a voluntary basis, to all freshmen in the second and third terms of the freshman year. This Honors work is intended to maintain, or to rekindle, an interest the student brought with him to the Institute, or to develop an interest suggested by the work or the staff at the Institute; it is not intended to be used to accumulate academic credit. The Honor Electives are available campus-wide; any reasonable program of work, including critical reading, is acceptable. Upon satisfactory completion of a term of Honors work, a grade of "H" will be recorded.

Selection of Option. In the middle of the third term freshmen must notify the Registrar's Office of their selection of an option in engineering, humanities, or science to be pursued in subsequent years. Upon the selection of an option, a freshman will be assigned an adviser in that option, whose approval must then be obtained for pre-registration for the following year.

An undergraduate may be allowed to major in two options for the Bachelor of Science degree. In order to do so he must obtain the approval of the Curriculum Committee prior to the beginning of his senior year. He will then be assigned an adviser in each option.

Change of Option. Students wishing, or required, to change options must first obtain a Change of Option petition from the Registrar's Office. The completed petition must be signed by the Option Representative for the new option who will assign a new adviser, and then the petition must be filed in the Registrar's Office.

Leave of Absence. Leave of absence involving non-registration for one or more terms must be sought by written petition. A leave up to one year can be granted by the appropriate dean for a student who is in good standing.* A petition for a *medical* leave of absence must carry the endorsement of the Director of Health Services or his representative and the appropriate dean. 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. All leaves of absence will be reviewed by the Committee. In case of brief absences from any given class activity, arrangements must be made with the instructor in charge.

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

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*A student in good standing is defined as a student who does not have to meet special grade-point requirements as a result of reinstatements.

Monday of November preceding the date at which he expects to receive the degree. His record at the end of that term must show that he is not more than 21 units behind the requirement in the regular work of his course as of that date. All subjects required for graduation, with the exception of those for which the candidate is registered during the last term of his study, must be completed by the second Monday of May preceding commencement.

Transcripts of Records. A student, or former student, may request that official transcripts of his records be forwarded to designated institutions or individuals. Requests should be filed at the Registrar's Office at least five days prior to the date on which the transcripts are to be mailed.

STUDENT HEALTH AND PHYSICAL EDUCATION

Physical Education

Prior to graduation each undergraduate is required to successfully complete three terms of physical education. This requirement may be satisfied entirely or in part by participation in intercollegiate athletics, successful completion of a physical education class, or successful completion of a student-designed program of physical recreation. Further explanation of each aspect of the program appears below.

Participation as a bona fide member of an intercollegiate team for the period covered by a sport in a given term satisfies the requirement for that term. Students dropping from an intercollegiate team prior to the end of the term or the season must enroll in a physical education class immediately, if they wish to receive credit for physical education.

A broad program of instruction is provided each term. Enrollment in the classes is conducted in the gymnasium and pool on the day of General Registration. A swimming test is required of those planning to enroll in scuba diving or sailing. Standards for evaluation of student performance will be clearly defined at the beginning of each class. Participation in intramural sports will count towards the successsful completion of an instructional activity.

Student-designed programs of physical recreation are submitted in writing to the Department of Physical Education during the pre-registration period. These programs must provide for regular participation in vigorous physical activity at least three days per week. The programs may consist of individual or group participation and may include intramural sports participation. At the end of the term the student files a brief written report with the Department of Physical Education reviewing his accomplishment of prestated objectives. It is assumed that students proposing their own program of physical recreation are competent in the activities proposed.

For graduate students there is no required work in physical education, but opportunities are provided for both recreational and competitive athletics. Graduate students should consult the Department of Athletics and Physical Education for further information.

Student Health

PRE-ADMISSION MEDICAL EXAMINATION

All admissions, whether graduate or undergraduate, are conditional until the Medical History and Physical Examination report is received and approved by the Director of Health Services (see page 165). Required are: tetanus immunization and tuberculosis testing.

STUDENT HEALTH SERVICES

The Archibald Young Health Center is located at 1239 Arden Road, south of California Boulevard. Facilities include a dispensary and a ten-bed infirmary. The Health Center provides general office medical care, minor emergency surgery, and psychological and psychiatric services. Complete laboratory facilities are available through the Pasadena Clinical Laboratory.

The services of the Health Center are available to undergraduate and graduate students. They are available for faculty on a limited basis, covering emergency care, on-the-job injuries, inoculations, and annual physical examinations under certain conditions. They are available for employees of the Institute for on-the-job injuries and inoculations.

The staff of the Health Center consists of attending physicians, consultants, psychologists, nurses, and a receptionist. A medical consultant in radiological safety is on the consulting staff. Close cooperation is maintained with leading specialists in all fields within the Pasadena area. The services of these doctors are used freely in maintaining high standards of modern medical care.

The attending physician is present Monday through Friday from 1:30-4:00 p.m., except during the summer months, when a slightly restricted schedule is observed. The Infirmary is operated (with a registered nurse available for emergency care, and a physician on call for emergencies) twenty-four hours a day, seven days a week, except during holidays and the summer period.

The Health Center is financed by the Institute and a Health Fee. During the summer, a special health fee of $17.50 is charged to student trainees and to students who have not been enrolled during the preceding three school terms, except that those graduate students who pay regular tuition during the summer months are exempt from this special fee.

STUDENT HEALTH PLAN

In addition to services available at the Health Center, year-around coverage under California Blue Cross is provided. This integrated two-part plan includes basic hospital and surgical and major medical coverage for 80% of costs up to $10,000 after a $100 deductible. Details of coverage are contained in booklets available at the Personnel Office. All students are included, and benefits continue for twelve months, on campus and off campus, provided students remain enrolled through the school year. Students have available the following services:

1. Office consultations and treatment with a staff physician at prescribed hours;
2. Laboratory tests, consultations, and radiographs as prescribed or ordered by the staff physician;
3. Inoculations and treatments administered by nurses;
4. Routine drugs and medicine which may be dispensed at the Health Center;
5. Infirmary and hospital care;

6. Emergency care, hospital benefits, physician visits while in the hospital, and surgical benefits outlined in the Student Health Plan brochure available at the Personnel Office and also distributed upon registration;
7. In hardship cases funds are available to the Faculty Health Committee to assist students with outstanding medical expenses;
8. Psychological counseling and psychiatric service. A staff psychiatrist and two staff psychologists are available at the Health Center;
9. The Department of Physical Education maintains an insurance plan covering accidents in intercollegiate athletic participation.

COVERAGE OF DEPENDENTS

Besides the student coverage outlined above, a student's spouse and all unmarried dependent children over 14 days and under 19 years of age are eligible under the California Blue Cross contract. Dependent care is not administered at the Health Center except in case of severe emergency.

Application for dependent's insurance must be made at the time of registration or within 31 days of registration for any one school term. Rates applicable to dependent coverage are contained in the Student Health Plan brochure.

SERVICES NOT PROVIDED BY STUDENT HEALTH PLAN

1. Services provided to the student not authorized or requested by the Health Center staff (except during vacations or emergencies when the student is unable to utilize services of the Student Health Center).
2. Services for pregnancy or conditions arising therefrom, except for ectopic pregnancies.
3. Workman's Compensation cases.
4. Services provided by federal or state governmental agencies or without cost to the student by any other governmental agency.
5. Services provided by any other medical or hospital service organization.
6. Eye refractions.
7. Hospitalization for tuberculosis after diagnosis, except when required for surgery.
8. Dental services, including oral surgery and hospitalization for such, except that up to $300 is provided for care of injury to the permanent teeth.
9. Allergy workup.

RESPONSIBILITY OF THE STUDENT

The responsibility for securing adequate medical attention in any contingency, whether emergency or not, is solely that of the student, whether the student is residing on or off campus. Apart from providing the opportunity for consultation and treatment at the dispensary and infirmary, as described above, the Institute bears no responsibility for providing medical attention.

Any expenses incurred in securing advice and attention in any case are entirely the responsibility of the student, except as specified above. To secure payment and substantiate a claim for services rendered away from the Institute, the student is required to retain bills for such services and present them with appropriate documentation when a major medical claim is made through the Personnel Office.

UNDERGRADUATE EXPENSES

For freshmen applying for admission, there is a $10 Application Fee, not refundable, but applicable upon registration to the Tuition Fee.

For freshmen and transfer students, there is a $10 Registration Fee payable upon notification of admission, and not refundable if admission is cancelled by the applicant. Housing contracts, accompanied by a $50 deposit, must be returned to the Master's Office by the date specified in the instructions accompanying the contract. The deposit will be applied to the first term room charge.

EXPENSE SUMMARY

	1973-74
General:	
General Deposit	$ 25.00[1]
Tuition	2,886.00
Health Fee	84.00
Student Body Dues, including *California Tech*	22.00[2]
Assessment for *Big T*	8.00[2]
	$3,025.00
Others:	
Books and Supplies (approx.)	$ 150.00
Student House Living Expenses	
(Room rates are subject to change)	
Room	620.00[3]
Dues	30.00
	$ 800.00
Meals — available at Chandler Dining Hall	

The following is a list of undergraduate student expenses at the California Institute of Technology for the Academic Year 1973-74 together with the dates on which the various fees are due. Charges are subject to change at the discretion of the Institute.

	First Term	***Fee***
September 19, 1973	General Deposit	**$ 25.00**
(*Freshmen*)	Tuition	962.00
September 24, 1973	Health Fee	84.00
(*All Others*)	Associated Student Body Dues	**7.00**
	Assessment for *Big T*	**3.00**
	Room	249.00
	Student House Dues	**10.00**

[1]This charge is made only once during residence at the Institute (see this page).

[2]Fees subject to change by action of the Board of Directors of the Associated Students of the California Institute of Technology.

[3]There are a few single rooms available which will rent for an additional $65 per year. Room contracts are on a term basis for all students.

	Second Term	
January 7, 1974	Tuition	$962.00
	Associated Student Body Dues	7.50
	Assessment for *Big T*	2.50
	Room	195.00
	Student House Dues	10.00
	Third Term	
April 1, 1974	Tuition	$962.00
	Associated Student Body Dues	7.50
	Assessment for *Big T*	2.50
	Room	176.00
	Student House Dues	10.00
Tuition Fees for fewer than	normal number of units:	
	Over 35 units	Full Tuition
	Per unit per term	28.00
	Minimum per term	280.00
	Auditor's Fee (p. 171) $40.00 per term, per lecture hour	

Refunds. Students withdrawing from the Institute or reducing their number of units during the first three weeks of a term for reasons deemed satisfactory to the Institute, are entitled to a refund of tuition less a pro rata charge. Computation of this charge is based on the period elapsed, from the beginning of the term to:

1. The date the request is made to the Dean of Students for *Withdrawals.*
2. The date the petition is presented to the Office of the Registrar for *Leave of Absence.*
3. The date that registration for the reduced units is approved by the Undergraduate Academic Standards and Honors Committee or the date that drop cards are filed in the Registrar's Office, whichever is later, for *reduction in units.*

Room contracts are charged on a term basis for all students. Premature termination of a room contract will be granted only with the approval of the Master of Student Houses.

Associated Student Body Dues. As a service to the Associated Students, ASCIT dues of $22 per year and an assessment of $8 for the college annual, the *Big T,* are collected by the Institute and turned over to ASCIT. A subscription to the student newspaper, *California Tech,* is included in these dues and the balance is used in the support of student activities as deemed appropriate by the ASCIT Board of Directors. Students not wishing to join ASCIT or to purchase the *Big T* should so indicate at the time of registration.

General Deposit. Each new student is required at his first registration 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.

Fees for late registration. Registration is not complete until the student has personally turned in the necessary registration forms for a program approved by his adviser and has paid his tuition and other fees. A penalty fee of $10 is assessed for failure to register within five days of the scheduled date, and a fee is also assessed for failure to pay fees within the specified dates. These requirements apply to all three terms.

Winnett Student Center. Winnett Student Center facilities are reserved for the use of Caltech students and their guests. A contribution of fifty cents a year is made by each member of the Associated Student Body ($1 by other students wishing to use the facilities) to help defray the expenses of the game room.

Student Houses. Students in the Houses must supply their own blankets. 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 155).

Special Fees. Students taking the Summer Field Geology course (Ge 123) should consult with the division about travel and subsistence arrangements and costs.

Unpaid Bills. All bills owed the Institute must be paid when due. Any student whose bills are delinquent may be refused registration for the term following that in which the delinquency occurs. Students who have not made satisfactory arrangements regarding bills due and other indebtedness to the Institute by the date of graduation will be refused graduation. Transcripts cannot be released until all bills due have been paid or satisfactory arrangements are made with the business office for payment.

SCHOLARSHIPS, STUDENT AID, AND PRIZES

1. Scholarship Grants for Entering Students

Freshman scholarship grants are awarded by the Freshman Admissions Committee to candidates who have been admitted to the Institute and have submitted a *Parents' Confidential Statement* (see below). Scholarship grants to transfer students are awarded on the same basis by the Upperclass Admissions Committee. Scholarship grants are awarded to the extent of available funds where financial need is demonstrated.

Applications by entering students for scholarship grants must be made on a form called the *Parents' Confidential Statement.* This form may be obtained in nearly all cases at the school the applicant is attending. If his school does not have a supply, he should write to the College Scholarship Service at one of the College Entrance Examination Board offices, the addresses of which are given on page 163. 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 163) and not to Caltech.

Parents' Confidential Statement forms must be sent to the appropriate College Board office not later than February 1 of the year in which admission is desired for freshman applicants, and by April 1 for transfer applicants. All applicants who have submitted this form by the above dates are considered for scholarship grants. *It is not necessary to apply for any particular scholarship by name.*

STATE AND NATIONAL SCHOLARSHIP AWARDS

Candidates for freshman scholarships are urged to make exhaustive inquiry of their school advisers and to watch their school bulletin boards for announcements of scholarship contests the winners of which may use the awards at the college of their choice. The State of California, for example, awards such scholarships annually to residents of the state who wish to attend a college within the state. Residents of the State of California who request financial aid will be penalized in consideration for scholarship grants if they do not apply for California State scholarships, provided their test scores indicate that they would have won a State award had they applied. Among the nationwide awards are the National Merit Scholarships and the Westinghouse Talent Search Awards. Applicants in need of financial assistance should enter any such contest for which they are eligible, in addition to applying for California Institute Scholarship grants. While duplicate awards will not be given beyond the actual extent of need, the more sources to which a candidate applies the greater are his chances of receiving scholarship assistance.

REGULATIONS AND RENEWALS

Recipients of scholarship grants are expected to maintain a satisfactory standing in their academic work during the year for which the scholarship is granted. If the recipient fails to maintain such an academic standing, or if, in the opinion of the Scholarships and Financial Aid Committee, the recipient in any way fails to justify the confidence placed in him, the Committee may cancel the scholarship. Recipients of scholarships which run for more than one year are expected to pass all courses in their freshman year and thereafter to maintain at least a 2.5 grade-point average. The amount of the award carried by these scholarships may be increased or decreased at the beginning of any year if the financial need has changed. Freshmen who receive scholarship awards for the freshman year only will be considered for scholarship aid in subsequent years on the basis of need according to the regulations in the following paragraph.

2. Upperclass Scholarship Grants

Sophomores, juniors, and seniors are considered for scholarships if need is demonstrated and if they have completed the preceding academic year with a satisfactory academic record. When individual scholarships carry amounts in excess of full tuition and other expenses exclusive of room and board, the excess is given in the form of a credit against room and board in the Student Houses. A student who expects to finish the academic year satisfactorily and who wishes to apply for a scholarship grant for the next year should obtain a scholarship form from the Admissions Office in March. This form is to be filled out by the student and his parents (or guardian) and returned to the Admissions Office by May 1. No one will be considered for a scholarship grant unless a scholarship form completely filled out and signed by parents (or guardian) is submitted by the proper date. If a scholarship applicant feels that his parents should no longer be responsible for his support, he may attach an explanatory note to the form, but the form must be filled out.

It is expected that students to whom awards are made will carry a full academic load and 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 special scholarship funds. Where the amount of a grant is not specified, there is a certain total sum available each year to be distributed among several scholarship holders in any proportion. It is not necessary to apply for any particular scholarship by name. Applicants for admission who have a *Parents' Confidential Statement* on file will be considered for the best award to which their relative need and academic standing entitle them.

4. Student Aid Loan Funds

INSTITUTE LOAN FUNDS

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 available funds. There are three sources of loan funds and the conditions governing each are described below.

1. California Institute loan funds are available in amounts not to exceed $1,000 in any one year and a maximum of $4,000 during undergraduate residence. No interest is charged and no repayment of principal is required during undergraduate residence as long as residence is continuous (the term "residence" includes the usual vacation periods). For those who do not go on to graduate school, repayment commences after graduation of their class and is at the rate of $65 per month including simple interest at 4 percent per annum on the unpaid balance. For those who go on to graduate school at Caltech or elsewhere not later than the fall following their class graduation, interest is charged at the rate of 3 percent per annum, but no principal is required until the final advanced degree is earned, provided that the borrower remains in continuous residence. After the final degree has been earned, repayment commences at the rate of $65 per month including interest at 4 percent on the unpaid balance. The interest rate increases to 5 percent starting three years after the final degree and to 6 percent starting five years after the final degree and continues at 6 percent until the loan has been repaid in full. If the borrower withdraws from undergraduate or graduate registration at any time before receiving the last degree for which he has been working, the total amount owed the Institute becomes due and payable at once, unless the Scholarships and Financial Aid Committee agrees to some exception to this rule.

It is inadvisable for foreign students from countries with seriously adverse rates of exchange to borrow more than they can repay from savings (after taxes) out of salaries earned in the United States. Upon application to the Federal Government, students may be allowed a maximum extension of only 18 months on students' visas for holders who engage in full-time commercial employment after they take their degrees. For practical purposes, this means that total indebtedness may not exceed $2,000

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

2. Federal loans under the National Direct Student Loan Program are available to undergraduate students who are citizens or permanent residents of the United States.

The program, in conjunction with the Institute practice, limits borrowing to $1,500 per year with a maximum of $2,500 for the first two years. After the initial two years are completed, the student may borrow $1,500 per year in the third and fourth years with a maximum of $5,000 while in undergraduate status. The borrower must demonstrate financial need and must submit an affidavit of educational purpose. No interest is charged on these loans nor is any repayment of principal required until nine months after the final degree has been earned. At that time repayment commences and interest is charged at the rate of 3 percent per annum on the unpaid balance.

For loans to graduate students under the National Direct Student Loan Program see page 285.

3. The Higher Education Act of 1965 also contains provisions for student assistance through loans insured by the federal government (Title IV, Part B). The maximum loan amount is $1,500 per academic year with an aggregate maximum of $7,500.

Deferred Payment Plan. In addition to loans there is available a plan under which any student in good standing may defer up to $1,500 of his college bills each year to a total of $6,000 and may pay the deferred portion in installments after the graduation of his class. Interest on the amount deferred is charged at the current bank prime rate plus 1% and is payable quarterly. The interest is the only payment made under this plan during the undergraduate years. On November 1 following his class' graduation, the student commences repayment on the deferred portion at the rate of $85 a month including interest. 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 bank under this plan becomes due and payable at once if continuous residence is not maintained.

Loans and the Deferred Payment Plan may be used in combination, but the total that may be borrowed or deferred may not exceed $1,500 in any one year (maximum of $7,500).

Entirely aside from loans and the Deferred Payment Plan, the following organizations offer plans for scheduled payments of education expenses:

1. EFI-Fund Management Corporation, 36 South Wabash, Chicago, Illinois 60603. They offer a ten-month budget plan for annual cost of tuition, fees, room and board. Payment under this plan begins on June 8. Cost of this program is a $20 participation fee per year.

2. The Insured Tuition Payment Plan, offered by the Richard C. Knight Insurance Agency Inc., 6 Saint James Avenue, Boston, Massachusetts 02116, offers two payment programs. Both programs include insurance protection which covers the balance of the cost of the entire education program in the event of the death or disability of the insured parent. They offer a Prepayment Program which begins before the first payment is due at the Institute and ends before graduation. Cost of this program is a $25 initial fee plus a $.50 per month service charge and insurance premium (if coverage is desired). The second program offered is an Extended Repayment Plan which finances the cost of education up to 77 months (six years and five months). Cost of this plan is a $25 initial fee plus interest and an insurance premium (if coverage is desired).

3. The Tuition Plan Inc., Concord, New Hampshire 03301, offers a monthly budget plan to cover tuition and fees over a period of one to four years. Life insurance is

available to all insurable parents. Monthly payments begin as early as June 1, or as late as October 1. Cost of this program is for interest expense and insurance premiums (if coverage is desired).

STUDENT EMPLOYMENT

Students who desire part-time or summer employment will receive assistance from the Placement Office. The requirements of the courses at the Institute are so exacting, however, that under ordinary circumstances, students who are entirely or largely self-supporting through employment should not expect to complete a regular course program in the usual time. It is highly inadvisable for freshman students to attempt to earn a major part of their expenses.

PLACEMENT SERVICE

The Placement Office provides assistance to undergraduate students, graduate students, research fellows, and alumni for the procurement of employment. It arranges for interviews by prospective employers for candidates for degrees and research fellows. Students, both graduate and undergraduate, desiring part-time employment during the school year or during vacations, should register with the Placement Office. Assistance will be given whenever possible in securing employment for summer vacations. Alumni who are unemployed, or desire a change in position, should register with the Placement Office.

The Placement Service maintains a Student Information Center which provides information in the form of brochures, catalogs, and announcements concerned with employment opportunities, admissions to colleges and universities, and fellowships and scholarships offered by universities, foundations, and industry. The brochures show employment opportunities offered by all types of organizations. The Director of Placements is available for consultation and guidance on placement problems.

The Institute assumes no responsibility in obtaining employment for its graduates, although the Placement Office will make every effort to provide suggestions for employment for those who wish to make use of this service.

5. Prizes

THE FREDERIC W. HINRICHS, JR., MEMORIAL AWARD

The Board of Trustees of the California Institute of Technology established the Frederic W. Hinrichs, Jr., Memorial Award in memory of the man who served for more than twenty years as dean and professor at the Institute. In remembrance of his honor, courage, and kindness, the award bearing his name is made annually to the senior who, in the judgment of the undergraduate deans, throughout his undergraduate years at the Institute has made the greatest contribution to the student body and whose qualities of character, leadership, and responsibility have been outstanding. At the discretion of the deans, more than one award or none may be made in any year. The award, presented at commencement without prior notification, consists of $100 in cash, a certificate, and a suitable memento.

THE MARY A. EARLE McKINNEY PRIZE IN ENGLISH

The Mary A. Earle McKinney Prize in English was established in 1946 by Samuel P. McKinney, M.D., of Los Angeles. Its purpose is to promote proficiency in writing. The terms under which it is given are decided each year by the English faculty. It may be awarded for essays submitted in connection with regular English classes, or awarded on the basis of a special essay contest. The prize consists of cash awards and valuable books.

THE DON SHEPARD AWARD

Relatives and friends of Don Shepard, class of 1950, have provided an award in his memory. The award is presented to a student, the basic costs of whose education have already been met but who would find it difficult, without additional help, to engage in extracurricular activities and in the cultural opportunities afforded by the community. The recipients, upperclassmen, are selected on the basis of their capacity to take advantage of and to profit from these opportunities rather than on the basis of their scholastic standing.

THE DAVID JOSEPH MACPHERSON PRIZE IN ENGINEERING

The David Joseph Macpherson Prize in Engineering was established in 1957 by Margaret V. Macpherson in memory of her father, a graduate of Cornell University in civil engineering, class of 1878. A prize of $400 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 and Applied Sciences.

THE ERIC TEMPLE BELL UNDERGRADUATE MATHEMATICS RESEARCH PRIZE

In 1963 the Department of Mathematics established an Undergraduate Mathematics Research Prize honoring the memory of Professor Eric Temple Bell and his long and illustrious career as a research mathematician, teacher, author, and scholar. His writings on the lives and achievements of the great mathematicians continue to inspire many hundreds of students at the California Institute and elsewhere. A prize of $150 is awarded annually to one or more juniors or seniors for outstanding original research in mathematics, the winners being selected by members of the mathematics faculty. The funds for this prize come from winnings accumulated over the years by Caltech undergraduate teams competing in the William Lowell Putnam Mathematics Contest, an annual nationwide competition.

THE GEORGE W. GREEN MEMORIAL PRIZE

The George W. Green Memorial Prize was established in 1963 based on contributions given in memory of George W. Green, who for fifteen years served on the staff of the Caltech business office and was from 1956-1962 Vice President for Business Affairs. The prize of $500 is awarded annually to an undergraduate student, in any class, selected by the division chairmen and the deans on the basis of original research, an original paper or essay in any field, or other evidence of creative scholarship beyond the normal requirements of specific courses.

THE DONALD S. CLARK ALUMNI AWARDS

From funds contributed by the Caltech Alumni Association annual awards may be made to a sophomore and a junior in recognition of service to the campus community and good academic performance. Preference is given to students in the Division of Engineering and Applied Science and to those in Chemical Engineering. The awards honor the work of Professor Clark, class of 1929, both in the field of engineering and in his service to the Alumni Association.

THE HAREN LEE FISHER MEMORIAL AWARD IN JUNIOR PHYSICS

Mr. and Mrs. Colman Fisher have established the Haren Lee Fisher Memorial Award in Junior Physics in memory of their son, who was killed in an automobile accident in May of 1967, in his junior year at Caltech. The General Electric Foundation also contributed to the fund under the matching plan of their Corporate Alumnus Program. A prize of $150 will be awarded annually to a junior physics major, to be selected by a physics faculty committee as demonstrating the greatest promise of future contributions to physics.

THE JACK E. FROEHLICH MEMORIAL AWARD

The family and friends of the late Jack E. Froehlich, who did his undergraduate and graduate work at the California Institute and was later the project manager for Explorer I for the Jet Propulsion Laboratory, have established a prize fund which will provide a gift of money to a junior in the upper five percent of his class who shows outstanding promise for a creative professional career.

THE SIGMA XI AWARD

In accordance with the aim of The Society of the Sigma XI to encourage original investigation in pure and applied science, the Institute Chapter of the Society annually awards a prize of $500, funded from membership dues, to a senior selected for an outstanding piece of original scientific research.

UNDERGRADUATE OPTIONS AND COURSE SCHEDULES

To qualify for a Bachelor of Science Degree at the California Institute of Technology, a student must satisfy the Institute requirements for graduation by obtaining a passing grade in each course listed below, and he must also satisfy the additional requirements listed under one of the undergraduate options.

The Curriculum Committee may in unusual cases excuse an undergraduate student from any of the following Institute requirements upon a petition submitted through his or her option (or prospective option).

INSTITUTE REQUIREMENTS, ALL OPTIONS

Course	Units
Freshman Mathematics (Ma 1abc)	27
Sophomore Mathematics (Ma 2abc)	27
Freshman Physics (Ph 1abc)	27
Sophomore Physics (Ph 2abc)	27
Freshman Chemistry (Ch 1abc)	18
Freshman Chemistry Laboratory (Ch 3a)	6
Additional Freshman Laboratory	9
Humanities Courses (Lit, H, Pl, Mu, Art, and Advanced Languages)	27
Social Sciences Courses (An, Ec, PS, Psy, SS)	27
Additional Humanities and Social Science Courses	54
Physical Education	9

Freshman Laboratory Requirement

All freshmen are required to take at least 15 units of laboratory work in experimental science including Ch 3a (6 units). The additional 9 units of laboratory work must be chosen from APh 9 (6 units per term), Bi 1 (units as arranged), Bi 9 (3 units), Ch 3bc (3 or 6 units per term), ChE 10 (3 units), E 5 (6 units), EE 10 (6 units), Ge 1 (3 units), Ph 3 (6 units), Ph 4 (6 units).

Humanities and Social Sciences Requirements

All students are required to complete satisfactorily 108 units in the humanities and social sciences, including 27 units in courses numbered through 10, normally taken in the freshman year. Students may be excused from this freshman requirement (but not from the 108-unit requirement) by virtue of having scored 4 or 5 on appropriate advanced placement tests, or as a result of their instructor's recommendation during the course of the year. All courses listed under Humanities and Social Sciences (anthropology, art, business economics and management, history, language, literature, music, philosophy, political science, psychology, and social science) count toward the 108-unit requirement except reading courses (these may be granted credit by petition). Work done under the HSS Tutorial Program may also be counted toward this requirement. No more than 27 units of business economics and management (BEM) courses may be used toward the 54-unit requirement of additional humanities or social sciences.

FIRST YEAR, ALL OPTIONS

TYPICAL COURSE SCHEDULE

Differentiation into the various options begins in the second year.

		Units per term 1st	2nd	3rd
Ma 1 abc	Freshman Mathematics (4-0-5)	9	9	9
Ph 1 abc	Kinematics and Particle Mechanics (4-0-5)	9	9	9
Ch 1 abc	General and Quantitative Chemistry (3-0-3)	6	6	6
Ch 3 a	Experimental Chemical Science (0-6-0)	6	.	.
HSS	Introductory courses in the humanities and social sciences. A wide choice of alternatives will be available to students; the registrar will announce the offerings for each term	9	9	9
	Freshman Laboratory Courses[1]	x	x	x
	Additional Electives[2]	x	x	x
PE 1 abc	Physical Education[3]	3	3	3

[1]The additional 9 units of laboratory work must be chosen from APh 9 — 6 units per term; Bi 1 — units as arranged; Bi 9 — 3 units; Ch 3 bc — 3 or 6 units per term; ChE 10 — 3 units; E 5 — 6 units; EE 10 — 6 units; Ge 1 — 3 units; Ph 3 — 6 units; Ph 4 — 6 units.

[2]A partial list of electives particularly recommended for freshmen includes the following: APh 3, APh 4, Ay 1, Bi 2, EE 4, EE 5, Env 1, Ge 1, Gr 1, IS 10, Ph 10, and Freshman Honors (non-credit), all divisions.

[3]Three terms (9 units) of PE are required for the B.S. degree. Students need not elect to take the required PE in the freshman year. It may be taken in any 3 terms prior to graduation.

x — Except for the minimum laboratory unit requirement, the number of units chosen here is optional. If the student chooses no electives except physical education and takes the minimum permissible laboratory courses, the total unit load will be 42 for two terms and 39 for one term. A total load including electives of more than 51 units per term is considered a heavy load. A load in excess of 58 units requires formal approval of a petition for overload (see page 176).

APPLIED MATHEMATICS OPTION

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

OPTION REQUIREMENTS

Passing grades must be received in all of the courses listed below.

1. Ma 5 abc
2. AMa 90 abc
3. AMa 95 abc or Ma 108 abc
4. AMa 101 abc
5. One full-year course from the following group: AMa 104, 105, 151, 152, 153, 161, 181.

6. One full-year course from the following group: Ma 118, 120, 121, 125, 137, 141, 143.
7. Minimum number of units for the B.S. degree — 537.

TYPICAL COURSE SCHEDULE

(For First Year see page 190)

Second Year

		Units per term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Humanities Electives[1]	9	9	9
	Electives	9	9	9
		45	45	45

Third Year

		1st	2nd	3rd
AMa 90 abc	Topics in Applied Mathematics (3-0-6)	9	9	9
AMa 95 abc or Ma 108 abc	Introductory Methods of Applied Mathematics (4-0-8) or Advanced Calculus (4-0-8)	12	12	12
	Humanities Electives[1]	9	9	9
	Electives	18	18	18
		48	48	48

Fourth Year

		1st	2nd	3rd
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
	Humanities Electives[1]	9	9	9
	Electives[2]	27	27	27
		45	45	45

[1]See Institute Requirements for specific rules regarding humanities.
[2]See items 5 and 6 under Option Requirements.

APPLIED PHYSICS OPTION

The applied physics option is designed to connect what is conventionally considered "engineering" and "pure physics." Research in applied physics is an effort to answer questions related to problems of technological concern. Since the interests of both engineering and pure physics cover a broad spectrum of fields which overlap, it is not possible to draw a definite dividing line between them. Realizing this, the applied physics option draws its faculty from the divisions of Physics, Engineering and Applied Science, Chemistry and Chemical Engineering, and Geology. This interdivisional aspect of the new option allows a flexibility and range in curriculum, appropriate to the student's particular research interests, that may end up being a mixture of courses and research in different divisions.

Specific subject areas of interest in the program cover a broad spectrum of physics related to different fields of technology. Solid state physics includes work in superconductivity, ferromagnetism, and semiconducting solid state. Work on electromagnetic waves extends from antenna problems into lasers and nonlinear optics. Fluid physics includes magnetohydrodynamics, high temperature plasmas and superfluids. Transport phenomena in gases, liquids, and solids form another active area related to nuclear and chemical engineering.

The undergraduate curriculum attempts to reflect and maintain a close relationship with the various disciplines. This facilitates a transition to or from any of these, if at any time in the student's course of study and research this would be considered to his benefit.

Attention is called to the fact that any student who has a grade-point average less than 1.9 at the end of the academic year in the subjects listed under Applied Physics may be refused permission to continue work of this option. A fuller statement of this regulation will be found on page 194.

OPTION REQUIREMENTS

Passing grades must be obtained in all courses listed below.

1. Any 3 of the following laboratory courses (Ph 3, Ph 5, Ph 6, Ph 7).
2. APh 50 abc.
3. AMa 95 abc.
4. APh 91 ab (2 terms).[1]
5. 54 units of APh electives.[2]
6. 27 units of science or engineering electives. (These may be in APh courses, but in that case they are in addition to the required 54 units).
7. Minimum total number of units for the B.S. degree — 530.

[1]One term of this requirement may be satisfied by not less than 6 units in one of the following laboratory courses: Ph 77, EE 91, Ch 26, ChE 126, MS 104, APh 154.

[2]Any applied physics course with a number greater than 100, Ph 106, Ph 125, Ch 125. None of the courses included in the 54 units shall be elected by the student to be taken on a Pass-Fail basis. Note that APh 100 cannot be used to satisfy this requirement.

TYPICAL COURSE SCHEDULE

(For First Year see page 190)

Second Year

		Units per term 1st	2nd	3rd
Ph 2 abc	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
	Humanities Electives[1]	9	9	9
	Laboratory Electives[2]	6	6	6
APh 17 abc	Statistical Thermodynamics (3-0-6)	9	9	9
	Other Electives[3]	9	9	9
		51	51	51

Third Year

APh 50 abc	Applied Physics (3-0-6)	9	9	9
APh 101 abc	Topics in Applied Physics	2	2	2
AMa 95 abc	Engineering Mathematics (4-0-8)	12	12	12
Ph 106 abc	Topics in Classical Physics	9	9	9
	Humanities Electives	9	9	9
	Other Electives	9	9	9
		50	50	50

Fourth Year

APh 91 ab	Projects Laboratory in Applied Physics minimum[4]	6	6	.
	APh Electives	18	18	18
	Humanities Electives	9	9	9
	Other Electives	18	18	18
		51	51	45

[1]See Institute Requirements for specific rules regarding humanities.
[2]See item (1) Option Requirements.
[3]See items (5, 6) Option Requirements.
[4]Given all 3 terms, open to seniors only.

Suggested Electives

The student may elect any course that is offered in any term provided he has the necessary prerequisites for that course. The following subjects are suggested as being especially suitable for a well-rounded course of study. They need not be taken in the year suggested. Units listed are per term.

Sophomore Year	*Junior Year*	*Senior Year*
Ge 1	Ph 77 ab	APh 91 c
Ge 2	EE 91 abc	APh 100
Bi 1	EE 114 abc	APh 105 abc
Ay 1	AMa 104	APh 114 abc
ME 1 ab	AMa 105 ab	APh 120 abc
ME 3	Ch 26 ab	AMa 101 abc
EE 13 abc	Ay 112 abc	AMa 104
EE 14 abc	Ay 113 abc	AMa 105 ab
EE 90 abc	Ay 10	Ch 125 abc
Ma 5 abc	Ay 15	Ph 125 abc
	Ge 154	Ph 129 abc
	Ge 166 a	Ph 77 ab
	Ge 166 b	
	APh 100	

More Specialized Courses[1]

APh 140 abc	APh 156 abc
APh 141	APh 161 abc
APh 153 abc	APh 163
APh 154	APh 175abc

APh 181 abc	Ch 26 ab
APh 185 abc	Ch 113 abc
APh 190 abc	EE 91 abc
APh 195 ab	Ge 104 abc
AM 135 abc	Ge 154
ChE 103 abc	Ge 166 a
ChE 105 abc	Ge 166 b
ChE 126 abc	

[1]These courses are taught at irregular intervals depending upon demand: consult the preregistration course listing.

ASTRONOMY OPTION

OPTION REQUIREMENTS

For graduation in the astronomy option a total of 521 units is required, consisting of the Institute requirement of 258 units (see page 189) and the option requirement of 263 units. The option requirements are as follows:

	units
Ay 20	11
Ph 3, Ph 5 or 6, Ph 7	12–18
Ph 92 abc	27
Ph 106 abc	27
Any two: Ay 21, Ay 22, Ay 100, Ay 110	15–21
Science or Engineering electives (18 out of division)	27
Ay or Ph electives	54
Electives	78–90
	263

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed in the Division of Physics, Mathematics and Astronomy may, at the discretion of his department, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 174.

TYPICAL COURSE SCHEDULE

(For First Year see page 190)

Second Year

		Units per term 1st	2nd	3rd
Ph 2 abc	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ay 20	Basic Astronomy and the Galaxy (3-2-6)	11	.	.
Ph 3, 5, 6, 7	Physics Laboratory[1]	0–6	0–6	6
	Humanities Electives[2]	9	9	9

	Electives[3]	0–9	12–15	12–15
	Suggested total number of units	44–47	45–48	45–48

[1]Students are required to take (a) Ph 3 if not already taken, (b) Ph 5 or Ph 6, and (c) Ph 7.
[2]For rules governing humanities electives, see page 189.
[3]Sophomore electives include at least 27 units of science and engineering courses, of which at least 18 units shall be in subjects other than mathematics, physics, and astronomy. It is desirable for a student to acquire as broad as possible a background in other related fields of science and engineering.

Electives in second, third, and fourth years must include two of the courses Ay 21, Ay 22, Ay 100, Ay 110.

Third Year

Ph 92 abc	Modern Physics (3-0-6)	9	9	9
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ay 101	The Physics of Stars (3-2-6)	.	11	.
Ay 102	Plasma Astrophysics and the Interstellar Medium (3-0-6)	.	.	9
	Humanities Electives[1]	9	9	9
	Electives	18–24	9–12	9–15
	Suggested total number of units	45–51	47–50	45–51

*For rules governing humanities electives, see page 189.

Fourth Year

Astronomy or Physics Electives	18	18	18
Humanities Electives[1]	9	9	9
Electives	18–24	18–24	18–24
Suggested total number of units	45–51	45–51	45–51

*For rules governing humanities electives, see page 189.

Students are encouraged (but not required) to undertake research leading to a senior thesis; credit for this work is provided through Ay 42.

Suggested Electives

The student may elect any course that is offered in any division in a given term, provided that he has the necessary prerequisites for that course. The following list contains courses useful to work in various fields of astronomy and astrophysics.

Bi 1	Introduction to Biology (3-3-3)	.	9	.
EE 5	Introduction to Linear Electronics (3-0-6)	.	.	9
Ge 1	Physical Geology (3-3-3)	9	.	.
Ge 2	Geophysics (3-0-6)	.	9	.
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
AMa 95 abc[1]	Introductory Methods of Applied Mechanics (4-0-8)	12	12	12
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
Ma 112 ab	Elementary Statistics (3-0-6)	9 or	9	.
EE 13 abc	Linear Systems Theory (3-0-6)	9	9	9
EE 14 abc	Electronic Circuits (3-0-6)	9	9	9

EE 20 abc	Physics of Electronic Devices (3-0-6)	9	9	9
EE 90 abc	Laboratory in Electronics (0-3-0)	3	3	3
Ge 152	Radar Astronomy (3-0-6)	.	9	.
Ge 155	Introduction to Planetary Science (4-0-5)	9	.	.
Ge 166 a	Physics of the Earth's Interior (3-0-6)	.	9	.
Ge 166 b	Planetary Physics (3-0-6)	9	.	.
Ph 77 ab	Advanced Physics Laboratory	.	6	6
Ph 93 abc[1]	Topics in Contemporary Physics (3-0-6)	9	9	9
Ph 125 abc[1]	Quantum Mechanics (3-0-6)	9	9	9
Ay 21	Galaxies and Radio Sources (3-0-6)	.	9	.
Ay 22	Solar System Astronomy (3-0-6)	.	.	9
Ay 100	Astronomical Measurements and Instruments (3-3-6)	12	.	.
Ay 110	Senior Seminar in Astrophysics (2-0-1)	.	6	.
Ay 131	Stellar Atmospheres (3-0-6)	9	.	.
Ay 132	Stellar Interiors (3-0-6)	9	.	.
Ay 133 abc	Radio Astronomy (3-0-6)	9	9	9
Ay 141 abc	Research Conference in Astronomy (1-0-1) ...	2	2	2

[1]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 190)

The undergraduate option in biology is designed to give the student an understanding of the basic facts, techniques, and concepts of biological science as well as a solid foundation in physical science. Emphasis is placed on the more general and fundamental properties of living creatures, thus unifying the traditionally separate fields of the life sciences. Involvement of undergraduates in the research programs of the division is encouraged.

Flexibility to accommodate varied individual scientific interests, within the broad scope of biology, is achieved through the provision of numerous electives courses, through the program of tutorial instruction (Bi 23) and through the Biology Scholar's Program (Bi 27 — see below).

The undergraduate option serves as a basis for graduate study in any field of biology or for admission to the study of medicine.

Biology Scholar's Program. This program permits — for a small number of biology juniors and seniors — the formulation of individual academic programs, combining course work and independent study, adapted to each student's interests and requirements. Each program must be acceptable to and is supervised by a faculty committee; work is undertaken and evaluated on the basis of a written "contract" between the student and his committee and instructors. Students in this program continue to be bound by the normal Institute requirements outside of the biology option; however credit within the program may be, by agreement, on a Pass-Fail basis.

Admission into the Scholar's Program is limited and continuance is contingent upon satisfactory progress. For further details, consult the Biology Undergraduate Student Adviser.

Undergraduate Research. The division encourages undergraduate participation in its research programs; such research can frequently be of a depth and caliber so as to result in a research report or scientific publication. Research opportunities may be arranged with individual faculty members or guidance may be obtained from the Biology Undergraduate Student Adviser.

Premedical Program. The undergraduate course for premedical students is essentially the same as that for biology students and is intended as a basis for later careers in research as well as in the practice of medicine. It differs in some respects from premedical curricula of other schools; however, it has been quite generally accepted as satisfying admission requirements of medical schools. Slight modifications in the curriculum may be required for admission to certain medical schools, or in cases in which the student wishes to try to complete admission requirements in three years instead of four.

It is recommended that all students contemplating application to medical school consult with the premedical adviser, Professor Hood.

Marine Biology. In addition to the courses listed in this catalog, arrangements may be made to take courses in marine biology offered at the Santa Catalina Marine Biological Laboratory.

TYPICAL COURSE SCHEDULE

Second Year

		Units per term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
	Humanities Electives[1]	9	9	9
	Science or Engineering Electives[2]	12	3	3
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
Bi 1	Introduction to Biology (3-3-3)	.	9	.
Bi 9	Cell Biology (3-3-3)	.	.	9
		48	48	48

[1]For rules governing humanities electives, see page 189.
[2]The following sophomore electives are recommended* for biology majors:

Electives

Ch 46 ab	Experimental Methods of Covalent Chemistry (0-6-2)	.	8	8

Third Year

	Humanities Electives*	9	9	9
Bi 7	Organismic Biology (3-5-4)	12	.	.
Bi 110 ab	Biochemistry (3-0-7)	10	10	.
Bi 111	Biochemistry Laboratory (0-8-2)	.	10	.
Bi 122	Genetics (3-3-6)	.	.	12
	Electives	15–21	17–23	25–31

[1]For rules governing humanities electives, see page 189.

Electives

Bi 3	Biology and Social Problems (2-0-4)	.		.		6
Bi 22	Special Problems	x	or	x	or	x
Bi 23	Biology Tutorial (units up to 6 maximum)	x	or	x	or	x
Bi 27	Biology Scholar's Program	x	or	x	or	x
Bi 101	Invertebrate Biology (2-6-4)	.		12		.
Bi 102	Vertebrate Biology (2-5-5)	.		12		.
Bi 106	Developmental Biology of Animals (2-3-4)	.		9		.
Bi 114	Immunology (3-0-4)	7		.		.
Bi 116	Immunology Laboratory (0-5-0)	5		.		.
Bi 119	Advanced Cell Biology (3-0-6)	.		.		9
Bi 134	Advanced Research Techniques in Molecular Biology (0-10-4)	14		.		.
Bi 135	Optical Methods in Biology (2-0-4)	6		.		.
Bi 136	Optical Methods in Biology Laboratory (0-6-2)	8		.		.
Bi 137	Multicellular Assemblies (2-2-4)	.		.		8
Bi 153	Brain Studies of Motivated Behavior (3-0-6)	.		.		9
Bi 155	Psychobiology (2-0-4)	.		6		.
Bi 156	Neurochemistry (3-0-6)	.		.		9
Ch 21 abc	Physical Chemistry (3-0-6)	9		9		9
Env 144	Ecology (2-1-3)	.		.		6
L 1 abc	Elementary French (3-1-6)	10		10		10
L 32 abc	Elementary German (4-0-6)	10		10		10
L 50 abc	Elementary Russian (4-0-6)	10		10		10

Fourth Year

	Humanities Electives*	9	9	9
Bi 151	Neurophysiology (3-0-6)	9	.	.
	Electives	31–36	37–42	37–42
		49–54	46-51	46–51

Electives

In addition to those listed for the third year:

Bi 115	Virology (3-4-3)	.		.		10
Bi 129	Biophysics (2-0-4)	.		6		.
Bi 132 ab	Biophysics of Macromolecules (3-0-6)	9		9		.
Bi 133	Biophysics of Macromolecules Laboratory (0-10-4)	.		14		14
Bi 141	Selected Topics in Evolution Theory (3-0-6)	.		.		9
Bi 152	Behavioral Biology (2-0-4)	.		6		.
Bi 161	Neurophysiology Laboratory (0-5-1)	6		.		.
Bi 208	Selected Topics in Neurobiology	.		x	or	x
Bi 209	Psychobiology Seminar (units to be arranged)	x	or	x	or	x
Bi 220 abc	Developmental Biology of Animals (1-0-3)	4		4		4
Bi 241	Advanced Topics in Molecular Biology (2-0-4)	.		.		6
Bi 260	Advanced Physiology (units to be arranged)	x	or	x	or	x
Ch 144 ab	Advanced Organic Chemistry (3-0-6)	9		9		.

Ch 244 ab	Molecular Biochemistry (3-0-3)	6	6	.
Env 145 a	Environmental Biology (2-4-4)	.	10	.
Env 145 b	Environmental Biology (3-0-6)	.	.	9
Ge 5	Geobiology (3-0-6)	.	.	9

Any advanced course offered by another division, subject to approval by the student's adviser.

[1]For rules governing humanities electives, see page 189.

CHEMICAL ENGINEERING OPTION

Chemical Engineering is one of the broader of the applied disciplines, since it involves intellectual development in the fundamental areas of mathematics, physics, and chemistry; in addition, it requires decision making in problem areas calling for judgment in economic and social matters. Study in this option leads, especially when followed by graduate work, to careers in teaching and research in colleges and universities or to opportunities in government and industrial concerns, including research, development, and management of broad classes of problems involving chemical systems.

The first-year general chemistry course, which is taken by all freshman students, emphasizes fundamental principles and their use to systematize descriptive chemistry. The one-term required laboratory is essentially in quantitative analysis, but is designed to train the student to plan, execute, and critically interpret experiments involving quantitative measurements of various physical quantities. The laboratory in the second and third terms is optional and is designed to introduce the student to current experimental work in chemical synthesis, structure, and dynamics. Students who show themselves to be qualified by having done well in an Advanced Placement or equivalent course, and having passed a short additional departmental examination, may elect to take an advanced general chemistry course that differs chiefly from the main course by having different lectures.

In the second year of chemical engineering there is a basic course in thermodynamics and a basic course covering the properties and reactions of covalent organic and inorganic compounds. The associated laboratory course is elective in the second year and is designed to provide knowledge of the fundamental manipulative and spectroscopic techniques through studies of reactions and preparations of covalent compounds. In addition, there are elective courses which can be used by the student to enlarge his understanding of other fields of science and engineering.

In the third year, the chemical engineering option requires a basic course in physical chemistry. Chemical engineering laboratory is required in the first term, and in the second term the student may continue that laboratory or take the laboratory in physical chemistry. The chemical engineering option requires professional courses which include transport phenomena and engineering mathematics.

In the fourth year, chemical engineering curriculum contains courses in chemical kinetics and optimal design of chemical systems as well as electives in engineering and science and a course in advanced analytical chemistry.

Undergraduate research is emphasized and students are encouraged even in the freshman year to participate in research in association with staff members. Over the past years these researches have resulted in a significant number of publications in scientific journals.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed under the Division of Chemistry and Chemical Engineering may, at the discretion of the faculty in this division, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 174.

OPTION REQUIREMENTS

Second Year

		Units per term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Sophomore Physics (4-0-5)	9	9	9
Ch 41 abc	Sophomore Chemistry (3-0-6)	9	9	9
ChE 63 abc	Chemical Engineering Thermodynamics (3-0-6)	9	9	9
	Electives[1]	9	9	9
		45	45	45

Third Year

ChE 126 ab[2]	Chemical Engineering Laboratory (1-6-2)	9	9	.
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
Ch 21 abc	The Physical Description of Chemical Systems (3-0-6)	9	9	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
	Electives[1]	9	9	18
		48	48	48

Fourth Year

ChE 101 ab	Applied Chemical Kinetics (3-0-6)	9	9	.
ChE 110 abc	Optimal Design of Chemical Systems (3-0-6)	9	9	9
	Electives[1]	18	18	33
		36	36	42

[1]A full statement of the electives requirements follows below.
[2]Students may elect Ch 26 a instead of ChE 126 b.

ELECTIVE COURSES

A minimum of 132 units of elective courses beyond the freshman year are required for graduation in the chemical engineering option. These must include:

a. a total of 81 units of courses in humanities or social sciences, in addition to the 27 units taken during the freshman year, to satisfy the Institute HSS requirement. Included in the combined 108 units, the chemical engineering option requires Ec 11;
b. a total of 18 units of chemistry courses, to be chosen in consultation with the adviser;
c. a total of 6 units of laboratory courses, in addition to the 9 units taken during the freshman year. These units must be different from those used to satisfy the chemistry requirement of 18 units, and may not include laboratory units from either applied mathematics or information science.

The remaining required elective units must be composed of either science or engineering courses, and must be approved by the adviser. It is intended that these electives supplement the specific professional requirements by providing the student with the opportunity to tailor his program to suit his own special interests or needs. Hence, the courses selected (in consultation with the adviser) may be used to enlarge the student's general understanding of other fields of science or engineering, to pursue special interests, to study more advanced topics from the chemical engineering curricula or to participate in undergraduate research. If research (ChE 80) units are to be used to fulfill elective requirements in the chemical engineering option, a thesis approved by the research director must be submitted in duplicate before May 10 of the year of graduation.

CHEMISTRY OPTION

(For First Year see page 190)

Study in the chemistry option leads, especially when followed by graduate work, to careers in teaching and research in colleges and universities, in research in government and industry, in operation and control of manufacturing processes, and in management and development positions in the chemical industry.

The first-year general chemistry course, which is taken by all freshman students, emphasizes fundamental principles and their use to systematize descriptive chemistry. The one-term required laboratory is essentially in quantitative analysis, but is designed to train the student to plan, execute, and critically interpret experiments involving quantitative measurements of various physical quantities. The laboratory in the second and third terms is optional and is designed to introduce the student to current experimental work in chemical synthesis, structure, and dynamics. Students who show themselves to be qualified by having done well in an Advanced Placement or equivalent course and having passed a short additional departmental examination may elect to take an advanced general chemistry course that differs chiefly from the main course by having different lectures.

There are no formal chemistry course requirements in the chemistry option except for 2 units of Ch 90. Each student, in consultation with his adviser, selects a suitable course of study under the supervision of the division. Within the total period of undergraduate study there are Institute requirements for Ma 1 abc, Ph 1 abc, Ma 2 abc, Ph 2 abc, and 108 units of humanities and/or social science as well as 9 units of physical education.

The group of courses listed below would constitute a common core for many students in the option.

Any student of the chemistry option whose grade-point average in the required chemistry subjects of any year is less than 1.9 will be admitted to the required chemistry subjects of the following year only with the special permission of the Division of Chemistry and Chemical Engineering.

Second Year

		Units per term 1st	2nd	3rd
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6) ...	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9

Ch 46 a	Experimental Methods of Covalent Chemistry (0-6-2)	.	8	.
	Electives	15–18	7–10	15–18
PE	Physical Education (0-3-0)	3	3	3
		45–48	45–48	45–48

Third Year

Ch 14	Chemical Equilibrium and Analysis (2-0-4)	6	.	.
Ch 15	Chemical Equilibrium and Analysis Laboratory	10	.	.
Ch 21 abc	The Physical Description of Chemical Systems (3-0-6)	9	9	9
Ch 90	Oral Presentation (1-0-1)	2	.	.
	Electives	20–24	38–42	38–42
		47–51	47–51	47–51

Fourth Year

Ch 26 a	Physical Chemistry Laboratory (0-6-4)	.	10	.
	Electives	47–51	37–41	47–51
		47–51	47–51	47–51

This core program is not rigorously required for graduation in the option, nor is it in any sense a complete program. Students are expected to work out individual programs suitable for their interests and professional goals in consultation with their advisers. Several representative programs, including sets of possible electives, are shown below. These may well approximate choices by students who intend to do graduate work in conventional areas of chemistry.

SUGGESTED REPRESENTATIVE COURSES OF STUDY FOR THOSE INTENDING TO DO GRADUATE WORK IN PARTICULAR AREAS OF CHEMISTRY

Inorganic Chemistry	*Chemical Physics*	*Organic Chemistry*	*Chemical Biology*
Sophomore Year	Sophomore Year	Sophomore Year	Sophomore Year
Ch 41 abc	Ch 41 abc	Ch 41 abc	Ch 41 abc
Ch 46 ab	Ch 46 a	Ch 46 ab	Ch 46 ab
Ph 2 abc	Ph 2 abc	Ph 2 abc	Ph 2 abc
Ma 2 abc	Ma 2 abc	Ma 2 abc	Ma 2 abc
PE 2 abc	PE 2 abc	PE 2 abc	PE 2 abc
Electives[a,b]	Electives[a,b]	Electives[c]	Electives[a]
Junior Year	Junior Year	Junior Year	Junior Year
Ch 21 abc	Ch 21 abc	Ch 21 abc	Ch 21 abc
Ch 14	Ch 14	Ch 14	Ch 14
Ch 15	Ch 15	Ch 15	Ch 15
Ch 90	Ch 26 ab	Ch 144 abc	Bi 110
Electives[a,b]	Ch 90	Ch 145 bc	Ch 90
	AM 95 ab	Ch 90	Electives[a]
	Electives[a,b]	Electives[c]	

Senior Year	Senior Year	Senior Year	Senior Year
Ch 26 ab	Ch 125 abc	Ch 26 ab	Ch 26 ab
Ch 113 abc	Ph 106 abc or	L 32 abc[a]	Ch 132 ab
Ch 125 abc	Ch 135	Ch 246 abc	Ch 133
Ch 135 or	Ch 226 abc or	Ch 247 ab	Ch 144
Ch 144 abc	Ch 227 abc	Electives[c]	Bi 111
Electives[a,b]	Electives[a,b]		Electives[a]

[a]It should be recognized that a major fraction of the existing chemical literature, especially of organic chemistry, is in German. Russian is an important language for chemistry but the leading Russian periodicals are translated and published in English. A reading knowledge of German is important for research at the doctoral level.

[b]Experience in computer programming and use is now important to all areas of chemistry.

[c]Courses in biology and biochemistry are recommended as part of these electives.

SUGGESTED ELECTIVE COURSES FOR THE CHEMISTRY OPTION

Ch 3 abc	Experimental Chemical Science (0-6-0 first term, 0-3-0 or 0-6-0 second and third terms)	6	3–6	3–6
Ch 24 abc*	Elements of Physical Chemistry (3-0-6)	.	.	9
Ch 80	Chemical Research	Units to be arranged		
Ch 81	Special Topics in Chemistry	Units to be arranged		
Ch 113 abc	Advanced Inorganic Chemistry (1-0-11)	12	12	12
Ch 117	Introduction to Electrochemistry (2-0-4)	.	6	.
Ch 118 ab	Experimental Electrochemistry	Units to be arranged		
Ch 122 ab	The Structure of Molecules (2-0-4)	6	6	.
Ch 125 abc	The Elements of Quantum Chemistry (3-1-5)	9	9	9
Ch 127 ab	Nuclear Chemistry (3-3-6) or (3-0-3)	12	12	.
Ch 130	Fundamentals of Photochemistry and Photobiology (3-0-3)	.	.	6
Ch 132 ab	Biophysics of Macromolecules (3-0-6)	9	9	.
Ch 133	Biophysics of Macromolecules Laboratory (0-10-4)	.	14 or	14
Ch 144 ab	Organic Chemistry (3-0-6)	9	9	
Ch 145 bc*	Organic Chemistry Laboratory (0-3-0) second term and (0-6-0) third term	.	3	6
ChE 10	Chemical Engineering Systems (3-3-3)	.	.	9
ChE 63 abc	Chemical Engineering Thermodynamics (3-0-6)	9	9	9
ChE 80	Undergraduate Research	Units to be arranged		
ChE 101 abc	Applied Chemical Kinetics (2-0-7)	9	9	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
ChE 105 abc	Applied Chemical Thermodynamics (3-0-6)	9	9	9
ChE 167 abc	Polymer Science (3-0-6)	9	9	9
ChE 168	Polymer Science Laboratory (0-7-2)	.	.	9
ChE 172 abc	Control Systems Theory (3-0-6)	9	9	9
ChE 173 ab	Advanced Problems in Transport (3-0-6)	.	9	9
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
Ay 1	Introduction to Astronomy (3-1-5)	.	9	.
Bi 1	Introduction to Biology (3-3-3)	.	9	.
Bi 9	Cell Biology (3-3-3)	.	.	9

*Not offered 1973-74.

Bi 110 ab	Biochemistry (3-0-7) (Prerequisite Ch 41 a)	10	10	.
Bi 119	Advanced Cell Biology (3-0-6)	.	.	9
Bi 122	Genetics (3-3-6)	.	.	12
E 5 ab	Laboratory Research Methods in Engineering and Applied Science (1-3-2)	.	6	6
Ec 4 ab	Economic Principles and Problems	6	6	.
		or .	6	6
APh 3	Introduction to Solid-State Electronics (3-0-3)	6	.	.
EE 5	Introductory Electronics (2-0-4)	.	.	6
APh 9	Solid-State Electronics Laboratory (1-3-2)	.	6	6
EE 90 abc	Laboratory in Electronics (0-0-3)	3	3	3
Ge 1	Physical Geology (3-3-3)	9	.	.
Ge 130 ab	Introduction to Geochemistry (2-0-4)	6	.	.
IS 10	Introduction to Use of Computers	.	6	6
L 32	Introductory Scientific German (0-0-10)	10	10	10
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
Ph 3	Physics Laboratory	6	6	6
Ph 4	Physics Laboratory	.	.	6
Ph 5	Physics Laboratory	6	.	.
Ph 6	Physics Laboratory	.	6	.
Ph 7	Physics Laboratory	.	.	6
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (4-0-5)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9

*Not offered 1973-74.

ECONOMICS OPTION

(For First Year see page 190)

TYPICAL COURSE SCHEDULE

Second Year

		Units per term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
Ec 11	Introduction to Microeconomics (3-0-6)	9	.	.
Ec 12	Introduction to Macroeconomics: Principles and Problems (3-0-6)	.	9	.
	Electives, not less than*	18	18	27
		45	45	45

Third Year

Ec 121 a	Price Theory (3-0-6)	9	.	.
Ec 122 a	Econometrics (3-0-6)	.	9	.

Ec 126 ab	Money, Income, and Growth (3-0-6)	9	9	.
Ma 112	Elementary Statistics (3-0-6)	9	.	.
	Electives, not less than*	18	18	18
		45	45	45

Fourth Year

Electives, not less than*	45	45	45

*These electives are to include:
a. 54 units of natural science, mathematics or engineering beyond the sophomore level. Students may concentrate on research by taking 54 units of supervised research in their senior year.
b. 45 units of economics, chosen from Ec 98 abc, Ec 111, Ec 112, Ec 115, Ec 116, Ec 120, Ec 121 b, Ec 122 b, Ec 123, Ec 124 ab, Ec 125 ab, Ec 127, Ec 128, IS 181 ab, or any other course approved by the adviser.

ENGINEERING AND APPLIED SCIENCE OPTION

The engineering and applied science option offers the opportunity for study in challenging areas of science and technology. In this option the student may undertake work in such diverse fields as environmental engineering science, solid state physics, the physics of fluids, applied mathematics, earthquake engineering, quantum electronics, aerodynamics, information and computer science, solid mechanics, the science of materials, soil mechanics, bio-engineering science, elasticity and plasticity, plasma physics, and the theory of waves and vibrations. For those students who, in later life, hope to apply the science they learn to the useful and productive solution of the problems now confronting society, the option in engineering and applied science offers an unusually broad curriculum which permits the student to tailor his course of study to his individual needs. The first year of the four-year course of study leading to a Bachelor of Science degree is common for all students of the Institute, although freshman elective subjects are available as an introduction to various aspects of engineering and applied science. At the end of the first year, a student who elects the engineering and applied science option is assigned an adviser in his general field of interest and, together, they develop a program of study for the next three years. Beyond the Institute-wide requirements of physics, mathematics, and humanities, this program requires one year of applied mathematics and a certain number of units selected from a wide variety of engineering and applied science courses as well as interdivisional options such as applied physics and applied mathematics courses, from which the student and his adviser may choose to build a solid foundation for the kind of engineering and applied science activity which the student desires to learn.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed under the Division of Engineering and Applied Science may, at the discretion of the faculty in this division, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 174.

OPTION REQUIREMENTS

Passing grades must be received in all courses listed below.

1. E 10 ab.
2. AMa 95 abc or Ma 108 abc.

3. 99 units of electives in the Division of Engineering and Applied Science, or APh or AMa[1].
4. 27 units of Science or Engineering electives. These units are in addition to requirement 3.
5. 9 units of laboratory from list below[2].
6. 9 additional units of laboratory (excluding those for which freshman credit is allowed)[3].
7. Minimum number of units for the B.S. degree — 525.

[1]These electives must be courses in the Division of Engineering and Applied Science (including Ae, AM, E, EE, ES, Env, Gr, Hy, IS, JP, MS, and ME) or in the interdivisional courses listed under APh and AMa. None of the courses included in the 99 units shall be elected by the student to be taken on a Pass-Fail basis. Any courses in the categories listed above and taken in the freshman year will automatically be graded Pass-Fail. All such courses shall be counted toward the 99-unit requirement since the freshman has no option regarding the grading basis. Laboratory courses taken to satisfy requirements 5 and 6 shall be included in the 99-unit requirement if in the categories listed above.

[2]Courses satisfying this laboratory requirement are:

	Units per term		Units per term
Ae 105 bc	6	EE 197	9
Ae 106 bc	6	Env 116	7
AM 155	9	Hy 111	6-9
AM 160	6	Hy 121	6+
APh 91 abc	6+	JP 170	9
APh 163	9	MS 11	9
APh 164	9	MS 104 abc	9
EE 90 abc	3	ME 126	9
EE 91 abc	6+		

[3]These electives must be complete laboratory courses and not the laboratory portion of a course. They may be selected from the list in (2) above or from laboratory courses offered by other options.

TYPICAL COURSE SCHEDULE

(For First Year see page 190)

Second Year

Ma 2 abc	9	9	9
Ph 2 abc	9	9	9
Humanities Electives[1]	9	9	9
Electives[2]	18	18	18
	45	45	45

Third Year

AMa 95 abc or Ma 108 abc	12	12	12
Humanities Electives[1]	9	9	9
Electives[2]	24	24	24
	45	45	45

Fourth Year

E 10 ab	2	2	.
Humanities Electives[1]	9	9	9
Electives[2]	33	33	33
	44	44	42

[1]See statement on page 189.

[2]See items (3, 4, 5, 6), Option Requirements. The units listed are typical. Most programs will vary somewhat from these numbers of units, but the total number must be selected so as to meet the overall unit requirement indicated in item 7.

NOTES:

I. Suggested electives suitable for particular fields of interest are given below.

II. The programs formed with these suggested electives are only samples of typical programs and are *not* meant to represent special option requirements.

III. These electives must be chosen so as to satisfy the laboratory requirements given in items 5 and 6 on page 206.

Suggested Electives

AERONAUTICS

Freshman Year

One course per term selected from ChE 10, E 5, EE 4, IS 10

*Sophomore Year**

ME 17 abc or APh 17 abc; one course per term selected from: ME 1 ab, ME 3, Ay 1, EE 5, APh 3

Junior Year

AM 97 abc, ME 19 abc; one course per term selected from: APh 50 abc, AM 151 abc, EE 90 abc[1], ME 5 abc, MS 5 abc

Senior Year

Ae 101 abc, or Hy 101 abc, or Ae 102 abc, and three courses per term selected from: Ae 103 abc, Ae 105 abc, AMa 101 abc, AM 112 abc, AM 160[1], Hy 111[1], ME 126[1], JP 121 abc, APh 101, MS 101 abc

APPLIED MECHANICS

Freshman Year

One course per term selected from: E 5, Ge 1, IS 10, EE 4, EE 10

*Sophomore Year**

ME 17 abc; one course per term selected from: ME 3, Ge 1, Bi 1, Ma 31, humanities

Junior Year

AM 97 abc or AM 151 abc, ME 19 abc; one course per term selected from: Ge 2, Ma 112 ab, EE 90 abc[1], APh 50 abc, MS 5 abc

Senior Year

AM 151 abc or AM 97 abc, AM 155, AM 125 abc or AMa 101 abc; one or two courses per term selected from: ME 126[1], AM 135 abc, AM 141 abc, Hy 101 abc, Ph 106 abc, AMa 104, AMa 105 ab

COMMUNICATIONS & CONTROL

Freshman Year

One or two courses per term selected from: IS 10, EE 4, EE 5, EE 10, Ph 3

*Sophomore Year**

EE 14 abc; one course per term selected from: EE 13 abc, IS 110, Ma 112 ab

Junior Year

EE 160 abc, EE 90 ab[1], IS 137, IS 138, IS 139; one course per term selected from: ChE 103 abc, EE 151 abc, Ma 5 abc

Senior Year

AMa 104, AMa 153 abc, EE 161 abc, EE 172 abc, EE 91 ab[1]; one course per term selected from: AMa 105 ab, ChE 173, Ma 144 ab

COMPUTER SCIENCE

Freshman Year

One or two courses per term selected from: IS 10, EE 4, EE 5, EE 10

*Sophomore Year**

IS 137, IS 138, IS 139, Ma 5 abc

Junior Year

IS 110 abc, Ma 116 abc; one course per term selected from:[2] Ma 121 abc, Lit 102, IS 121 abc, IS 141

*Students who have completed Ma 2 or Ma 1.5 prior to their sophomore year are encouraged to take AMa 95 abc as sophomores. Courses suggested in the junior and senior years may then be taken correspondingly earlier.

[1]Satisfies laboratory requirement, no. 5 on page 206.

[2]Consult adviser as to laboratory requirements nos. 5 and 6, on page 206.

[3]Consult adviser as to laboratory requirements nos. 5 and 6, on page 206.

Senior Year

IS 130, Ma 121 abc, AMa 104, AMa 105 ab, IS 140 ab

ELECTRON DEVICE PHYSICS

Freshman Year

One or two courses per term selected from: APh 3, APh 9, EE 4, EE 5, EE 10, Ph 3

*Sophomore Year**

EE 14 abc, APh 17 abc

Junior Year

APh 50 abc, EE 151 abc or Ph 106 abc, EE 90 ab[1], one course per term from: EE 13 abc, MS 5, MS 101

Senior Year

APh 114 abc, APh 181 abc, APh 91 ab[1]; one course per term selected from: APh 105, APh 140, MS 102 abc, Ph 125

ELECTRONIC CIRCUITS

Freshman Year

One or two courses per term selected from: APh 3, IS 10, EE 4, EE 5, EE 10

*Sophomore Year**

EE 14 abc; one course per term selected from: APh 17 abc, IS 110 abc

Junior Year

EE 13 abc, EE 151 abc, EE 90 ab[1]; one course per term selected from: APh 50 abc, IS 137, IS 138, IS 139, ME 19 abc

Senior Year

EE 114 abc, EE 172 abc, EE 91 ab[1]; one course per term selected from: AMa 105 ab, APh 181 abc, EE 160 abc

ENVIRONMENTAL ENGINEERING SCIENCE

(Note: By suitable choice of electives, students may place special emphasis on air, water, or other aspects of the environment)

Freshman Year

Env 1; one course per term selected from: Bi 1, Bi 9, ChE 10, Ch 3 bc, E 5, Ge 1, IS 10

Sophomore Year

ME 17 abc or ChE 63 abc, Ec 4 ab; one course per term selected from: Ch 14, Ch 41 abc, EE 4, EE 10, Env 144, Ge 5, ME 3

Junior Year

ME 19 abc or ChE 103 abc, Env 118; one course per term selected from: AM 97 abc, Ch 15, Ch 21 or 24, Hy 111, Ma 112 ab (or other electives listed above)

Senior Year

AMa 104, AMa 105 ab, AMa 181 abc, CE 105, CE 115 ab, Env 112 abc, Env 116, Env 117, Env 142 ab, Env 145 ab, Env 146 abc, Env 170 ab, Ge 130, Hy 101 abc, Hy 113 ab, (or other electives listed above); also research, Env 100.

NOTE: The following humanities and social science electives are of special interest for students in environmental engineering science:
An 1, An 123, Ec 115, Ec 119, Ec 128 abc, Ec 130 ab, Ec 131 (PS 131), PS 1 abc, PS 135 abc.

FLUIDS ENGINEERING AND JET PROPULSION

Freshman Year

One course per term selected from: Gr 1, E 5, IS 10

*Sophomore Year**

ME 17 abc, APh 3, EE 4, EE 5

Junior Year

ME 19 abc, AM 97 abc; one course per term selected from: ME 5 abc, ME 126[1], ES 102 ab

*Students who have completed Ma 2 or Ma 1.5 prior to their sophomore year are encouraged to take AMa 95 abc as sophomores. Courses suggested in the junior and senior year may then be taken correspondingly earlier.

[1]Satisfies laboratory requirement, no. 5 on page 206.

Senior Year

Hy 101 abc, AM 151 abc; one course per term selected from: AM 155, ME 118 abc, JP 121 abc, JP 170[1], Hy 111[1]

HYDRAULICS AND WATER RESOURCES

Freshman Year

One course per term selected from: Gr 1, IS 10, E 5, Ge 1, Ge 2

*Sophomore Year**

ME 17 abc; one course per term selected from: Ph 3[2], Ph 4[2], EE 4, EE 10, ME 3, Gr 1

Junior Year

AM 97 abc, ME 19 abc, Ec 11, Ec 12

Senior Year

CE 10 abc, CE 115 ab and CE 150, Hy 103 ab, Hy 111[1] or ME 126[1], Hy 113 ab, Env 112 abc, or Env 117 or Env 146 abc

MATERIALS SCIENCE

Freshman Year

One course per term selected from: E 5, IS 10, Gr 1, ChE 10, EE 4, APh 3, APh 9

*Sophomore Year**

ME 17 abc or APh 17 abc; one course per term selected from: ME 1 ab, ME 3, EE 5

Junior Year

AM 97 abc, MS 5 abc, APh 50 abc, ChE 107 abc

Senior Year

MS 101 abc, MS 102 abc, MS 104 abc[1]

MECHANICAL BEHAVIOR OF MATERIALS

Freshman Year

One course per term selected from: E 5, IS 10, Gr 1, ChE 10, EE 4

*Sophomore Year**

ME 17 abc or APh 17 abc; one course per term selected from: ME 1 ab, ME 3, EE 5

Junior Year

AM 97 abc, MS 5 abc, ChE 107 abc

Senior Year

MS 102 abc, MS 104 abc[1], MS 105, MS 101 abc

MECHANICAL DESIGN

Freshman Year

One course per term selected from: Gr 1, E 5, EE 5

*Sophomore Year**

ME 1 ab, ME 3, ME 17 abc

Junior Year

ME 19 ab, AM 97 abc; one course per term selected from: ME 5 abc, ME 126[1], MS 10, MS 11, IS 10, EE 90

Senior Year

AM 151 abc, MS 5 ab; two courses per term selected from: Ae 241 abc, AM 155[1], EE 13 ab

PHYSICAL METALLURGY

Freshman Year

One course per term selected from: E 5, IS 10, Gr 1, ChE 10, EE 4

*Sophomore Year**

ME 17 abc or APh 17 abc; one course per term selected from: ME 1 ab, ME 3, EE 5

Junior Year

AM 97 abc, MS 5 abc, MS 10

Senior Year

MS 101 abc, MS 104 abc[1], MS 105

*Students who have completed Ma 2 or Ma 1.5 prior to their sophomore year are encouraged to take AMa 95 abc as sophomores. Courses suggested in the junior and senior years may then be taken correspondingly earlier.

[1]Satisfies laboratory requirement, no. 5 on page 206.

[2]Satisfies laboratory requirement, no. 6 on page 206.

STRUCTURAL AND SOIL MECHANICS

Freshman Year

One course per term selected from: Gr 1, IS 10, E 5, Ge 1, Ge 2

*Sophomore Year**

ME 17 abc; one course per term selected from: Ph 3[2], Ph 4[2], EE 4, EE 10, ME 3, Gr 1

Junior Year

AM 97 abc, ME 19 abc

Senior Year

CE 10 abc, CE 115 ab and CE 150, AM 151 abc, CE 180, CE 181, and CE 182 or Hy 113 ab and Hy 111[1], Env 112 abc or Env 146

STRUCTURE AND PROPERTIES OF ALLOYS

Freshman Year

One course per term selected from: E 5, IS 10, Gr 1, ChE 10, EE 4, APh 3, APh 9[2]

*Sophomore Year**

ME 17 abc or APh 17 abc; one course per term selected from: ME 1 ab, ME 3, EE 5

Junior Year

AM 97 abc, MS 5 abc, APh 105 abc, Ch 21 abc, APh 50 abc

Senior Year

APh 114 abc, MS 101 abc, MS 102 abc, Ph 125 abc, MS 104 abc[1]

*Students who have completed Ma 2 or Ma 1.5 prior to their sophomore year are encouraged to take AMa 95 abc as sophomores. Courses suggested in the junior and senior years may then be taken correspondingly earlier.

[1]Satisfies laboratory requirement, no. 5 on page 206.

[2]Satisfies laboratory requirement, no. 6 on page 206.

ENGLISH OPTION

(For First Year see page 190)

Attention is called to the requirement that all students in the English option must demonstrate competence in one foreign language. This means the satisfactory completion (grade of C or better) of the first year of an Institute language course, or the equivalent.

TYPICAL COURSE SCHEDULE

Second Year

		Units per term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
	Electives, not less than*	24	24	24
		42	42	42

Third Year

Electives, not less than*	45	45	45

Fourth Year

Electives, not less than*	45	45	45

*Students in the English option must complete successfully:
a. at least 54 units of natural science, mathematics, or engineering taken beyond the sophomore year;
b. 108 units of English beyond the freshman year.

GEOLOGY, GEOCHEMISTRY, AND GEOPHYSICS OPTIONS

(For First Year see page 190)

The aim of the undergraduate program in the geological sciences is to provide thorough training in basic geological disciplines and, wherever possible, to integrate the geological studies with and build upon the courses in mathematics, physics, chemistry, and biology taken during the earlier years at the Institute. Special emphasis is also placed on field work because it provides first-hand experience with geological phenomena that can never be satisfactorily grasped or understood solely from classroom or laboratory treatment. Options are offered in geology (including paleontology and paleoecology), geophysics, and geochemistry. Sufficient flexibility in electives is provided to permit a student to follow lines of special interest in related scientific and engineering fields. Students 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 flexible minds that enable them to grapple with complex problems involving many variables. Most students majoring in the earth sciences now find further training at the graduate level necessary.

Undergraduate Research and Bachelor's Thesis. The division encourages undergraduate research, particularly of such scope and caliber as to merit the preparation of a Bachelor's Thesis. Guidance in seeking research opportunities and in drawing up a research plan leading to the Bachelor's Thesis is available from the divisional Undergraduate Research Counselor.

Attention is called to the fact that any student whose grade-point average in freshman and sophomore physics, chemistry, and mathematics is less than 1.9 at the end of an academic year may, at the discretion of the Division of Geological and Planetary Sciences, be refused permission to register in the geological sciences options. Furthermore, any student whose grade-point average is less than 1.9 in the subjects in the Division of Geological and Planetary Sciences for the academic year, may, at the discretion of the division, be refused permission to continue in the geological sciences options.

		YEAR				
		1st	2nd	3rd	S	4th
Institute Requirements						
Ma 1 abc	Freshman Mathematics	27				
Ph 1 abc	Kinematics, Particle Mechanics, and Electric Forces	27				
Ch 1 abc	General and Quantitative Chemistry	18				
Ch 3 a[2]	Experimental Chemical Science	6				
	Freshman Laboratory[2]	9				

HSS	Humanities and Social Science Electives[3,4]	27	27	27		27
PE 1 abc	Physical Education[5]	9				
	Freshman Electives[5]	3				
Ma 2 abc	Sophomore Mathematics		27			
Ph 2 abc	Electricity, Fields, and Quantum Mechanics		27			
	Sophomore Science and Engineering Electives[6]		27			
	Total required courses	126	108	27		27
Division Requirements						
Ge 100	Geology Club					1
Ge 102	Oral Presentation					2
Ge 104 abc	Advanced General Geology			27		
Ge 105 abc	Geologic Field Training and Problems			18		
	Sophomore Laboratory course[2]		9			
	Language Elective[4]					30
	Electives[7]					
	Total required courses	126	117	72		60
Geology Option Requirements						
Ge 114	Optical and X-ray Mineralogy					12
Ge 115 a c	Petrology and Petrography					24
Ge 123	Summer Field Geology				30	
Ge 121 abc	Advanced Field Geology					36
	Chemistry Electives[8]			27		
	Geology Electives[9]			25-27		
	Total required courses	126	117	124-126	30	132
Geochemistry Option Requirements						
Ge 114	Optical and X-ray Mineralogy					12
Ge 115 a c	Petrology and Petrography					24
Ge 123	Summer Field Geology				30	
Ch 21 abc	Physical Chemistry			27		
Ch 26 ab	Physical Chemistry Laboratory			16		
Ch 14[2])	Chemical Equilibrium and Analysis					6
Ch 15[2])	Chemical Equilibrium and Analysis Laboratory					10
	Total required courses	126	117	115	30	112
Geophysics Option Requirements						
Ph 106 abc	Topics in Classical Physics			27		
AMa 95 abc	Engineering Mathematics			36		
	Physics or Math or Geophysics Electives[10]					54
	Total required courses	126	117	135		114

[1]A suggested sequence of courses is indicated but is not a requirement.

[2]The division requires that 24 units of physics, chemistry, and/or engineering laboratory courses be completed by the end of the third year. These units will normally consist of 16 units, including Ch 3 a, taken in the first year and an additional 9 units taken in the second year. The units may be selected from the first-

year physics, chemistry, and engineering courses (see page 190), Ph 5, Ph 6, Ph 7, and Ch 15. Geochemistry and geology majors may find it advantageous to elect both Ch 14 and Ch 15 in their second year.

[3]The Institute requires 108 units of humanities and social sciences for graduation (see page 189). Of these, 27 units must be taken in the first year.

[4]The division requires 30 units of French, German, or Russian for graduation. Students with a good knowledge of one of these languages may petition the Academic Officer for waiver of this requirement. Note that either of the two-year sequences, L 130 abc-L 131 abc and L 152 abc-L 153 abc provides 30 units toward the Institute humanities requirement. Students with adequate training in secondary school may take L 131 abc or L 153 abc as part of the Institute humanities requirement. These choices are highly recommended for students planning to do graduate work.

[5]Three terms (9 units) of PE are required for graduation. If PE is not taken in the freshman year, electives must be added to meet the minimum requirement of 126 units in the first year (see page 190).

[6]These electives should be used to broaden the student's background in science and engineering and to help him select an option. None of the introductory courses in the division, including Ge 1, Ge 2, Ge 4, Ge 5, and Ge 155, is specifically required of majors, but the election of one or more of these is highly recommended in the second year.

[7]The division requires that at least 405 units of required courses, plus electives, be taken after the first year, based on an average of 45 units per quarter. Electives should be chosen with the advice and consent of the student's adviser.

[8]Choose from Ch 24 abc or Ch 24 ab plus Ch 14[2] or Ch 21 abc or Ch 41 abc or Ch E 63 abc.

[9]These 27 units may include Ge electives taken in other years and are taken in the fourth year if French, Russian, or German is taken in the third year (see note 4). The student should particularly note the opportunity for undergraduate research provided by Ge 40 and Ge 41.

[10]These electives may include most mathematics, science, or engineering courses pertinent to the student's interest, but must be chosen with the consent of the student's adviser. Ge 2 is not included.

HISTORY OPTION

(For First Year see page 190)

The history option is a flexible program. While its core is historical studies, it is designed to provide students with ample opportunities to advance their understanding of the social sciences, language, literature, philosophy, and the natural sciences and mathematics. The option offers excellent preparation for graduate study in history. It also furnishes a highly desirable background for careers in law, business, or medicine.

History majors are expected to prepare themselves in two of the following fields of concentration, one of which will normally become the area of investigation of the senior research paper: Medieval European to 1500, Modern European, American, and Non-Western History. Overall, the option requires the successful completion of 90 units of work in history itself, including usually H 97 ab, H 98 ab, H 99 abc, and three electives.

First and Second Years

Since it is Caltech policy that students not specialize in a restrictive fashion before the end of the sophomore year, all entering students take roughly similar courses, including math, physics, chemistry and introductory humanities courses; sophomores are required to take Ma 2 and Ph 2. Students considering the history major are encouraged to take H 1, 2, 6, or 8 as freshmen, and middle or upper level courses as sophomores. The particular choice of courses will depend upon the expected possible areas of concentration and should be worked out in consultation with an adviser from the history option. The sophomore year is also a good time to pursue the study of literature, philosophy, or language and introductory work in the social sciences.

A suggested sophomore program is as follows: (Requirements are underlined; courses in parentheses are recommended.)

Second Year

	Units per term 1st	2nd	3rd
<u>Math 2 abc</u>	9	9	9
<u>Physics 2 abc</u>	9	9	9
Middle- or Upper-Level History	9	9	9
Literature, Philosophy, or Language	9	9	9
Social Science	9 (Ec 11)	9 (SS 12 a)	9 (SS 12 b)
	45	45	45

Third and Fourth Years

Students will normally choose their two areas of concentration in the third year. Preparation in these areas will usually be accomplished by intensive tutorial study (H 97 ab and H 98 ab), though appropriate elective courses may be substituted for H 98 ab. In the senior year, students will write a research paper in one of the areas of concentration under the supervision of a faculty member in a research tutorial (H 99 abc). In addition to the three tutorials, students must take at least 27 units of electives chosen from the offerings listed under "Advanced Courses" in fields outside the two areas of concentration.

Caltech history majors are required to take 54 units of science and math beyond the sophomore year. Since statistics is a useful tool in historical analysis, the history option recommends that two of these courses be Ma 112 a and 112 b. Students who may wish to write their research papers or do graduate work in the history of science are encouraged to use the rest of the 54 units to advance their understanding of one or two particular scientific disciplines, for example, physics and/or biology.

Throughout the junior and senior years, students should also choose, in consultation with their advisers, a program of courses outside of history which will reinforce and complement historical studies. It is recommended that students who elect to write research papers in European history acquire a reading knowledge of an appropriate foreign language by the beginning of the senior year. It is further recommended that students in all areas of concentration choose at least some of their electives from philosophy and literature and some from the social sciences, since these latter disciplines are becoming increasingly important in historical analysis.

A suggested program for the third and fourth years is as follows: (Requirements are underlined; courses in parentheses are recommended.)

Third Year

History Tutorial		9 (H 97a)	9 (H 97b)
History Electives	18	9	9
Science or Mathematics	9 Ma 112a)	9 (Ma 112b)	9
Advanced Language, Philosophy or Literature	9	9	9
Advanced Social Science	9	9	9
	45	45	45

Fourth Year

History Research	9 (H 99a)	9 (H 99b)	9 (H 99c)
History Electives	9 (H 98a)	9 (H 98b)	9
Science or Mathematics	9	9	9
Electives	18	18	18
	45	45	45

INDEPENDENT STUDIES PROGRAM

An Independent Studies Program will be offered as an option during the 1973-74 academic year. The faculty committee which administers the program consists of B. Barish (chairman), F. Anson, F. Bohnenblust, L. Breger, P. Goldreich, F. Humphrey, J. Knowles, G. Neugebauer, and W. Wood.

Administrative Procedures and Guidelines

1. A student applying for the program must formulate a written proposal describing his goals, reasons for applying, general plan of study while at Caltech, and a detailed plan for the next quarter. It is also the responsibility of the student to recruit three faculty members, representing at least two divisions of the Institute, who approve of his plans and agree to act as his advisory "committee of three."

2. The committees of three will form the heart of the program and will bear the chief responsibility for overseeing the progress of each student. One adviser will be designated chairman of the committee of three and must be on the professorial staff. Of the other two members of the committee of three, one must be on the professorial staff and the other may be any qualified individual who agrees to accept the responsibilities of being an adviser and is acceptable to the ISP committee. Postdoctoral fellows, graduate students or faculty of other institutions could be utilized when appropriate. A faculty member who agrees to serve on a committee of three will be accepting responsibility to that involved in offering a more conventional tutorial course. He will need to set aside adequate time for counseling the student and monitoring his progress in any unstructured academic pursuits. Any ISP courses taken by a student will be the joint responsibility of the course instructor and a member of the committee of three. A considered, written evaluation of each student's performance and progress each quarter will be required by the ISP Committee from each member of every committee of three.

3. The ISP committee will consider each proposed program in consultation with the prospective members of the committee of three faculty advisers. If the program seems suitable, a three-party written contract will be drawn up among the ISP committee, the committee of three, and the student. This contract will include the agreed-

upon content of the student's program and the methods for ascertaining satisfactory progress for those parts of the student's program which are not standard Institute courses. Duplicate copies of the student's contract, along with all ISP records for each student and his transcript, will be kept in permanent files in the Registrar's Office and in the ISP office.

4. The progress of each student in the ISP will be monitored at least every quarter by consultation between the ISP committee and each committee of three. Standards for acceptable progress and satisfactory completion of the terms of the three-party contract will be the responsibility of the ISP committee. When the ISP committee is satisfied that the terms of his contract have been fulfilled by the student, he will be recommended for graduation by the committee to the faculty.

Independent Studies Program Course

A course for ISP students is intended to accommodate individual programs of study or special research that fall outside ordinary course offerings. Students signing up for the ISP course will prepare, with the help of their advisory committee, a description of the course of study, a syllabus delineating the work to be accomplished, and a time schedule for reports both on progress and for work completed. The units of credit and form of grading of this course are decided by mutual agreement between the ISP committee, the student, and his three-member advisory committee.

MATHEMATICS OPTION

(For First Year see page 190)

The four-year undergraduate program in mathematics leads to the degree of Bachelor of Science. The purpose of the undergraduate option is to give the student an understanding of the broad outlines of modern mathematics, to stimulate his interest in research, and to prepare him for later work, either in pure mathematics or allied sciences. Unless a student has done exceptionally well in his freshman and sophomore years, he should not contemplate specializing in mathematics. An average of at least "B" in his mathematics courses is expected of a student to major in mathematics.

Since the more interesting academic and industrial positions open to mathematicians require training beyond a bachelor's degree, the student who expects to make mathematics his profession must normally plan to continue, either here or elsewhere, with graduate work leading to the degree of Doctor of Philosophy. The undergraduate should bear this in mind in choosing his course of study. In particular he is urged to include at least one year, and preferably two years, of language study in his program. Overloads in course work are strongly discouraged; students are advised instead to deepen and supplement their course work by independent reading. The mathematics library is housed on the seventh floor of the Robert A. Millikan Memorial Library. In addition, there is a reference library of duplicate books and periodicals located on the third floor of the Sloan Laboratory of Mathematics and Physics. Books that are not on reserve for special courses may be borrowed from the Millikan Library. Current periodicals may be consulted in either library.

Undergraduates who join the option at the beginning of the sophomore year are required to take course Ma 5 abc during the second year. Students transferring from another option at the end of the sophomore year who have not yet taken this course will take it as their selected course in mathematics during their junior year concurrently with Ma 108, and will also take two selected courses in mathematics during their senior year.

The schedule of courses in the undergraduate mathematics option is flexible. It enables each 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 the junior and senior years students normally take 18 units of courses in mathematics or applied mathematics, including the required course Ma 108. Any course listed under applied mathematics is regarded as an elective in mathematics and not as an elective in science, engineering or humanities.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of the academic year in the subjects under mathematics and applied mathematics may, at the option of his department, be refused permission to continue the work of the mathematics option. A fuller statement of this regulation will be found on page 174.

TYPICAL COURSE SCHEDULE

Second Year

		Units per term		
		1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Electives in Science, Engineering or Humanities	9	9	9
	Humanities Electives,[1] minimum for first two years: 45 units	0–9	0–9	0–9
		36–45	36–45	36–45

Third Year

Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
	Selected courses in Mathematics . . . . . minimum	9	9	9
	Humanities Electives,[1] minimum for first three years: 81 units	9–18	9–18	9–18
	Electives in Science, Engineering, or Humanities . . . . . minimum	9	9	9
	For each term the total number of units is required to fall within range	39–48	39–48	39–48

Fourth Year

Selected course in Mathematics	9	9	9
Humanities Electives,[1] minimum for graduation: 108 units	9–18	9–18	9–18
Electives in Mathematics, Science, Engineering, or Humanities . . . . . minimum	18	18	18

For each term the total number of units is required to fall within range	36–45	36–45	36–45

Normally a junior will elect 9 units each term, and a senior 18 units each term, in mathematics. Sophomores who have not taken Ma 5 must take this course as juniors, postponing the selected course in mathematics to the senior year. They are strongly advised to take one or preferably two full-year courses in languages.

[1]For rules governing humanities electives, see page 189.

PHYSICS OPTION

OPTION REQUIREMENTS

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 quantum mechanics, electromagnetic fields, and atomic structure will be treated in the second year. Those who want to major in physics take intensive courses during their junior and senior years that provide an unusually thorough preparation for graduate work. The curriculum provides for the teaching of classical and modern physics from the first year through the entire undergraduate course of study. Elective courses during the junior and senior years provide flexibility which enables the student to select a program to fit his individual requirements. Many of the undergraduate students who elect physics are also given an opportunity to participate in some of the thirty to sixty research projects which are always under way and the graduate seminars which are open to undergraduates at all times.

Attention is called to the fact that any student whose grade-point average for one academic year is less than 1.9 in the subjects listed under this division will normally be refused permission to continue in the physics option. A more complete statement of this regulation will be found on page 174.

Passing grades must be obtained in all courses listed below.

1. Ph 3 or Ph 4
2. Ph 5 or Ph 6
3. Ph 7
4. Ph 92 abc[1]
5. Ph 106 abc
6. Ph 77 ab[2]
7. 54 units of physics electives, which must be chosen from (a) the list of elec-

tives suggested below for the senior year, or (b) any physics graduate course with number 200 or greater.[3]

8. 27 units of science and engineering electives, of which at least 18 units shall be other than mathematics and physics courses. *(This requirement is to be fulfilled in the sophomore year.)*
9. Minimum number of units for the B.S. degree: 516.

[1]This requirement may also be satisfied by Ph 112 or Ph 125.
[2]This requirement may also be satisfied by 18 units of Ph 78 or two terms of APh 91.
[3]Subjects taken by a student to fulfill the senior physics elective requirement may not be elected by a student to be taken on a Pass-Fail basis, although such grades are permissible if the course is offered only on this basis.

TYPICAL COURSE SCHEDULE

(For First Year see page 190)

Second Year

	Units per term		
	1st	2nd	3rd
Ph 2 abc	9	9	9
Ma 2 abc	9	9	9
Humanities Elective[1]	9	9	9
Physics Laboratory[2]	0	6	6
Electives[3]	12	9	9
	39	42	42

Third Year

Ph 92 abc	9	9	9
Ph 106 abc	9	9	9
Humanities Elective[1]	9	9	9
Electives	18	18	18
	45	45	45

Fourth Year

Ph 77 ab	6	6	.
Physics Electives	18	18	18
Humanities Elective[1]	9	9	9
Electives	18	18	18
	51	51	45

Physics Laboratory Requirements

Students choosing a major in physics must complete the following laboratory requirements by the end of the second year:

Ph 3 or Ph 4	6 units
Ph 5 or Ph 6	6 units
Ph 7	6 units
	18 units

Ph 3	Physics Laboratory (sophomores only)	6	.	.
	(freshmen only)	.	6	6
Ph 4	Physics Laboratory	.	.	6
Ph 5	Physics Laboratory	6	.	.

Ph 6	Physics Laboratory	.	6	.
Ph 7	Physics Laboratory	.	.	6

[1]See Institute Requirements for specific rules regarding humanities.
[2]See Option Requirements 1, 2 and 3.
[3]See Option Requirement 8 and suggested electives below.

Suggested Electives

Sophomore Year

Ma 5 abc	Ay 22	EE 13 abc
Ge 1	ME 1 ab	EE 14 abc
Bi 1	ME 3	Ch 41 abc
Ay 20	APh 17 abc	Ch 46 ab
Ay 21	EE 5	L 130 abc

Junior Year

Ph 77 ab	Ge 166 ab	EE 14 abc
Ph 125 abc	Bi 9	EE 90 abc
Ph 171[1]	Ay 100	Ch 21 abc
Ph 172[1]	Ay 101	Ch 26 ab
AMa 95 abc	Ay 102	L 102 abc
Ma 108 abc	EE 13 abc	

Senior Year

Ph 78 abc	Ph 125 abc	APh 105 abc
Ph 79 abc	Ph 127 abc	APh 114 abc
Ph 93 abc	Ph 129 abc	APh 140 abc
Ph 112 abc	APh 91 ab[2]	APh 156 abc

[1]No more than 9 units per term of Ph 171, Ph 172 or Ph 173 can be counted toward graduation.
[2]APh 91 may not be used to satisfy both requirements 6 and 7.

SOCIAL SCIENCE OPTION

(For First Year see page 190)

The social science option is designed to provide undergraduate students with an opportunity to gain a bachelor's degree in social science rather than in economics, political science or some other specific discipline. The program will focus on social change.

TYPICAL COURSE SCHEDULE

Second Year

		Units per term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
	Electives, not less than*	24	24	24
		42	42	42

Third Year

SS 142 a	Computing Modeling and Data Analysis (3-0-6)	.	9	.
Ec 121 ab	Microeconomic Theory I & II (3-0-6)	9	9	.
Ec 122 a	Econometrics (3-0-6)	.	9	.
PS 131	Analytical Political Science (3-0-6)	.	.	9
An 101 or 123 a	Selected Topics: The Anthropology of Development (3-0-6)	.	.	.
or Psy 13	Social Psychology (3-0-6)	9	.	.
	Electives, not less than*	27	18	36
		45	45	45

Fourth Year

	Electives, not less than*	45	45	45
		45	45	45

*The electives taken in these years are to include 54 units of natural science, mathmatics, or engineering beyond the sophomore level. Students may concentrate on research by taking 54 units of supervised research in their senior year.

Section IV

INFORMATION AND REGULATIONS FOR THE GUIDANCE OF GRADUATE STUDENTS

The Graduate Program

The Institute offers graduate work leading to the degrees of Master of Science and Doctor of Philosophy. In addition, it offers the following intermediate degrees: Aeronautical Engineer, Civil Engineer, Electrical Engineer, Geological Engineer, Geophysical Engineer, and Mechanical Engineer.

The academic work of the Institute is organized in six divisions:

- Biology
- Chemistry and Chemical Engineering
- Engineering and Applied Science
- Geological and Planetary Sciences
- The Humanities and Social Sciences
- Physics, Mathematics and Astronomy

Graduate work at the Institute is further organized into graduate options. Each option is supervised by those professors whose interests and research are closely related to the area of the option, within the administrative jurisdiction of one or more of the divisions. The graduate student who is working for an advanced degree in one of the graduate options is associated with an informal group of those professors who govern the option, other faculty including research associates and fellows, and other graduate students working for similar degrees.

A faculty member from each area of graduate study is available for consultation on problems concerning academic programs, degree requirements, financial aid, etc. The representatives for 1973-74 are as follows:

Aeronautics:	Prof. B. Sturtevant
Applied Mathematics:	Prof. H. B. Keller
Applied Mechanics:	Prof. F. S. Buffington
Applied Physics:	Prof. R. W. Vaughan
Astronomy:	Prof. J. E. Gunn
Biology:	Prof. J. F. Bonner
Chemical Engineering:	Prof. G. L. Leal
Chemistry:	Prof. R. E. Ireland
Civil Engineering:	Prof. F. S. Buffington
Electrical Engineering:	Prof. R. D. Middlebrook
Engineering Science:	Prof. F. S. Buffington
Environmental Engineering Science:	Prof. F. S. Buffington
Geological and Planetary Sciences:	Prof. A. L. Albee
Materials Science:	Prof. F. S. Buffington
Mathematics:	Prof. R. P. Dilworth
Mechanical Engineering:	Prof. F. S. Buffington
Physics:	Prof. W. Whaling
Social Sciences:	Prof. L. E. Davis

General Regulations

*Admission to Graduate Standing**

Application for admission to graduate standing should be made to the Dean of Graduate Studies, on a form obtained from his office. Admission to graduate standing will be granted *only to a limited number of students of superior ability,* and application should be made as early as possible. No application fee is required. In general, admission to graduate standing is effective for enrollment only at the beginning of the next academic year. The California Institute of Technology encourages applications from both men and women, including members of minority groups. Students applying for assistantships or fellowships need not make separate application for admission to graduate standing, but should submit their applications before February 15.

Although the application form permits the applicant to state his intended major field of study and special interests, the application may actually be considered by two or more divisions or interdisciplinary programs.

To be admitted to graduate standing an applicant must in general have received a bachelor's degree representing the completion of an undergraduate course in science or engineering substantially equivalent to one of the options offered by the Institute. He must, moreover, have attained such a scholastic record and, if from another institution, must present such recommendations as to indicate that he is fitted to pursue, with distinction, advanced study and research. In some cases examinations may be required. If the applicant's preliminary training has not been substantially that given by the four-year undergraduate options at the Institute, he may be admitted subject to satisfactory completion of such undergraduate subjects as may be assigned. Admission sometimes may have to be refused solely on the basis of limited facilities in the department concerned.

Prior to final acceptance for admission, each applicant is required to submit a report of Medical History and Physical Examination on a form which will be sent him at the time he is notified of admission. It is the applicant's responsibility to have this form filled out by a Doctor of Medicine (M.D.) of his own choosing. Admission is tentative pending such examination, and is subject to cancellation if the report indicates the existence of a condition that the Director of Health Services deems unsatisfactory. A standard two-injection tetanus inoculation (or booster shot if appropriate) and tuberculosis testing are required. Students who have been on leave of absence for two years or more must submit Medical History and Physical Examination reports under the same conditions as for new students.

Admission to graduate standing does not of itself admit to candidacy for a degree. Application for admission to candidacy for the degree desired must be made as provided in the regulations governing work for the degree. The student himself is responsible for seeing that admission is secured at the proper time.

Students from non-English-speaking countries are expected to read, write, and speak English and comprehend the spoken language. Applicants whose first language or native language is not English are required to take the Test of English as a Foreign Language (TOEFL) as part of their application procedure. This test is given at centers throughout the world on several dates each year. The testing schedule and registration information may be obtained by writing to TOEFL, Educational Testing Service, Princeton, New Jersey 08540. Results of the test should be sent to the Gradu-

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*Individuals are considered for admission to student status — and all student services, facilities, programs, and activities are administered — in a nondiscriminatory manner without regard to race, religion, color, sex, or national origin, and fully in accordance with the existing laws and regulations.

ate Office. Special no-credit classes in English are available for those students who need to improve their command of the language or who wish to perfect it. Information regarding these classes can be obtained from the Chairman of the Faculty Committee on Foreign Students and Scholars or from the International Desk. It is strongly recommended, however, that students who achieve a low TOEFL score make arrangements for remedial work during the summer preceding their registration.

In exceptional cases, students who have already decided to pursue a graduate degree may be permitted to earn credits toward that degree during their undergraduate years by being admitted also to graduate studies at the Institute prior to receipt of their undergraduate degree, thus allowing their undergraduate and graduate studies to overlap. Application for admission to graduate studies should be made in the normal way.

Special students, not working for degrees, are admitted only under exceptional circumstances.

Graduate Residence

One term of residence shall consist of one term's work of not fewer than 36 units of advanced work in which a passing grade is recorded. If fewer than 36 units are successfully carried, the residence will be regarded as shortened in the same ratio; but the completion of a large number of units in any one term will not be regarded as increasing the residence. The residency requirement for each degree will be found under the degree regulation. In general, the degree requirements are: Master of Science, after a minimum of one year of graduate work; Aeronautical Engineer, Civil Engineer, Electrical Engineer, Geological Engineer, Geophysical Engineer, and Mechanical Engineer, after a minimum of six terms (two years) of graduate work; and Doctor of Philosophy, after a minimum of nine terms (three years) of graduate work.

Advanced work is defined as study or research in courses whose number is greater than or equal to 100.

Registration

Students are required to register and file a program card in the Registrar's Office at the beginning of each term of residence, whether they are attending a regular course of study, carrying on research or independent reading only, writing a thesis or other dissertation, or utilizing any other academic service.

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

The number of units allowed for a course is so chosen that one unit corresponds roughly to one hour a week of work throughout the term for a student of superior ability.

A student will not receive credit for a course unless he is properly registered. At the first meeting of each class he should furnish the instructor with a class admission card for the course, obtained on registration. *The student himself is charged with the responsibility of making certain that all grades to which he is entitled have been recorded.*

Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Except by specific action of the Committee on

Graduate Study, graduate students will be required to register for at least 36 units during each of their first three terms of attendance at the Institute. Exceptions for part-time students are subject to regulations detailed in the following section on *Part-Time Programs.* A graduate student who is registered for 36 or more units is classed as a full-time student.

Graduate students will be required to maintain their admission status until all requirements for a degree are fulfilled, whether by continuity of registration or on the basis of approved leave of absence. In case of lapse in graduate standing, readmission must be sought before academic work may be resumed or requirements for the degree completed.

Graduate students are encouraged to continue their research during the whole or a part of the summer, but in order that such work may count in fulfillment of the residence requirements, the student must file a registration card for such summer work in the office of the Registrar on May 15. A minimum of 10 units must be taken. Incoming graduate students who begin their graduate program during the summer are charged a fee for Health Insurance, although there is no tuition charge for summer research units.

All changes in registration must be reported, on drop or add cards, to the Registrar's Office by the student. Such changes are governed by the last dates for adding or dropping courses as shown on the academic calendar on pages 4 and 5. A student may not withdraw from or add a course after the last date for dropping or adding courses without, in addition to his department's consent, the approval of the Dean of Graduate Studies. M.S. candidates must obtain the signature of the Dean of Graduate Studies on all drop or add cards.

In registering for research, students should indicate on their program card the name of the instructor in charge, and should consult with him to determine the number of units to which the proposed work corresponds. At the end of the term the instructor in charge may decrease the number of units for which credit is given in case he feels that the progress of research does not justify the full number originally registered for.

A graduate student who undertakes activities related to the Institute (studies, research, and assisting, or other employment) aggregating more than 62 hours per week must receive approval from the Dean of Graduate Studies. Petition forms for this purpose may be obtained from the Graduate Office and must carry the recommendation of the student's major department before submission to the Graduate Office.

Registration is required for the term or summer period in which the requirements for an advanced degree are completed, including either the final examination or submission of a thesis. Registration with minimum tuition will be allowed for, at most, one term, except for summer registration.

With the approval of the Committee on Graduate Study, any graduate student whose work is not satisfactory may be refused registration at the beginning of any term by the department in which the student is doing his major work.

The registration of a graduate student is not complete unless his photograph for the Registrar's record card is affixed thereto, or 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.

Part-Time Programs

Part-time graduate study programs at the Institute are subject to the following rules:

1. Applicants for the part-time program must submit a regular application form.
2. Any research work done for academic credit shall be supervised by a Caltech faculty member.
3. Students admitted to the part-time program are required to take at least 27 units of graduate course work or research work each term during the academic year. They may not commit themselves to work for more than 20 hours per week for the sponsoring organization.
4. Part-time studies, on the program, will be limited to the first two years of academic residence for each student. Beyond the initial period, students continuing their graduate work must do so on a full-time basis.
5. The program will, in each option, be restricted each year to at most 20 percent of the planned number of new graduate students, with the understanding that adjustments to this limit are permissible for small options.
6. Any option at the Institute retains the right not to participate in the program or accept it under more stringent conditions.

Caltech Graduate Students Working at Special Laboratories

1. Any student who desires to take advantage of the unique opportunities available at the Special Laboratories, e.g., JPL or EQL, for Ph.D. thesis work, should be allowed to do so, provided he maintains good contact with academic life on campus, and the Laboratories commit support for the duration of the thesis research, and provided that all Caltech graduate thesis research carried out at the Special Laboratories be under the supervision of Caltech faculty members.

2. A student's request to carry out thesis work at the Special Laboratories should be formally endorsed by the appropriate committee of his option and by an appropriate Special Laboratories group on a petition submitted through the option representative to the Dean of Graduate Studies. By such approval, the Special Laboratories would recognize its commitment of special equipment or any other resources required to the thesis work. Approval of the Special Laboratories should also indicate that the thesis topic is a sensible one from its point of view, but that the subject is not likely to be preempted from the student.

3. Special Laboratories support of Caltech students doing thesis research at the Special Laboratories should be provided, if possible, in the form of a traineeship or otherwise through a campus graduate research assistantship (GRA) under a suitable work order. In this way a student can also receive a tuition scholarship (almost always awarded in conjunction with a GRA) and be on the same basis as a campus thesis student.

4. Employment by the Special Laboratories of a graduate student for work not connected with his thesis should be regarded as equivalent to other outside employment. No fixed policy regarding payment of tuition should be adopted for these situations. A student request for a tuition grant should be considered on an individual basis.

Grades in Graduate Courses

Term examinations are held in all graduate courses unless the instructor, after consultation with the chairman of the division, shall arrange otherwise. No student taking a course for credit shall be exempt from these examinations.

Grades for all graduate work are reported to the Registrar's office at the close of each term.

The following system of grades is used to indicate class standing in graduate courses: "A" excellent, "B" good, "C" satisfactory, "D" poor, "E" conditioned, "F" failed, "Inc" incomplete. In addition to these grades, which are to be interpreted as having the same significance as for undergraduate courses (see page 192), the grade of "P," which denotes passed, may be used at the discretion of the instructor, for all or some of the students, in the case of seminar or other work which does not lend itself to more specific grading. In graduate research, only the grades of "P" and "F" are given.

Exchange Program with Scripps Institution of Oceanography

An exchange program has been established with the Scripps Institution of Oceanography (SIO), University of California, San Diego, permitting Caltech graduate students to enroll in and receive credit for graduate courses offered by SIO. Arrangements should be made through the student's major department and the office of the Dean of Graduate Studies. The student must obtain the advance approval of the instructors of courses to be taken at SIO. In some cases, when it is in the best interests of the student, arrangement may be made for the student to be temporarily in full-time residence at SIO.

Thesis research work done partly at SIO may be arranged directly by the student's department and the staff of appropriate research laboratories at SIO, without the necessity of enrolling for SIO courses designated for research; in this case the student will continue to be under the supervision of his Caltech thesis adviser and enroll for Caltech research units.

Degree Regulations

Degree of Master of Science

The Master of Science degree is a professional degree intended to prepare a student for teaching, for further graduate studies, or for more advanced work in industry. Detailed requirements are based primarily on professional studies, and the program should be planned in consultation with the faculty in the appropriate discipline.

Under normal circumstances, the requirements for the M.S. degree can be completed in one academic year, but students from other schools who do not have completely adequate preparation may require longer.

Special regulations for the Master's Degree in each graduate option are on pages 234 through 281.

Residence and Units of Graduate Work Required

At least one academic year of residence at the Institute (as defined on page 225) and 135 units of graduate work subsequent to the baccalaureate degree are required for the master's degree. Included in these are at least 27 units of free electives or of required studies in the humanities. Courses used to fulfill requirements for the bachelor's degree may not be counted as graduate residence.

To qualify for a master's degree, a student must complete the work indicated in the section on special regulations for his option with a grade-point average of at least 1.9, considering the grade of "P" as being equivalent to "C", and excluding grades for research.

In special cases, with the approval of the instructor and the Dean of Graduate Studies, courses taken elsewhere prior to enrollment at the Institute may be offered for credit. An examination may be required to determine the acceptability of such courses. Course credit, if granted, shall not be construed as residence credit.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree, he must file in the Office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. On the candidacy form, the student will submit his proposed plan of study, which must have the approval of his department. This plan of study, if approved, shall then constitute the requirements for the degree, and changes in the schedule will not be recognized unless initialed by the proper authority.

All changes in registration must be reported on drop or add cards to the Registrar's Office. M.S. candidates must obtain the signature of the Dean of Graduate Studies on all drop or add cards.

Engineer's Degree

The work for an engineer's degree must consist of advanced studies and research in the field appropriate to the degree desired. It must conform to the special requirements established for the degree desired and should be planned in consultation with the members of the faculty concerned. Advanced studies are defined on page 224. Regulations governing registration will be found on page 225. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a new petition to continue graduate work toward the desired degree. Students who have received an engineer's degree will not in general be admitted for the doctor's degree.

Residence. At least six terms of graduate residence (as defined on page 225) 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 1.9 considering the grade of "P" as being equivalent to "C" and excluding grades for research. Work upon research and the preparation of a thesis must constitute no fewer than 55 units. More than 55 units may be required by certain departments, and the student should determine the particular requirements of his department when establishing his program.

In the case of a student registered for work toward an engineer's degree, and holding a position as graduate assistant or other Institute employee, the actual number of hours per week required by his teaching or research services shall be deducted from the total number of units for which he might otherwise register. This number of units shall be determined by his department.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree he must file in the office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. Upon receipt of this application, the Dean, in consultation with the chairman of the appropriate division, will appoint a committee of three members of the faculty to supervise the student's work and to certify to its satisfactory completion. One of the members of the committee must be in a field outside the student's major field of study. The student should then consult with this committee in planning the details of this work. The schedule of his work as approved by the committee shall be entered on the application form and shall then constitute a requirement for the degree. Changes in the schedule will not be recognized unless initialed by the proper authority. No course which appears on the approved schedule and for which the applicant is registered may be removed after the last date for dropping courses as listed in the catalog.

The student will be admitted to candidacy for the degree when his supervising committee certifies: (a) that all the special requirements for the desired degree have been met, with the exception that certain courses of not more than two terms in length may be taken after admission to candidacy; (b) that the thesis research has been satisfactorily started and probably can be finished at the expected time.

Such admission to candidacy must be obtained by mid-term of the term in which the degree is to be granted.

Thesis. At least two weeks before the degree is to be conferred, each student is required to submit to the Dean of Graduate Studies two copies of his thesis in accordance with the regulations governing the preparation of doctoral dissertations, which may be obtained from the Graduate Office.

The use of "classified" research as thesis material for any degree will not be permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Before submitting his thesis, the candidate must obtain written approval of it by the chairman of the division and the members of his supervising committee, on a form obtained from the office of the Dean of Graduate Studies.

Examination. At the option of the department representing the field in which the degree is desired, a final examination may be required. This examination would be conducted by a board to be appointed by the candidate's supervising committee.

Degree of Doctor of Philosophy

The degree of Doctor of Philosophy is conferred by the Institute primarily in recognition of breadth of scientific attainment and of power to investigate scientific problems independently and efficiently, rather than for the completion of definite courses of study through a stated period of residence. The work for the degree must consist of scientific research and the preparation of a thesis describing it, and of systematic studies of an advanced character primarily in science or engineering. In addition, the candidate must have acquired the power of expressing himself clearly and forcefully both orally and in written language.

Subject to the general supervision of the Committee on Graduate Study, the student's work for the degree of Doctor of Philosophy is specifically directed by the department in which he has chosen his major subject. Each student should consult his department concerning special divisional and departmental requirements. See pages 234-281.

Admission. With the approval of the Committee on Graduate Study, students are admitted to graduate standing by the department in which they choose their major work toward the doctor's degree. In some cases, applicants for the doctor's degree may be required to register for the master's or engineer's degree first. These degrees, however, are not general prerequisites for the doctor's degree. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a request to continue graduate work toward the desired degree. Students who have received an engineer's degree will not, in general, be admitted for the doctor's degree.

During the second or third term of work toward the engineer's degree, a student may apply for admission to work toward the doctor's degree. If this admission is granted, his admission for the engineer's degree will be cancelled.

Major and Minor Programs of Study. The work for the doctor's degree must consist of scientific research and advanced studies in some branch of science or engineering, called the major program of study. The minor program of study will be at the option of the student, either a general minor or a subject minor.

Advanced studies include courses with numbers of 100 or over. Graduate courses taken as an undergraduate may in some instances be allowed for residence credit and/or used toward the Ph.D. general minor if they were not used to fulfill B.S. requirements and if they meet with the approval of the major department. No residence credit is given for courses with numbers under 100 when they constitute prerequisites to the student's minor subject. 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 and the work has been taken after admission to graduate standing.

(a) *General Minor.* The work will consist of at least 36 units of advanced work and of 18 units of either advanced or undergraduate work (including introductory language courses) taken after admission to graduate standing. The requirement for these 18 units will be waived for graduate students who, in the opinion of the staff in languages, have an adequate knowledge of French, German, or Russian, provided the language chosen is not their native tongue. The waiver will be granted on the basis of an examination, or of an adequate past score of a GSFLT test, or appropriate course work taken previously.

The work in the minor must be in one or more disciplines in the humanities, sciences or engineering, other than that of the major subject. The choice and scope of this work must be approved by the division in charge of the major subject, on a form obtainable from the Graduate Office.

(b) *Subject Minor.* The work is concentrated in one discipline, including at least 45 units of advanced work in this discipline, and must be comprehensive enough to give the student a fundamental knowledge of it. The minor subject may be in the humanities or languages or in any discipline listed on pages 234-281, 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 233). A student who has satisfied the requirements for such a minor program of study will be given recognition for this work by explicit mention on his Ph.D. diploma of the minor subject or minor subjects if the requirements have been satisfied in more than one discipline.

Residence. At least nine terms (three academic years) of residence subsequent to a baccalaureate degree equivalent to that given by the Institute are required for the doctor's degree. Of this at least one year must be in residence at the Institute. It should be understood that these are minimum requirements, and students must usually count on spending a somewhat longer time in residence. 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 226 regarding summer registration for research.)

A student whose undergraduate work has been insufficient in amount or too narrowly specialized, or whose preparation in his special field is inadequate, must count upon spending increased time in work for the degree.

Admission to Candidacy. On recommendation of the chairman of the division concerned, the Committee on Graduate Study will admit a student to candidacy for the degree of Doctor of Philosophy after he has been admitted to work toward the doctor's degree and has been in residence at least one term thereafter; has initiated a program of study approved by his major department and, if needed, by his minor department; has satisfied the several departments concerned by written or oral examination or otherwise that he has a comprehensive grasp of his major and minor subjects as well as of subjects fundamental to them; has fulfilled any necessary language requirements; has shown ability in carrying on research with a research subject approved by the chairman of the division concerned. For special departmental regulations concerning admission to candidacy, see pages 234-281. Members of the Institute staff of rank higher than that of assistant professor are not admitted to candidacy for a higher degree.

A standard form, to be obtained from the Dean of Graduate Studies, is provided for making application for admission to candidacy. Such admission to candidacy must be obtained before the close of the second term of the year in which the degree is to be conferred. *The student himself is responsible for seeing that admission is secured at the proper time.* A student not admitted to candidacy before the beginning of the fourth academic year of graduate work at the Institute must petition through his division to the Dean of Graduate Studies for permission to register for further work.

Foreign Languages. The Institute believes in the importance of the knowledge of foreign languages and encourages their study as early as possible and preferably before admission to graduate standing. Although there is no Institute-wide foreign language requirement for the degree of Doctor of Philosophy, graduate students should check for possible specific requirements set by their division or smaller academic unit.

To encourage the study of foreign languages, the Institute recognizes previous work (see general minor, page 231) and offers the possibility of further study as a graduate student. Course work in languages is recognized for part of a general minor. The Institute offers also a two-year intensive program in French, German, and Russian. In addition, successful completion of this program, together with 27 additional course work units in the literature of the language, entitles the student to a subject minor in that language. The latter is not open to foreign students in their native language.

Examination. During his course of study every doctoral candidate shall be examined broadly and orally on his major subject, the scope of his thesis and its significance in relation to his major subject. The examination, subject to the approval of the Committee on Graduate Study, may be taken at such time after admission to candidacy as the candidate is prepared, except that it must take place at least two weeks before the degree is to be conferred.

The examination may be written in part, and may be subdivided into parts or given all at one time at the discretion of the departments concerned. The student must petition for this examination on a form obtained from the Dean of Graduate Studies in time for the examination to be announced in the Institute's weekly calendar. For special departmental regulations concerning candidacy and final examination, see pages 234-281.

If the candidate has a subject minor, he must also be examined broadly and orally on the subject of that program. This examination may, but need not, be included in the final examination. It may be given at a time to be determined by agreement between the major and minor departments.

Thesis. Two weeks before the degree is to be conferred, the candidate is required to submit to the Dean of Graduate Studies two copies of his thesis in accordance with the regulations governing the preparation of doctoral dissertations, obtainable from the Graduate Office. For special departmental regulations concerning theses, see pages 234-281.

With the approval of the department concerned, a portion of the thesis may consist of one or more articles published jointly by the candidate and members of the Institute staff or other co-authors. In any case, however, a substantial portion of the thesis must be the candidate's own exposition of his work.

The use of "classified" research as thesis material for any degree will not be permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Regulations and directions for the preparation of theses may be obtained from the office of the Dean of Graduate Studies, and should be followed carefully by the candidate.

Before submitting his thesis to the Dean of Graduate Studies, the candidate must obtain approval of it by the chairman of his division and the members of his examining committee. This approval must be obtained in writing on a form which will be furnished at the office of the Dean. The candidate himself is responsible for allowing sufficient time for the members of his committee to examine his thesis.

Special Regulations of the Graduate Options

AERONAUTICS

Aims and Scope of Graduate Study in Aeronautics

Graduate study in aeronautics can be weighted toward fluid mechanics, solid mechanics, jet propulsion, or flight dynamics. These fields cover a very broad area and overlap sufficiently to offer a graduate student a wide choice of study and research, particularly in view of the close relations which exist between the Aeronautics, Applied Physics, and Applied Mathematics options as well as with Materials Science and Applied Mechanics. This makes it possible for students in aeronautics to pursue interests ranging from, say, fluid physics to the design of spacecraft structures while at the same time remaining members of a rather closely knit group in GALCIT, a coherence which is strengthened by a number of regular research conferences between students and faculty. A set of three seminars is used to bring to the campus the latest advances and problems in fields of interest.

Admission

Students who have completed an undergraduate course in an engineering discipline or in applied science are eligible for admission to work toward the Master's Degree in Aeronautics. Work for the more advanced degrees may be undertaken only by students who have received the Master's Degree in Aeronautics at Caltech, or the equivalent.

Degree of Master of Science in Aeronautics

Of the 135 units of graduate work required by Institute regulations, at least 108 units must be in the following subject areas:

Fluid mechanics	27 units
Solid mechanics	27 units
Experimental technique and laboratory work	27 units
Mathematics or Applied Mathematics	27 units

In addition, three units of Ae 150 are required. Each student must have his proposed program approved by his adviser prior to registration for the first term of work toward the degree.

Degree of Aeronautical Engineer

The prerequisite for admission to work toward the degree of Aeronautical Engineer is at least one year of graduate study equivalent to the above Master of Science program. The degree of Aeronautical Engineer is awarded after satisfactory completion of at least 135 additional units of advanced graduate work. The program of study and research must consist of:

a. not less than 60 units of research in aeronautics or jet propulsion (Ae 200 or JP 280);
b. three units of an advanced seminar such as Ae 208, Ae 209, or JP 290; and
c. satisfactory completion (with a grade of C or better) of at least 27 units of aeronautics courses numbered Ae 200 or higher, excluding research and seminars.

A proposed program conforming to the above regulations must be approved by the student's adviser prior to registration for the first term of work toward the degree.

A thesis is required based on the research program and may consist of the results of a theoretical and/or experimental investigation or may be a comprehensive literature survey combined with a critical analysis of the state-of-the-art in a particular field.

No student will be allowed to continue to work toward the degree of Aeronautical Engineer for more than 4 terms of graduate residence nor more than 6 registrations for full- or part-time academic work beyond the Master of Science degree except by permission after petition to the aeronautics faculty.

Degree of Doctor of Philosophy in Aeronautics

In general, a graduate student is not admitted to work for the doctor's degree in aeronautics until he has completed at least 40 units of research in his chosen field. Thus, upon completion of his first year of graduate work he will be admitted to work toward the degree of Aeronautical Engineer. If he wishes to continue toward the doctorate, a qualifying examination for admission to work toward the doctor's degree must be taken. Upon satisfactorily passing this examination, he will be admitted to work toward the degree of Doctor of Philosophy and his admission to work towards the engineer's degree will be cancelled.

To be recommended for candidacy for the Ph.D. in aeronautics the applicant must pass with a grade of C or better one of the following, or its equivalent:

AMa 101 abc	Methods of Applied Mathematics
AM 125 abc	Engineering Mathematical Principles
Ma 108 abc	Advanced Calculus
Ph 129 abc	Methods of Mathematical Physics

and in addition must pass with a grade of C or better at least 45 units of aeronautics courses numbered Ae 200 or higher, excluding research and seminars. If any of the above subjects were taken elsewhere than at the Institute, the candidate may be required to pass special examinations indicating an equivalent knowledge of the subject.

To be admitted to candidacy, the applicant must pass a candidacy examination at least one year before the degree is to be conferred. By the beginning of the third term of the year in which the degree is to be conferred, a candidate for the degree of Doctor of Philosophy must deliver rough drafts of the thesis to his supervising committee. Not less than two weeks after the submission of the thesis rough draft, the candidate is expected to give a seminar covering the results of his research, and this seminar will be followed by a thesis examination by his supervising committee. The seminar should be given as early as possible, but not later than two months before the degree is to be conferred.

APPLIED MATHEMATICS

Aims and Scope of Graduate Study in Applied Mathematics

A program for graduate study in applied mathematics is organized jointly by the Division of Physics, Mathematics and Astronomy and the Division of Engineering and Applied Science. The course of study leads to the Ph.D. degree and requires three or four years. This program is aimed at those students with a background in mathematics, physics, or engineering who wish to obtain a thorough training and to develop their research ability in applied mathematics. Students will be admitted to one of the two divisions according to background and interests.

As the joint sponsorship by the two divisions indicates, several different groups in the Institute contribute to the teaching and supervision of research. Conversely, students in applied mathematics should combine their basic mathematical studies with deep involvement in some field of application. In accordance with this, basic general courses are listed specifically under applied mathematics; these are to be supplemented according to the student's interests from the courses offered under mathematics, and from the whole range of Institute courses in specific areas of physics, engineering, etc. Further advanced courses will be added as this program develops.

There is also an applied mathematics colloquium in which visitors, faculty, and students discuss current research.

Admission

Each new graduate student admitted to work for the Ph.D. in applied mathematics will be given an informal interview on Thursday or Friday of the week preceding the beginning of instruction for the fall term. The purpose of this interview is to ascertain the preparation of the student and assist him in mapping out a course of study. The work of the student during the first year will usually include some independent reading and/or research.

Categories of Courses

Courses which are expected to form a large part of the student's program are divided into three categories as follows:

Group A. Courses in mathematics and mathematical methods. Examples of these would include:

AMa 101	Methods of Applied Mathematics I
AMa 201	Methods of Applied Mathematics II
AMa 104	Matrix Theory
AMa 105	Introduction to Numerical Analysis
Ma 109	Delta Functions and Generalized Functions
Ma 125	Analysis of Algorithms
Ma 137	Real Variable Theory
Ma 141	Ordinary Differential Equations
Ma 143	Introduction to Functional Analysis
Ma 144	Probability

Group B. Courses of a general nature in which common mathematical concepts and techniques are applied to problems occurring in various scientific disciplines. Examples of these include:

AMa 110	Introduction to the Calculus of Variations
AMa 151	Perturbation Methods
AMa 152	Linear and Non-Linear Wave Propagation
AMa 153	Stochastic Processes
AMa 161	Mathematical Theory of Information, Communication and Coding
AMa 181	Mathematical Programming and Game Theory
AMa 251	Applications of Group Theory
AMa 260	Special Topics in Continuum Mechanics

Group C. Courses dealing with special topics in the sciences. A complete list cannot be given here but examples are courses in elasticity, fluid mechanics, dynamics, quantum mechanics, electromagnetism, communication theory, etc.

Master's Degree in Applied Mathematics

Entering graduate students are admitted for the Ph.D. program. The master's degree may be awarded in exceptional cases. Of the 135 units of graduate work required by Institute regulations, at least 81 units of advanced graduate work should be in applied mathematics.

Degree of Doctor of Philosophy in Applied Mathematics

The Oral Candidacy Examination. In order to be recommended for candidacy the student must, in addition to satisfying the general Institute requirements, pass an oral candidacy examination. This examination will normally be given during the first term of the second graduate year. It will be based upon one year's work in courses of the type described in Group A above, and upon one year's work in courses of the type described in Groups B and C. The examination will also cover the independent study carried out by the student during his first graduate year.

Further Requirements. In order to be recommended for the Ph.D. in applied mathematics, the student must do satisfactory work in a program containing at least 45 units of work in courses of the type indicated in Group A, and at least 45 units of courses chosen from Groups B and C. This is intended to prevent undue specialization in either the more mathematical or the more engineering type of courses.

The Minor. Students majoring in applied mathematics must satisfy the minor requirements of the Institute. A proposal for a General Minor must involve fields of study sufficiently far removed from the student's major field and is subject to approval by the applied mathematics faculty. In accordance with Institute requirements, candidates who elect a Subject Minor must pass a special examination in this subject. It is the responsibility of the candidate to arrange for this examination, which should be taken as soon as possible after completion of course work in the minor field.

Submission of Thesis. On or before the first Monday in April of the year in which the degree is to be conferred, a candidate for the degree of Ph.D. in applied mathematics must deliver a typewritten or printed copy of his completed thesis to his research supervisor.

Final Examination. The final oral examination will be held as nearly as possible four weeks after the submission of the thesis. The examination will cover the thesis and related areas.

Subject Minor in Applied Mathematics

Students majoring in other fields may take a subject minor in applied mathematics provided the program consists of 45 units sufficiently far removed from their major program of study and is approved by the applied mathematics faculty.

APPLIED MECHANICS

Master's Degree in Applied Mechanics

Study for the degree of Master of Science in Applied Mechanics ordinarily will consist of three terms of course work totaling at least 135 units. AM 125 abc: Engineering Mathematical Principles, and E 150 abc: Engineering Seminar, are required. With faculty approval, AM 125 abc may be replaced by Ma 108 abc: Advanced Calculus, AMa 101 abc: Methods of Applied Mathematics, or other satisfactory substitute. A minimum of 54 units must be selected from the Elective Course List below; however, substitution for electives from this list may be made with the approval of the student's adviser and the faculty in applied mechanics. Students are encouraged to consider a humanities elective as part of their free electives.

Degree of Doctor of Philosophy in Applied Mechanics

The degree of Doctor of Philosophy in Applied Mechanics will ordinarily involve a second year of graduate work in advanced courses and research, plus at least one additional year on a comprehensive thesis research project. Such study and research programs are individually planned to fit the interests and background of the student.

Course Requirements. To be recommended for candidacy for the Ph.D. degree in applied mechanics, the student must, in addition to the general Institute requirements:

a. complete 12 units of research;
b. complete at least 50 units of advanced courses arranged by the student in conference with his adviser and approved by the faculty in applied mechanics;
c. pass with a grade of at least C an advanced course in mathematics or applied mathematics such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the faculty in applied mechanics. The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward the minor requirements.

Language Requirements. The student is encouraged to discuss with his adviser the desirability of taking foreign languages, which may be included in a general minor or as a subject minor with the proper approvals. Foreign languages are not required.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his specialized field of research.

Subject Minor in Applied Mechanics

A student majoring in another branch of engineering, or another division of the Institute, may, with the approval of the faculty in applied mechanics, elect applied mechanics as a subject minor.

Elective Course List

		Units per term		
		1st	2nd	3rd
AMa 104	Matrix Algebra	9	.	.
AMa 105 ab	Introduction to Numerical Analysis	.	11	11
AMa 151 abc	Perturbation Methods	9	9	9
AMa 153 abc	Stochastic Processes	9	9	9
AM 112 abc	Structural Mechanics	9	9	9
AM 135 abc	Mathematical Elasticity Theory	9	9	9
AM 136 abc	Advanced Mathematical Elasticity Theory	9	9	9
AM 140 abc	Plasticity	9	9	9
AM 141 abc	Wave Propagation in Solids	9	9	9
AM 151 abc	Dynamics and Vibrations	9	9	9
AM 175 abc	Advanced Dynamics	9	9	9
Ae 101 abc	Fluid Mechanics	9	9	9
Ae 102 abc	Basic Solid Mechanics	9	9	9

Ae 202 abc	Advanced Solid Mechanics	9	9	9
EE 172 abc	Optimal Control Theory	9	9	9
Hy 101 abc	Fluid Mechanics	9	9	9
JP 121 abc	Jet Propulsion Systems and Trajectories	9	9	9
Ph 106 abc	Topics in Classical Physics	9	9	9

APPLIED PHYSICS

Aims and Scope of the Graduate Program in Applied Physics

A graduate student in applied physics may be admitted to work toward a master's degree or toward the Ph.D. degree.

A professional in the field should be able to cope with any physics problem that confronts him in a technological context. Graduate study in applied physics should therefore cover considerable ground with the least possible loss of depth. Independent and original research is essential, but not for the purpose of acquiring advanced knowledge in a narrow specialty. In the rapidly changing technology of today an applied physicist should not expect to remain precisely within the field of his thesis research; instead through his research he should have gained the confidence to be able to contribute actively and rapidly to any related field in physics.

Master's Degree in Applied Physics

APh 101 abc	Topics in Applied Physics (2-0-0)	6 units
	Applied Physics Electives[1]	Minimum 54 units

Suggested Electives[2]

		Units per term 1st	2nd	3rd
APh 105 abc	States of Matter (3-0-6)	9	9	9
APh 114 abc	Solid-State Physics (3-0-6)	9	9	9
APh 120 abc	Fluid Mechanics (3-0-6)	9	9	9
APh 140 abc	Cryogenics (3-0-6)	9	9	9
APh 141	Superconductivity and its Applications	.	.	9
APh 153 abc	Modern Optics (3-0-6)	9	9	9
APh 154	Modern Optics Laboratory (1-4-4)	9 or	9	.
APh 156 abc	Plasma Physics (3-0-6)	9	9	9
APh 161 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
APh 181 abc	Physics of Semiconductors and Semiconductor Devices	9	9	9
APh 185 abc	Ferromagnetism (3-0-6)	9	9	9
APh 190 abc	Quantum Electronics (3-0-6)	9	9	9
APh 200 abc	Applied Physics Research			
Ph 125 abc	Quantum Mechanics (3-0-6)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9

[1]Must be selected from APh 114, Ch 125 or Ph 125, APh 105, APh 120 or APh 156.

[2]As a result of consultation with his adviser a student may be required to take AM 113 abc, depending on his previous preparation.

AMa 104	Matrix Theory (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AM 135 abc	Mathematical Elasticity Theory (3-0-6)	9	9	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
ChE 105 abc	Applied Chemical Thermodynamics (3-0-6)	9	9	9
Ch 113 abc	Advanced Inorganic Chemistry	9	9	9
Ch 120	The Nature of the Chemical Bond	.	9	9
Ch 125 abc	Introduction to Chemical Physics (3-0-6)	9	9	9
Ch 129 abc	The Structure of Crystals (3-0-6)	9	9	9
Ge 104 abc	Advanced General Geology (4-2-3)	9	9	9
Ge 154	Atmospheric Physics (3-0-6)	9	.	.
Ge 166 a	Physics of the Earth's Interior (3-0-6)	.	9	.
Ge 166 b	Planetary Physics (3-0-6)	.	.	9

Degree of Doctor of Philosophy in Applied Physics

Candidacy. To be recommended for candidacy for the doctor's degree the applicant must satisfy the requirements listed below.

a. Competence must be demonstrated in the following subjects, at the levels indicated.

   1. Classical Physics: Mechanics and Electromagnetism
      course level: Ph 106
   2. Quantum Mechanics
      course level: Ph 125 or Ch 125
   3. Mathematical Methods
      course level: AMa 101, AM 125, or Ph 129
   4. Statistical Physics and Thermodynamics
      course level: APh 105
   5. Solid-State Physics or Fluid Dynamics
      course level: APh 114, APh 120, or APh 156

   Competence in three of the subjects, including number 3, Mathematical Methods, must be demonstrated by grades no lower than C in an appropriate Caltech course. In unusual cases, it will be possible for a student to be deemed competent in any of the subjects by showing evidence of having done well in an equivalent course offered elsewhere, or by passing a suitable written examination. The examination must cover all of the specified course, and the student will not be permitted to take it in parts (e.g., term by term) or more than twice.

   The two subjects which remain will be dealt with in a single oral examination. The student will be permitted to repeat a failed oral only once, with or without change of subject. Demonstration of (subject) competence must be complete before the close of the student's second year of residence.

b. Competence in research must be demonstrated as follows: The student must have a doctoral thesis adviser and must have completed 18 units of thesis research with this adviser no later than the beginning of his third year of residence.

c. The student must obtain approval of a minor course of study. Courses for either a subject or a general minor may be offered only if their content is primarily in a field other than that of the student's thesis research. Preferably some of the courses in a general minor should be outside of the option of applied physics.

Thesis and Final Examination. The candidate is required to take a final oral examination covering his doctoral thesis, its significance and relation to this major field. This final examination will be given not less than two weeks after the doctoral thesis has been presented in final form, and prior to its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted. In addition to his doctoral thesis, the student should write an explanation, approximately 500 words, of the motivation and results of his research in a language that can be understood by an intelligent nonscientist. This will be kept on file in the Applied Physics Library.

ASTRONOMY

Admission

It is strongly recommended that applicants, including those from foreign countries, for admission to graduate study in astronomy submit Graduate Record Examination test scores for verbal and quantitative aptitude tests and the advanced test in physics.

Placement Examinations

Each student admitted to work for an advanced degree in astronomy is required to take the Placement Examinations in physics, (see Placement Examinations, page 277) covering material equivalent to Ph 92, Ph 106, and Ph 125. An oral examination by the staff covering material equivalent to Ay 20, Ay 21, Ay 101, and Ay 102 is given on the Friday preceding the beginning of instruction for the first term. These examinations will test whether the student's background of atomic and nuclear physics, mathematics, physics, and astronomy is sufficiently strong to permit advanced study in these subjects. If it is not, students will be required to pass the appropriate courses.

Master's Degree in Astronomy

The choice of astronomy and other science elective courses must be approved by the department. At least 36 units of the 135 units must be selected from Ay 131, Ay 132, Ay 133, Ay 134, Ay 136, Ay 138, Ay 139, Ay 201. The courses Ay 120, Ph 92, Ph 106, and Ph 125 may be required of those students whose previous training in some of these subjects proves to be insufficient. At least 27 units of advanced courses not in astronomy are required.

Degree of Doctor of Philosophy in Astronomy

Astronomy Program: The student's proposed overall program of study must be planned and approved by the department during the first year. Required courses for candidacy are Ay 131, Ay 132, Ay 133 ab, Ay 138, and Ay 139. The student should take these courses as soon as they are offered. Also required are research and reading projects, starting in the second term of the first academic year. Credit for this work will be given under courses Ay 142 and Ay 143. Written term papers dealing with the research or reading done will be required at the end of each term.

Physics Program: The student's program during the first two years of graduate study should include at least 36 units of physics courses, exclusive of Ph 92, Ph 106, and Ph 125. This requirement may be reduced on written approval of the department for students who take substantial numbers of units in Ph 92, Ph 106, and Ph 125. Students in radio astronomy should include Ph 209 in the required 36 units of physics; they may take the remaining units in an advanced course in electrical engineering or applied mechanics. Theoretical astrophysics students should include at least 54 units of physics courses in their program. Students in planetary physics may substitute appropriate advanced courses in geophysics and geochemistry. All the above courses must be passed with a grade of C or better.

The Minor: Fields in which subject minors are usually taken include physics, geology, or engineering, dependent on the student's field of specialization.

Language Requirement: To be admitted to candidacy for the Ph.D. degree in astronomy, the student must demonstrate a knowledge of Russian, German, or French sufficient for the reading of technical material in his field. Students will be required to take a special examination administered by the staff in fulfillment of this requirement.

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

(a) complete satisfactorily 36 units of research Ay 142 or reading Ay 143;
(b) pass with a grade of C or better, or by special examination, Ay 131, Ay 132, Ay 133 ab, Ay 138, and Ay 139;
(c) pass an oral examination (see below);
(d) fulfill the language requirement (see above); and
(e) be accepted for thesis research by a staff member.

Students in radio astronomy may omit Ay 131. Theoretical astrophysics students may omit Ay 133a; they are normally expected to take part in the theoretical seminar Ay 215. Students in planetary physics may omit Ay 138 and Ay 139, substituting a corresponding number of units from Ay 134, Ay 136, Ge 166, or Ge 220, after consultation with their advisers and the instructors.

The oral examination must be taken before the end of the second term of the second year. The candidacy examination will cover material from (1) the required astronomy courses, (2) the basic physics courses Ph 92, Ph 106, and Ph 125, and (3) the material submitted as term papers for courses Ay 142 (research) and Ay 143 (reading). Special permission will be required for further registration if the candidacy course requirements and the oral examination are not satisfactorily completed by the end of the second year of graduate work.

Final Examination: A final draft of the thesis must be submitted at least six weeks before the commencement at which the degree is to be conferred. At least two weeks after submission of the thesis, the student will be examined orally on the scope of his thesis and its relation to current research in astronomy.

Subject Minor in Astronomy

The program for a subject minor in astronomy must be approved by the department during the first year of graduate work. In addition to general Institute requirements, the student must (a) complete satisfactorily, with an average grade of C or better, 45 units in advanced courses in astronomy, and (b) pass a short oral examination given by the department.

BIOLOGY

Aims and Scope of Graduate Study in Biology

Graduate students in biology come with very diverse undergraduate preparation — majors in physics, chemistry, and mathematics, or psychology, as well as in biology and its various branches. The aims of the graduate program are to provide, for each student, individual depth of experience and competence in his particular chosen major specialty; perception of the nature and logic of biology as a whole; sufficient strength in basic science to allow him to continue self-education after his formal training has been completed and thus to keep in the forefront of his changing field; and the motivation to serve his field productively through a long career. In accordance with these aims, the graduate study program in biology includes the following parts: (a) the major program which is to provide the student with early and intense original research experience in a discipline of biology of his own choice, supplemented with advanced course work and independent study in this discipline; (b) the minor program, usually designed to provide him with professional insight into a discipline outside his major one and consisting of specialized course work, or course work and a special research program; and as a rule (c) a program of course work in advanced subjects, designed to provide him with a well-rounded and integrated training in biology and the appropriate basic sciences, and adjusted to his special interests and needs. (b) and (c) may include supervised, independent study. An individual program will be recommended to each student when he meets with his advisory committee (see section IV). A student majoring in psychobiology or experimental psychology may arrange to do one or more terms on another campus to obtain relevant course work in psychology and medicine not offered at the Institute.

Admission

Applicants are expected to meet the following minimal requirements: mathematics through calculus, general physics, organic chemistry, physical chemistry (or the equivalent), and elementary biology. Students with deficient preparation in one or more of these categories may be admitted but required to remedy their deficiencies in the first years of graduate training, no graduate credit being granted for such remedial study. This will usually involve taking the courses in the categories in which the student has deficiencies. In certain instances, however, deficiencies may be corrected by examinations following independent or supervised study apart from formal courses. Furthermore, the program in biology is diverse, and in particular fields such as psychobiology and experimental psychology or in interdisciplinary programs such as neurophysiology-electrical engineering, other kinds of undergraduate preparation may be substituted for the general requirements listed above. Graduate Record Examinations (verbal, quantitative, and the advanced test in *any* science) are required of applicants for graduate admission intending to major in biology.

Placement Examinations

All students admitted to graduate work in biology are required either to take placement examinations in cell biology and in organismic biology, or to take the equivalent courses (Bi 9 and Bi 7). The examination in organismic biology is so constructed as to test basic knowledge of either animal or plant biology. The examinations or courses must be passed with a grade of B- or better before the end of the first year of graduate study.

Advisory Committee

During the week preceding registration for the first term, each entering student confers with the divisional Graduate Advisory Committee. The committee consists of a chairman and three other members of the faculty representing diverse fields of biology. The committee will advise the student of deficiencies in his training; will design a remedial study program where necessary; and will recommend an individual study program of advanced course work in accordance with item (c), section 1. The committee will also be available for consultation and advice throughout his graduate study until the student is admitted to candidacy (see below).

Teaching Requirements for Graduate Students

All students must acquire teaching experience.

Master's Degree in Biology

The Biology Division does not admit students for work toward the M.S. degree. In special circumstances the M.S. degree may be awarded, provided Institute requirements are met and the student has received a passing grade on each of two placement examinations. In general the degree is not conferred until the end of the second year of residence. The degree does not designate any of the disciplines of the division, but is an M.S. in Biology.

Degree of Doctor of Philosophy in Biology

Major Subjects of Specialization. A student may pursue major work leading to the doctor's degree in any of the following disciplines:

Biochemistry	Genetics
Biophysics	Immunology
Cell Biology	Neurophysiology
Developmental Biology	Psychobiology
Experimental Psychology	Virology

At graduation, a student may choose if his degree is to be awarded in biology or in his selected discipline. If the award is to be in biology, the minor (page 245) will be designated only if it is from another division of the Institute.

Minor Subjects. A student majoring in one of the above disciplines may elect to take a minor in one of the following ways, subject to the approval of the graduate advisory committee: (a) a general minor consisting of not less than 54 units of advanced course work in one or more disciplines in biology (if not closely related to the major discipline), other sciences, engineering or the humanities; (b) a subject minor in another division of the Institute; or (c) a subject minor in one of the disciplines listed above under major subjects of specialization, provided the subject matter of this discipline is not too closely related to that of his major field. When a student takes a subject minor, his degree designates the disciplines of his major and minor (e.g. biophysics and chemistry; biochemistry and neurophysiology). When he takes a general minor, his degree designates only his major discipline (e.g. biochemistry or neurophysiology). Courses listed jointly by the Biology Division and another division are not credited toward a general minor for majors in a closely related discipline of biology, even if the student registers for the course under the other division's course number.

Admission to Candidacy. To be recommended by the Division of Biology for admission to candidacy for the doctor's degree, the student must have demonstrated his ability to carry out original research and have passed, with a grade of B or better, the candidacy examination in his major. With regard to his minor: (a) a student who elects to take a general minor is required to complete the course requirements of the minor with grades of B or better; (b) in case the minor is taken outside the Biology Division, the student is required to fulfill the minor requirements of the outside division and of the Institute.

Thesis Committee. After admission to candidacy, a thesis committee is appointed for each student by the chairman of the division upon consultation with the student and his professor. This committee will consist of the student's major professor as chairman and four other appropriate members of the faculty including a member of the faculty of the subject minor (if any). The thesis committee will meet with the student soon after his admission to candidacy and at intervals thereafter to review the progress of his thesis program. This committee will, with the approval of the Dean of Graduate Studies, also serve as the thesis examination committee (see below).

Thesis and Final Examination. Two weeks after copies of the thesis are provided to the examination committee, the candidate collects the copies and comments for correction. At this time, the date for the final examination is set at the discretion of the major professor and the division chairman, to allow as necessary for such matters as publication of the examination in the Institute calendar, thesis correction, preparation of publications, and checking out and ordering of the student's laboratory space. The final oral examination covers principally the work of the thesis, and according to Institute regulation must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate and are deposited in the Institute library. A third copy is retained in the division library.

Subject Minor in Biology

A student majoring in another division of the Institute may, with the approval of the Biology Division, elect a subject minor in any of the disciplines listed above under major subjects of specialization. Requirements for such a minor consist of (a) passing the placement examination in cell biology *or* organismic biology, and (b) passing the qualifying examination in the discipline elected. A minor program in biology is also available to students of other divisions. Such a program shall consist of 45 units of upper division course work in the Biology Division, each course passed with a grade of "C" or better. Approval of each program must be obtained from the Biology Graduate Advisory Committee. Advanced courses in the Biology Division can of course be included in a General Minor under the supervision of the student's major division. A student majoring in another division who elects a subject minor in one of the disciplines of biology may if desired arrange to have his minor designated as biology, rather than with the name of his specific minor discipline.

CHEMICAL ENGINEERING

Aims and Scope of Graduate Study in Chemical Engineering

The Institute was one of the earliest schools to use the engineering science approach to chemical engineering. The emphasis in both instruction and research is on basic subjects rather than on specialized material relating primarily to particular industries or processes. It is believed that the basic subjects essential to constructive thinking in engineering are most easily mastered with sympathetic and continuous instruction, whereas the material of applied nature is more properly learned in the industrial environment.

The general objective of the graduate work in chemical engineering is to produce individuals who are exceptionally well trained to apply the principles of mathematics, the physical sciences, and engineering to new situations involving chemical reactions and the transport of momentum, energy, and material.

Admission

It is expected that each applicant for graduate study in the Division of Chemistry and Chemical Engineering will have studied mathematics and physics substantially to the extent that these subjects are covered in the required undergraduate courses at Caltech. In case the applicant's training is not equivalent to this, the division may prescribe additional work in these subjects before recommending him as a candidate.

Master's Degree in Chemical Engineering

The master's degree is intended for students who plan to pursue careers in design, process engineering, development, or management. The degree is normally obtained in one academic year.

Course Requirements. The requirements include ChE 126 abc, Chemical Engineering Laboratory, and ChE 291 which is required for one, two, or three terms at the discretion of the instructor. ChE 126 bc represents two terms of research under the supervision of a chemical engineering faculty member. The student who has taken ChE 126a or its equivalent as an undergraduate may substitute an equal amount of research, ChE 280. A student originally admitted to work toward the Ph.D. degree can substitute an equal amount of research, ChE 280, for all or part of this requirement but must also submit a research report in thesis form and have it accepted by the faculty in chemical engineering. A research report is required for the master's degree. In addition, there are electives, which may include humanities as well as graduate courses from other branches of science and engineering. A minimum of 18 units of these electives must be in advanced chemical engineering subjects; the remainder are to be chosen from other approved advanced subjects but may also include up to 30 units of freely elected graduate courses, which may be in humanities as well as in engineering and science subjects. In addition to 81 units of advanced professional subjects, AM 113 abc must be taken if the equivalent has not been studied previously.

Degree of Doctor of Philosophy in Chemical Engineering

The work leading to the Ph.D. degree prepares students for careers in universities and in the research laboratories of industry and government, although Ph.D. graduates are also well qualified for the areas listed for the master's degree. Usually the first year of graduate work is principally devoted to course work in chemical engineering and in the minor program. ChE 291 is required for one, two, or three terms at the discretion of the instructor. The research program is also started during this period. During the second year the student is expected to spend at least half time on his research, and to complete his minor and the candidacy requirements. Some time is available for elective courses. It is expected that the research project will occupy full time during the third year. Thus, if summers are spent on research and other academic pursuits, the Ph.D. requirements may be completed in three calendar years.

Admission. During the Friday preceding General Registration for the first term of graduate study, students admitted to work for the Ph.D. degree are required to consult with the professor in charge of the courses of engineering design, chemical thermodynamics, transport phenomena, and applied chemical kinetics. This informal consultation is aimed at planning course work for each student.

Minor. The units of study offered to satisfy a minor requirement are in general to be in graduate courses other than research; however, the Division of Chemistry and Chemical Engineering may, by special action, permit up to one-half of these units to be in appropriate research. The general minor must represent an integrated program approved by the division; for students in chemical engineering it must consist of courses other than chemical engineering. A grade of C or better is required in these courses.

Candidacy Requirements. To be recommended for candidacy the student must demonstrate proficiency at a graduate level in chemical engineering. This will be done by way of chemical engineering courses, an oral subject examination which is to be taken before the end of the third term of the student's first year of graduate residence at the Institute, and a written progress report on his research to be submitted before the end of second term of the student's second year of graduate residence. The oral examination will cover thermodynamics, applied chemical kinetics, transport phenomena, and design, with emphasis at the discretion of the committee. Approval of the research report constitutes the final step for admission to candidacy. A student who fails to satisfy the division's candidacy requirements by the end of the third term of his second year of graduate residence at the Institute will not be allowed to register in a subsequent academic year except by special permission of the Division of Chemistry and Chemical Engineering.

Proposition Requirement. Each student is required to submit, and have approved by the faculty, one proposition. This may be done at any time during the period of graduate study, but in every case this requirement must be *completed* before the final oral examination can be scheduled. The proposition is intended to foster breadth, and to allow the student the opportunity to pursue, on his own, and in some depth, a subject of interest to him which is outside the immediate area of his thesis research. The proposition should be stated explicitly and the argument presented in writing with adequate documentation. Originality, technical content and clarity of presentation will constitute the primary criteria of the faculty in judging the acceptability of the proposition.

Thesis and Final Examination. The candidate must submit a copy of his thesis in final form to the chairman and to each member of his examining committee, not less than two weeks prior to his final examination, which according to the Institute regulation must be held at least two weeks before the degree is conferred. After his examination two copies of the thesis are to be submitted to the office of the Dean of Graduate Studies to be proofread. In addition, one copy, corrected after proofreading by the Graduate Office, is to be submitted to the divisional graduate secretary for the divisional library. All reproduced copies may be either electrostatic bound copy (Xerox or similar) or electrostatic vellum (Xerox or similar).

The final examination will be concerned with the candidate's oral presentation and defense of a brief resume of his research.

CHEMISTRY

Aims and Scope of Graduate Study in Chemistry

The graduate program in chemistry emphasizes research. This emphasis reflects the Institute's traditional leadership in chemical research and the conviction that has permeated the Division of Chemistry and Chemical Engineering from its founding, that participation in original research is the best way to awaken, develop, and give direction to creativity.

As a new graduate student, soon after you arrive in the laboratories, you will attend a series of orienting seminars that introduce you to the active research interests of the staff. You then talk in detail with each of several staff members whose fields attract you, eventually settle upon the outlines of a problem that interests you, and begin research upon it early in the first year. You can elect to do research which crosses the boundaries of areas that are commonly distinguished by schismatic names; for in this relatively compact division, a student is encouraged to go where his scientific curiosity drives him; he is not confined to a biochemical or physical or organic laboratory. A thesis that involves more than one adviser is common, and interdisciplinary programs with biology, physics, and geology are open and encouraged.

An extensive program of seminars will enable you to hear of and discuss notable work in your own and other areas. In the Divisional Research Conferences, members of the staff and distinguished visitors present accounts of research of broad interest. More specialized seminars are devoted to such subjects as theoretical chemistry, physical organic chemistry, electrochemistry, crystal-structure analysis, and biological chemistry. Graduate students are encouraged also to attend seminars in other divisions.

Placement Examination

During the week preceding General Registration for the first term of graduate study, graduate students admitted to work for advanced degrees will be required to take a written placement examination in the field of inorganic, analytical, organic, and physical chemistry. This examination will cover these respective subjects to the extent that they are treated in the undergraduate chemistry option offered at the Institute. In general, it will be designed to test whether you possess an understanding of general principles and a power to apply these to specific problems, rather than a detailed informational knowledge. You will be expected to demonstrate a proficiency in the above subjects not less than that acquired by abler undergraduates. Students who have demonstrated this proficiency in earlier residence at the Institute may be excused from these examinations.

A special section of the examination will deal with chemical physics. It will be designed specifically to test the preparation of students who wish to carry on research in this area, and will require a knowledge of physics and mathematics beyond the corresponding courses normally required for the undergraduate chemistry option at the Institute. Students taking and passing the chemical physics examination with sufficiently high marks may, with permission, use this performance to satisfy a placement examination deficiency in one other field.

In the event that you fail to show satisfactory performance in any area of the placement examination, you will be required to register for a prescribed course, or courses, in order to correct the deficiency promptly. In general no graduate credit is given for these courses. If your performance in the required course or courses is not satisfactory, you will not be allowed to continue graduate studies except by special action of the Division of Chemistry and Chemical Engineering on receipt of a petition to be allowed to continue.

Course Program

For an advanced degree, no graduate courses in chemistry are specifically required. You should plan a program of advanced courses in consultation, at first with a representative of the divisional Committee on Graduate Study and later with your research adviser.

Master's Degree in Chemistry

Students are not ordinarily admitted to graduate work leading to an M.S. degree, but the master's program is available. All master's programs for the degree in chemistry must include at least 40 units of chemical research and at least 30 units of advanced courses in science. The remaining electives may be satisfied by advanced work in any area of mathematics, science, engineering, or humanities, or by chemical research. Two copies of a satisfactory thesis describing this research, including a one-page digest or summary of the main results obtained, must be submitted to the divisional graduate secretary at least ten days before the degree is to be conferred. The copies of the thesis should be prepared according to the directions formulated by the Dean of Graduate Studies and should be accompanied by a statement approving the thesis, signed by the staff member directing the research and by the chairman of the Committee on Graduate Study of the division.

Candidates must satisfy the department of languages that they are able to read scientific articles in at least one of the following languages: German, French, or Russian.

Degree of Doctor of Philosophy in Chemistry

Candidacy. To be recommended for candidacy for the doctor's degree in chemistry, in addition to demonstrating an understanding and knowledge of the fundamentals of chemistry, you must give satisfactory evidence of proficiency at a high level in your primary field of interest, as approved by the division. This is accomplished by an oral candidacy examination which must be held during or before your fifth term of graduate residence (excluding summer terms). At this examination you will be asked to demonstrate scientific and professional competence and promise by discussing a research report and propositions as described below.

The research report should describe your progress and accomplishments to date and plans for future research. Three propositions, or brief scientific theses, must accompany the report. These should reflect your breadth of reading, originality, and ability to see valid scientific problems. They should *not* all be in your own field of research. The research report and propositions must be in the hands of your examining committee one week prior to the examination.

If you fail to pass the oral examination or if any of your propositions are judged inadequate, then you will have to correct the deficiencies or in some cases schedule a new examination the following term. You must be admitted to candidacy at least three terms before your final oral examination. You cannot continue in graduate work in chemistry past the end of the sixth term of residence without being admitted to candidacy, except by petitioning the division for special permission. This permission, to be requested by a petition submitted to the divisional graduate committee in advance of registration day stating a proposed timetable for correction of deficiencies, must be obtained prior to registration for each subsequent term until admission to candidacy is achieved.

Language Requirements and Candidacy. Satisfactory completion of the language requirement and removal of placement examination requirements are also necessary before you can be admitted to candidacy. Ph.D. chemists must demonstrate proficiency in *one* language: French, German, or Russian. This demonstration can be by test, good performance in a course at Caltech, or by sufficient undergraduate course work in the language.

The Minor. The units of study offered to satisfy a minor requirement are to consist in general of graduate courses other than research; however, the Division of Chemistry and Chemical Engineering may, by special action, permit up to one-half of these units to consist of appropriate research. The general minor must represent an integrated program approved by the division; it must consist of courses other than chemistry. A grade of C or better is required in these courses.

Thesis and Final Examination. The final examination will consist in part of oral presentation and defense of a brief resume of your research and in part of the defense of a set of propositions prepared by you. Five propositions are required. In order to obtain diversity with respect to subject matter, not more than two shall be related to the immediate area of your thesis research. Each proposition shall be stated explicitly and the argument presented in writing with adequate documentation. Propositions of exceptional quality presented at the time of the candidacy examination may be included among the five submitted at the time of final examination.

The propositions should display originality, breadth of interest, and soundness of training; you will be judged on your selection and formulation of the propositions as well as on your defense of them. You should begin formulating a set of propositions early in the course of graduate study.

You must submit a copy of the thesis and propositions in final form to the chairman and to each member of the examining committee, and a copy of the propositions and an abstract of the propositions to the divisional graduate secretary, *not less than* two weeks prior to your final examination. One reproduced copy of the thesis, corrected after proofreading by the Graduate Office, is to be submitted to the divisional graduate secretary for the divisional library.

Subject Minor in Chemistry

Graduate students taking chemistry as a subject minor shall complete a program of study which in general shall include Ch 125 or Ch 144 and one or more graduate courses in chemistry so selected as to provide an understanding of at least one area of chemistry. The total number of units shall not be less than 45, and a grade of C or better in each course included in the program will be required.

CIVIL ENGINEERING

Aims and Scope of Graduate Study in Civil Engineering

Students who have not specialized in civil engineering as undergraduates, as well as those who have, may be admitted for graduate study. As preparation for advanced study and research, a good four-year undergraduate program in mathematics and the sciences may be substituted for a four-year undergraduate engineering course with the approval of the faculty. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his program in consultation with a member of the faculty. In some cases, the student may be required to make up deficiencies in engineering science courses at the undergraduate level. However, in every case the student will be urged to take some courses which will broaden his understanding of the overall field of civil engineering, as well as courses in his specialty. Most graduate students are also required to take further work in applied mathematics.

Master's Degree in Civil Engineering

Although the first year of graduate study involves specialized engineering subjects, the student working for the Master of Science degree is encouraged not to overspecialize in one particular field of civil engineering. For the M.S. degree a minimum of 138 units of academic credit is required. The program must include 3 units of CE 130 abc; 27 units of courses in humanities or social sciences; and 108 units (minimum) of courses from the five groups of electives listed below. Each student's program should include selections from at least three of the five groups that are approved by his adviser. Students who have not had AM 95 abc or its equivalent will be required to include AM 113 abc as part of their elective units. Other courses not listed here may be elected if approved by the civil engineering faculty.

Electives in Structures

		Units per term 1st	2nd	3rd
Ae 102 abc	Basic Solid Mechanics (3-0-6)	9	9	9
AM 112 abc	Structural Mechanics (3-0-6)	9	9	9
AM 135 abc	Mathematical Elasticity Theory (3-0-6)	9	9	9
AM 151 abc	Dynamics and Vibrations (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
AM 160	Vibrations Laboratory (0-3-3)	.	6	.
CE 121	Analysis and Design of Structural Systems (0-9-0)	.	.	9
CE 124	Special Problems in Structures	9 or	9 or	9
CE 180	Experimental Methods in Earthquake Engineering (1-5-3)	9	.	.
CE 181	Principles of Earthquake Engineering (3-0-6)	.	9	.
CE 182	Structural Dynamics of Earthquake Engineering (3-0-6)	.	.	9
CE 212 abc	Advanced Structural Mechanics (3-0-6)	9	9	9

Electives in Soil Mechanics

CE 105	Introduction to Soil Mechanics (2-3-4)	9	.	.
CE 115 ab	Soil Mechanics (3-0-6; 2-3-4)	9	9	.
CE 150	Foundation Engineering (3-0-6)	.	.	9

Electives in Hydraulics and Water Resources

Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
Hy 103 ab	Advanced Hydraulics and Hydraulic Structures (3-0-6)	9	9	.
Hy 105	Analysis and Design of Hydraulic Projects[2]	.	.	.
Hy 111	Fluid Mechanics Laboratory[1]	.	.	.
Hy 113 ab	Coastal Engineering (3-0-6)	9	9	.
Hy 213	Advanced Coastal Engineering (3-0-6)	.	.	9
Hy 121	Advanced Hydraulics Laboratory[2]	.	.	.

Electives in Environmental Engineering

Env 112 abc	Hydrologic Transport Processes (3-0-6)	9	9	9
Env 116	Experimental Methods in Air Pollution (1-3-3)	.	.	7
Env 117	Fundamentals of Air Pollution Engineering (3-0-6)	.	.	9
Env 142 ab	Applied Chemistry of Natural Water Systems (2-3-4)	9	9	.
Env 144	Ecology (2-1-3)	.	6	.
Env 145 ab	Environmental Biology (2-4-4; 2-3-4)	.	10	9

[1]Six to nine units as arranged, second or third term.
[2]Six or more units as arranged, any term.

Env 146 abc	Analysis and Design of Water and Wastewater Systems (3-0-6)	9	9	9
Env155	Special Problems in Waste Management (2-3-4)	.	9	.
Env 156	Industrial Wastes (3-0-6)	.	.	9
Env 170 ab	Behavior of Disperse Systems in Fluids (3-0-6)	9	9	.
	Electives in Mathematics			
AMa 101 abc	Methods of Applied Mathematics I (3-0-6)	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AMa 181 abc	Mathematical Programming and Game Theory (3-0-6)	9	9	9
AM 113 abc	Engineering Mathematics (4-0-8)	12	12	12
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
Ma 112 ab	Elementary Statistics (3-0-6)	9	or 9	9

Degree of Civil Engineer

Greater specialization is provided by work for the engineer's than for the master's degree. The candidate for this degree is allowed wide latitude in selecting his program of study, and is encouraged to elect related course work of advanced nature in the basic sciences. The degree of Civil Engineer is considered to be a terminal degree for the student who desires advanced training more highly specialized and with less emphasis on research than is appropriate to the degree of Doctor of Philosophy. However, research leading to a thesis is required for both degrees. The student should refer to Institute requirements for the engineer's degree.

Degree of Doctor of Philosophy in Civil Engineering

Upon admission to work toward the Ph.D. degree in civil engineering, a counselling committee of three members of the faculty is appointed to advise the student on his program. One member of the committee who is most closely related to the student's field of interest serves as interim chairman and adviser. The student's thesis adviser is chosen by the student and the advisory committee at a later time when the student's research interests are more clearly defined.

Major Subjects of Specialization. A student may pursue major work leading to the doctor's degree in civil engineering in any of the following disciplines: structural engineering and applied mechanics, earthquake engineering, soil mechanics, hydraulics, coastal engineering, and environmental engineering. Other disciplines may be selected with approval of the civil engineering faculty.

Minor Requirements. The purpose of the minor program of study is to broaden the student's outlook by acquainting him with subject matter outside his major field. The minor requirement is satisfied by the completion of advanced courses arranged by the student in consultation with his advisory committee, and approved by the faculty in civil engineering.

A student may elect to take a minor in either of the following ways:

(a) a subject minor in a discipline sufficiently removed from his major field of work; or

(b) a general minor consisting of at least 54 units of work, of which at least 36 units must be in advanced subjects in humanities, sciences or engineering; a portion should be taken outside the Division of Engineering and Applied Science. The remaining 18 units may be either advanced or undergraduate work (including introductory language courses) taken after admission to graduate standing. The student is encouraged to discuss with his adviser the desirability of taking foreign languages; foreign languages are not required. The minor program (subject or general) may not include the courses used to satisfy the mathematics requirement (including prerequisites) nor any course in the student's specialized field of thesis research.

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

(a) complete a program of advanced courses as arranged by him in consultation with his advisory committee, and approved by the faculty of civil engineering;

(b) pass at least 27 units of course work in advanced mathematics, such as AM 125, AMa 101, Ph 129, or a satisfactory substitute. For a student whose program is more closely related to the sciences of biology or chemistry than physics, AMa 104 and AMa 105 ab (or AMa 104 and AMa 181 ab) will be an acceptable substitute for the mathematics requirement;

(c) pass an oral candidacy examination on the major subject, and if the student has a subject minor, examination on the minor subject may be included at the request of the discipline offering the minor.

The oral candidacy examination must be taken before registration day of the fifth term of his residence as a post-M.S. student or equivalent and will comprise:

(a) a section where the student will be questioned on the content of courses taken during his graduate residence in which he will be expected to demonstrate an understanding of his major field of interest;

(b) a discussion of his research report describing accomplishments to date including reading, study, and plans for future research.

At least ten days before the examination the student must present to the examining committee a brief research report.

Thesis and Final Examination. Copies of the completed thesis must be provided to the examining committee two weeks prior to the examination. The date for the final oral examination is decided at the discretion of the major professor and the division chairman to allow as necessary for such matters as publication of the examination in the Institute Calendar. The oral examination covers principally the work of the thesis, and according to Institute regulations, must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate, one of which is deposited in the Institute library and the other is deposited with University Microfilms. The examining committee will consist of such individuals as may be recommended by the chairman of the division and approved by the Dean of Graduate Studies.

ELECTRICAL ENGINEERING

Aims and Scope of Graduate Study in Electrical Engineering

The Bachelor of Science degree is followed by additional graduate work for the Master of Science degree in Electrical Engineering, usually completed in one year. For exceptional students, instruction is offered leading to the degrees of Electrical Engineer and Doctor of Philosophy. The graduate curriculum is sufficiently flexible to allow the student to select courses closely aligned with his particular field of interest. Students are encouraged to participate in graduate seminars and in research projects with the electrical engineering faculty.

Placement Examination

Students admitted to work toward the degree of Master of Science in Electrical Engineering are required to take a placement examination in mathematics. This examination is given on the Friday of the week preceding registration, and will be concerned primarily with subject matter of the undergraduate course, AMa 95 abc. The result of this examination has no bearing on a student's admission to graduate study, but in the event that preparation in this subject area is judged to be inadequate, the student will be required to enroll in AM 113 ab, for which graduate credit may be received. In cases where there is a clear basis for ascertaining the student's preparation, the examination may be waived. Notices of the placement examination are sent well in advance of the examination date.

Master's Degree in Electrical Engineering

A minimum of 102 units are required from the following list of courses.

		Units per term		
		1st	2nd	3rd
EE 113 abc	Modern Optics (3-0-6)	9	9	9
EE 114 abc	Electronic Circuit Design (3-0-6)	9	9	9
EE 151 abc	Electromagnetism (3-0-6)	9	9	9
EE 155 abc	Electromagnetic Fields (3-0-6)	9	9	9
EE 161 abc	Mathematical Theory of Information, Communication, and Coding (3-0-6)	9	9	9
EE 172 abc	Control Systems Theory (3-0-6)	9	9	9
EE 194	Microwave Laboratory (1-4-4)	.	.	9
EE 197 ab	Modern Optics Laboratory (1-4-4)	9	9	.
EE 281 abc	Semiconductor Devices (3-0-6)	9	9	9
EE 291	Advanced Work in Electrical Engineering	.	.	.
APh 105 abc	States of Matter (3-0-6)	9	9	9
APh 114 abc	Solid-State Physics (3-0-6)	9	9	9
APh 140 abc	Cryogenics (3-0-6)	9	9	9
APh 156 abc	Plasma Physics (3-0-6)	9	9	9
APh 181 abc	Physics of Semiconductors and Semiconductor Devices (3-0-6)	9	9	9
APh 185 abc	Ferromagnetism (3-0-6)	9	9	9
APh 190 abc	Quantum Electronics (3-0-6)	9	9	9
APh 214 abc	Solid-State Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (3-0-6)	9	9	9
Ph 127 abc	Statistical Physics (3-0-6)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9
Ph 209 abc	Electromagnetism and Electron Theory (3-0-6)	9	9	9
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
IS 110 abc	Principles of Digital Information Processing (3-3-3)	9	9	9
IS 129 abc	Introduction to Programming Systems (3-0-6)	9	9	9

AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AMa 153 abc	Stochastic Processes (3-0-6)	9	9	9
AMa 181 ab	Linear Programming (3-0-6)	.	9	9
Ma108 abc	Advanced Calculus (4-0-8)	12	12	12

Other electives may be substituted upon approval of the electrical engineering faculty. E 150 abc: Engineering Seminar, is also required. Students are urged to consider including a humanities course in the free electives.

Degree of Electrical Engineer

To be recommended for the degree of Electrical Engineer the applicant must pass the same subject requirements as listed for the doctor's degree.

Degree of Doctor of Philosophy in Electrical Engineering

Admission. In general, a graduate student is not admitted to work for the doctor's degree in electrical engineering until he has received a degree of Master of Science or equivalent.

Admission to graduate work beyond the M.S. degree is by recommendation of the EE faculty, based upon three factors: (1) the student's academic record, (2) performance in a preliminary oral examination normally taken the January before he obtains his M.S. degree, and (3) future research potential as evaluated by his proposed thesis adviser.

Candidacy. To be recommended for candidacy for the doctor's degree the applicant must satisfy the requirements listed below.

a. Complete 18 units of research in his field of interest.
b. Obtain approval of a minor course of study. Courses for either a subject or a general minor may be offered only if their content is primarily in a field other than that of the student's thesis research. Preferably some of the courses in a general minor should be outside the Division of Engineering and Applied Science.
c. Pass one of the following subjects with no grade lower than C:

AMa 101 abc	Methods of Applied Mathematics
AM 125 abc	Engineering Mathematical Principles
Ma 108 abc	Advanced Calculus
Ph 129 abc	Methods of Mathematical Physics

   An applicant may also satisfy any of the above course requirements by taking an examination in the subject with the instructor in charge. Every examination of this type will cover the whole of the course specified, and the student will not be permitted to take it either in parts (e.g. term by term) or more than twice.
d. Pass a qualifying oral examination covering broadly his major field and minor program of study. This examination is normally taken in the third term of the student's first post-M.S. year.

Thesis and Final Examination. The candidate is required to take a final oral examination covering his doctoral thesis and its significance in and its relation to his major field. This final examination will be given not less than two weeks after the doctoral thesis has been presented in final form, and prior to its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted.

ENGINEERING SCIENCE

Aims and Scope of Graduate Study in Engineering Science

The Engineering Science option at Caltech is designed for students of subjects which might be called classical, and semi-classical, physics, and mathematics, or the subjects which form the core of the new "interdisciplinary" sciences. These branches of science provide the basis for modern technology. Students tend to choose physics and applied mathematics as their minor subjects and to choose a thesis adviser within the Division of Engineering and Applied Science. The possibilities of choice of research subject may be seen in the following thesis titles: "Multiple Scattering of Acoustic Waves," "Studies of Cyclotron Echoes in Plasmas," "Problems of Palladium-Silicon Alloys," "Mechanical Properties of the Red Blood Cell," "Biomechanics and Physiology of Micro-organism Motility," "Acoustic Waves and Stratified Flows in the Ocean and Atmosphere."

Students wishing to pursue graduate studies in nuclear engineering may apply for admission in this option. Students who wish to follow a program in the biological engineering sciences or in information science may do so in engineering science.

Master's Degree in Engineering Science

One of the following courses in mathematics is required:

AMa 101 abc	Methods in Applied Mathematics I
AM 125 abc	Engineering Mathematical Principles
Ph 129 abc	Methods of Mathematical Physics

A minimum of 54 units must be selected from the Elective Course List below; however, substitutions for electives in this list may be made with the approval of the student's adviser and the faculty in engineering science.

Degree of Doctor of Philosophy in Engineering Science

Course Requirements. To be recommended for candidacy for the Ph.D. degree in engineering science, the student must, in addition to the general Institute requirements:

a. complete 12 units of research;
b. complete at least 50 units of advanced courses arranged by the student in conference with his adviser and approved by the faculty in engineering science;
c. pass with a grade of at least C an advanced course in mathematics or applied mathematics such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the faculty in engineering science.

In place of AM 125 abc, Ph 129 abc, or AMa 101 abc, students in information science are required to take Ma 108 abc and at least 27 units of advanced mathematics such as Ma 116 abc, EE 162a, or AM 153 abc.

The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward the minor requirements.

Language Requirements. The student is encouraged to discuss with his adviser the desirability of taking foreign languages, which may be included in a general minor or as a subject minor with the proper approvals. Foreign languages are not required.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his specialized field of research.

Subject Minor in Engineering Science

A student majoring in another branch of engineering, or another division of the Institute, may, with the approval of the faculty in engineering science, elect engineering science as a subject minor.

Elective Course List

		Units per term 1st	2nd	3rd
AMa 104	Matrix Algebra	9	.	.
AMa 105 ab	Introduction to Numerical Analysis	.	11	11
AM 135 abc	Mathematical Elasticity Theory	9	9	9
ChE 103 abc	Transport Phenomena	9	9	9
EE 133 abc	Interaction of Radiation and Matter	9	9	9
EE 135 abc	Ferromagnetism	9	9	9
EE 172 abc	Feedback Control System	9	9	9
Env 141	Applied Aqueous Solution Chemistry	9	.	.
Env 142 ab	Applied Chemistry Natural Water System	.	9	9
APh 102 abc	Applied Modern Physics	9	9	9
APh 161 abc	Nuclear Reactor Theory	9	9	9
APh 163 abc	Nuclear Radiation Measurements Laboratory	.	9	.
APh 164 abc	Nuclear Energy Laboratory	.	.	9
APh 261 abc	Transport Theory and Reactor Physics	9	9	9
ES 131 abc	Thermodynamics and Statistical Mechanics	9	9	9
Hy 101 abc	Fluid Mechanics	9	9	9
Hy 204 abc	Hydrodynamics of Free Surface Flows	9	9	9
IS 110 abc	Principles of Digital Information Processing	9	9	9
IS 129 abc	Formal Languages and Programming Systems	9	9	9
Ma 108 abc	Advanced Calculus	12	12	12
Ma 125 abc	Analysis of Algorithms	9	9	9
Ph 106 abc	Topics in Classical Physics	9	9	9
Ph 113 abc	Introduction to Solid State Physics	9	9	9
Ph 125 abc	Quantum Mechanics	9	9	9
Ph 127 abc	Statistical Physics	9	9	9
Ph 216 abc	Introduction to Plasma Physics	9	9	9

ENVIRONMENTAL ENGINEERING SCIENCE

Aims and Scope of Graduate Study in Environmental Engineering Science

By their nature, environmental problems cut across many diverse disciplines. The graduate program in environmental engineering science attempts to emphasize the problem areas and to draw together work from whatever traditional disciplines are relevant. Close interactions among engineers, scientists, and social scientists are considered essential.

In selecting courses and research topics, each student is expected to plan for both breadth of study of the environment and depth of research on a particular subject. There are no fixed course requirements, and not all students are expected to study all subjects. The seminars (Env 150 and 250) offer an opportunity for all students to become acquainted with the full range of environmental research and engineering control procedures.

The curriculum has been planned primarily for the students pursuing the Ph.D. degree, although the M.S. degree is also offered. The purpose of the Ph.D. program is to prepare students for careers of specialized research, or advanced engineering and planning in various aspects of the environment. Although students are expected and encouraged to develop a broad awareness of the full range of environmental problems, the program is not designed to train environmental generalists.

Admission

Students with bachelor's degrees in engineering science, mathematics, or economics may apply for admission to work for either the M.S. or Ph.D. degree. Programs of study are arranged individually by each student in consultation with his faculty adviser. In some instances students may need to take some additional undergraduate subjects in preparation for the graduate courses in this field.

Master's Degree in Environmental Engineering Science

For the M.S. degree a minimum of 135 units of academic credit in advanced courses is required. Each student's program should be well balanced with courses in several sub-disciplines to avoid over-specialization, and should be approved by the faculty adviser.

The program must have at least 105 units of electives from the list below, including 3 units of Env 150 abc. The remaining units are for free electives of any advanced courses at the Institute. Students are encouraged to include social science or humanities courses among their free electives. Students who have not had AMa 95 abc or its equivalent are required to include AM 113 abc as part of their elective units.

List of Electives

		Units per term		
		1st	2nd	3rd
Env 100	Special Topics in Environmental Engineering Science[1]			
Env 103 ab	Introduction to Processes of the Atmosphere and Hydrosphere (3-0-6)	9	9	.
Env 112 abc	Hydrologic Transport Processes (3-1-5; 3-0-6)	9	9	9
Env 116	Experimental Methods in Air Pollution (1-3-3)	.	.	7
Env 117	Fundamentals of Air Pollution Engineering (3-0-6)	.	.	9
Env 118	Environmental Economics (3-0-6)	.	.	9
Env 142 ab	Chemistry of Natural Water Systems (2-3-4)	9	9	.
Env 144	Ecology (2-1-3)	.	6	.
Env 145 ab	Environmental Biology (2-4-4; 3-0-6)	.	10	9
Env 146 abc	Analysis and Design of Water and Wastewater Systems (3-0-6)	9	9	9
Env 150 abc	Seminar in Environmental Engineering Science	1	1	1
Env 155	Special Problems in Waste Management (2-3-4)	.	9	.
Env 156	Industrial Wastes (3-0-6)	.	.	9
Env 160	Biological Fluid Flows: Hemorheology (2-0-4)	.	6	.

[1]Six or more units as arranged, any term.
[2]Units by arrangement, any term.
[3]Six or nine units as arranged, second or third term.

Env 170 ab	Behavior of Disperse Systems in Fluids (3-0-6)	9	9	.
Env 203	Advanced Topics in Environmental Engineering Science[2]			
Env 206 abc	Special Problems in Biological Engineering Science[2]			
Env 214 abc	Advanced Environmental Fluid Mechanics (3-0-6)	9	9	9
Env 250	Advanced Environmental Seminar (2-0-2)	4	4	4
Env 300	Thesis Research[2]			
AMa 101 abc	Methods of Applied Mathematics I (3-0-6)	9	9	9
AMa 104	Matrix Theory (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AMa 181 abc	Mathematical Programming and Game Theory	9	9	9
AM 113 abc	Engineering Mathematics (4-0-8)	12	12	12
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
Bi 110 ab	Biochemistry (4-0-8)	12	12	.
Bi 111	Biochemistry Laboratory (0-8-2)	.	10	.
Ch 124 abc	Elements of Physical Chemistry (3-0-3)	6	6	6
ChE 101 ab	Applied Chemical Kinetics (2-0-7)	9	9	.
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
ChE 162	Catalysis and Surface Chemistry (3-0-6)	9	.	.
ChE 164	Introduction to Statistical Thermodynamics (3-0-6)	9	.	.
ChE 165 ab	Applied Chemical Thermodynamics (3-0-6)	.	9	9
ChE 172 abc	Optimum Control Theory (3-0-6)	9	9	9
ChE 173 ab	Advanced Problems in Transport Phenomena (3-0-6)	.	9	9
ChE 203 ab	Interfacial Phenomena (3-0-6)	.	9	9
CE 115 ab	Soil Mechanics (3-0-6; 2-3-4)	9	9	.
Ec 115	Seminar in Population Problems (3-0-6)	.	.	9
Ec 128 abc	New Technology and Economic Change (3-0-6)	9	9	9
Ge 111 ab	Invertebrate Paleontology (2-5-2)	.	9	9
Ge 130	Introduction to Geochemistry (2-0-4)	.	6	.
Ge 137 ab	Laboratory Techniques in the Geological Sciences (1-4-4)	.	9	9
Ge 244 ab	Paleoecology (Seminar)	.	5	5
Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
Hy 103 ab	Advanced Hydraulics and Hydraulic Structures (3-0-6)	9	9	.
Hy 111	Fluid Mechanics Laboratory[3]			
Hy 113 ab	Coastal Engineering (3-0-6)	9	9	.
Hy 121	Advanced Hydraulics Laboratory[1]			
Hy 213	Advanced Coastal Engineering (3-0-6)	.	.	9

Degree of Doctor of Philosophy in Environmental Engineering Science

Upon admission to work toward the Ph.D. degree in environmental engineering science, a counselling committee of three members of the faculty is appointed to ad-

[1]Six or more units as arranged, any term.
[2]Units by arrangement, any term.
[3]Six or nine units as arranged, second or third term.

vise the student on his program. One member of the committee who is most closely related to the student's field of interest serves as interim chairman and adviser. The student chooses a permanent thesis adviser at a time when the student's research interests become clearly defined.

Major Subjects of Specialization. Students may do major study including the doctoral thesis in any of the following general areas: air pollution control, aerosol physics and chemistry, water quality control (including treatment and disposal systems), aquatic chemistry, marine ecology, hydrology and water resources, hydraulic engineering, coastal engineering, environmental health engineering, bioengineering, environmental economics and systems analysis. Other subjects may be selected with approval of the faculty in environmental engineering science.

Thesis research may be arranged as an activity of the Environmental Quality Laboratory (see p. 141), provided it is done under the supervision of a professorial member of the environmental engineering science faculty.

Minor Requirements. The purpose of the minor program of study is to broaden the student's outlook by acquainting him with subject matter outside his major field. The minor requirement is satisfied by the completion of advanced courses arranged by the student in consultation with his advisory committee, and approved by the faculty in environmental engineering science.

Students are expected to fulfill the minor requirement by taking a *subject* minor rather than a *general* minor. A subject minor requires at least 45 units of advanced subjects in a discipline other than the candidate's major field of work. The subjects must be approved by the minor division, and the student must also pass an examination arranged by that division. Under special circumstances the EES faculty will approve a general minor, consisting of at least 54 units of work, of which at least 36 units must be in advanced subjects outside his major field; a portion should be taken outside the Division of Engineering and Applied Science. The remaining 18 units may be either advanced or undergraduate work (including language courses) taken after admission to graduate standing. The minor program (subject or general) may not include the courses used to satisfy the mathematics requirement (including prerequisites), nor any course in the student's specialized field of thesis research. In order to gain approval, a general minor program must be a sequence of courses chosen with some rationale and coherence, and may not consist of a group of introductory courses in unrelated topics.

Admission to Candidacy.

To be recommended for admission to candidacy for the Ph.D. degree in environmental engineering science the student must, in addition to the general Institute requirements:

(a) complete most of his program of advanced courses as arranged by him in consultation with his advisory committee, and approved by the faculty of environmental engineering science, in accordance with guidelines established by that faculty;

(b) pass at least 27 units of course work in advanced mathematics, such as AM 125, AMa 101, Ph 129, or a satisfactory substitute. For a student whose program is more closely related to the sciences of biology or chemistry than physics, AMa 104 and AMa 105 ab (or AMa 181 abc) will be an acceptable substitute for the mathematics requirement;

(c) pass an oral candidacy examination on the major subject.

The oral candidacy examination must be passed before registration day of the winter quarter of the *third* year of graduate study, except for students entering with an M.S. degree (or equivalent) the time limit is registration day of the winter quarter of the *second* year of their graduate study at Caltech. The examination will comprise:

(a) a section in which the student will be expected to demonstrate an understanding of his major field;

(b) a discussion of his research report describing accomplishments to date including reading, study, and plans for future research.

At least ten days before the examination the student must present to the examining committee a brief research report.

Thesis and Final Examination. Copies of the completed thesis must be provided to the examining committee two weeks prior to the examination. The date for the final oral examination covers principally the work of the thesis and, according to Institute sary for such matters as publication of the examination in the Institute Calendar. The oral examination covers principally the work of the thesis and, according to Institute regulations, must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate, one of which is deposited in the Institute library and the other is deposited with University Microfilms. The examining committee will consist of such individuals as may be recommended by the Chairman of the Division of Engineering and Applied Science and approved by the Dean of Graduate Studies.

Subject Minor in Environmental Engineering Science

A doctoral student in another major field who wishes to take a subject minor in environmental engineering science should submit his proposed minor program to the departmental representative for approval.

GEOLOGICAL AND PLANETARY SCIENCES

Aims and Scope of Graduate Study

Graduate students in the Division of Geological and Planetary Sciences enter with very diverse undergraduate preparation — majors in physics, astronomy, chemistry, and mathematics, as well as in geology, geophysics, and geochemistry. Graduate study and research within the division is equally diverse and the graduate program aims to provide for each student a depth of competence and experience in his major field, sufficient strength in the basic sciences as to allow him to continue self-education after his formal training has been completed, and the motivation and training to keep him in the forefront of his field through a long and productive career.

Graduate Record Examination Test Scores

All North American applicants for admission to graduate study in the Division of the Geological and Planetary Sciences are required to submit Graduate Record Examination test scores for verbal and quantitative aptitude tests and the advanced test in geology, or their field of undergraduate specialty if other than geology. Non-North American applicants are strongly urged to submit Graduate Record Examination scores and TOEFL (Test of English as a Foreign Language) scores to assist in proper evaluation of the applications.

Placement Examinations

On Wednesday, Thursday, and Friday of the week preceding registration for his first term of graduate work, the student will be required to map a small field area and to take written placement examinations covering basic aspects of the earth sciences and including elementary physics, mathematics, chemistry, and biology. These examinations will be used to determine the student's understanding of basic scientific principles and his ability to apply these principles to specific problems. It is not expected that he possess detailed informational knowledge, but it is expected that he demonstrate a degree of proficiency not less than that attained by undergraduate students at the California Institute. A student who has demonstrated proficiency in earlier residence at the Institute may be excused from these examinations.

The student's past record and his performance in the placement examinations will be used to determine whether he should register for certain undergraduate courses. Any deficiencies must be corrected at the earliest possible date.

Adviser

Each member of the division faculty serves as an academic adviser to a small number of graduate students intending to major in his field. Each graduate student will be notified, prior to his arrival, who his adviser will be, and prior to registration day the student should seek the counsel of his adviser in planning his program for each term. A student can and should consult with other staff members concerning his program of study and research. It is the responsibility of the adviser to see that the student registers at the earliest possible time for the proper courses to provide background, fulfill requirements, and to constitute a sensible, integrated program. It is the responsibility of the student to seek and consider his adviser's advice. If a student elects to do a Ph.D. thesis under his academic adviser, another staff member will then be appointed as his academic adviser, as distinct from his thesis adviser.

Registration for Early Research

It is the wish of the division that its graduate students become productively research-minded as early as possible. To that end it is strongly recommended that each student register for not less than 8 units of research in two out of the first three terms of residence. Each of these terms of research should be under the direction of *different* staff members. Guidance in arranging for research should be sought from the student's adviser and from individual members of the staff. The primary objective is to communicate to the students the excitement of discovery based on original investigations. An important by-product can be the formulation of propositions for the Ph.D. oral examination or an orientation toward Ph.D. thesis research.

Master's Degree in the Geological and Planetary Sciences

Master's degree students in geology, geochemistry, geophysics, or planetary science will be expected to have satisfied, either before arrival or in their initial work at the Institute, the basic requirements of the undergraduate geology, geochemistry, or geophysics curriculum (pages 211-213). Particular attention is called to requirements in petrology, field geology, chemistry, physics, and mathematics; competence in these subjects will be evaluated during the placement examination. Twenty-seven units of such course work may be counted toward the Institute requirement of 135 graduate units. In addition, students must take, in consultation with their advisers, 81 of the 135 units in courses numbered over 100 in geology or other science and engineering options that are not required in the geology, geochemistry, and geophysics undergraduate curriculum. Humanities work may be included in the remaining 27 units, which are free electives. For most students, two years will be required to meet the Master's degree requirements.

Degree of Doctor of Philosophy in the Geological and Planetary Sciences

Major Subject. The work for the doctorate in the Division of Geological and Planetary 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
Geobiology
Geochemistry
Geophysics
Planetary Science

Admission to Candidacy. A student may be admitted to candidacy for the Ph.D. degree by vote of the division staff upon meeting the following requirements.

a. He must pass the qualifying examination.
b. He must satisfy minimum course requirements in his major and minor subjects.
c. He must satisfy the language and oral presentation requirements.
d. He must satisfy his academic and thesis advisers that his course work has prepared him to undertake research in his major subject.
e. He must be accepted for thesis research by a division staff member.

A student admitted to work for the Ph.D. degree must file with the division before the end of the ninth term of residence the regular form for admission to candidacy with evidence of having met these requirements. If the requirements are not met by that time, the student must petition the division for continued registration. After the third year of graduate work a student can only register with the approval of his thesis adviser.

Qualifying Examination. This examination will consist of the oral defense of four propositions prepared by the student, each supported by a succinct one-paragraph statement of the problem and of the candidate's specific approach to it. The propositions offered must represent a knowledge and breadth of interest judged acceptable by the division in terms of the student's maturity. The student has the privilege of consultation and discussion with various staff members concerning his ideas on propositions but the material submitted must represent the work of the student and not a distillation of comments and suggestions from the staff. Candidates should realize that propositions based on field investigations are just as acceptable as those arising from laboratory or theoretical work. In general, the examination is designed to evaluate a student's background in the earth sciences and allied fields and to determine his capabilities in applying scientific principles to the solution of specific problems. The ideal candidate will display originality and imagination as well as scholarship.

Propositions must be submitted to the division office at least one week before registration day of the 4th term of residence, and the examination will be taken within the ensuing two-week period at a time and before a committee arranged by the division.

Graduate students are encouraged to register for as many as 15 units per term of advanced study (Ge 297) under appropriate staff members to gain experience and background for preparation of their propositions.

Minimum Course Requirements for Ph.D.

Basic Division Requirement: The solution of many problems in each of the subdisciplines or major subjects included within the division requires some basic understanding of the other subdisciplines. Therefore all graduate students are required to take at least 45 units within the division in subjects other than their own major subject. The courses are chosen in consultation with the student's adviser, and are subject to the approval of the staff at admission to candidacy. Ge 104a and Ge 104b are specifically required and Ge 104c, Ge 105abc, Ge 155, and Ge 160 are especially recommended as part of these courses. These 45 units may be counted as part of a general minor or as part of a subject minor within the division. Students who take a subject minor in another division or who show evidence of similar course work elsewhere may, by petition to the Academic Officer, be excused from up to 27 units of such courses.

Geology and Geobiology: In addition to the general Institute and basic division requirements the candidate for the Ph.D. in geology or geobiology must successfully complete a minimum of 90 units of 100-200 level courses, including the 200-level courses most pertinent to his major field, but excluding languages, research and reading courses, and certain courses constituting basic preparation in his field as follows: Ma 1, Ma 2, Ph 1, Ph 2, Ch 1, Ge 104-105, Ge 114, Ge 115, Ge 121, Ge 123, Ch 124 ab. At least 36 of the 90 units must be taken outside the geology division (with a grade of C or better) and may be used as part of the minor. For good work in most modern earth science fields a proficiency in mathematics equivalent to that represented by AM 113 (Engineering Mathematics) is essential. Summer study and research at a marine biology laboratory are required of most candidates in geobiology. Throughout his graduate work a student is expected to participate in departmental seminars and in seminar courses led by distinguished visitors.

Geochemistry: In addition to the general Institute and basic division requirements, the Ph.D. candidate in geochemistry must demonstrate a knowledge of both geology and chemistry equivalent to the average attained in the Caltech undergraduate curriculum in geochemistry. This can be done by either (a) adequate performance on *both* the geological sciences and chemistry division placement examinations, or (b) appropriate supplemental course work. The typical student should be able to perform well on one of the placement examinations, although not necessarily on both. Beyond this, the candidate will be expected to take a minimum of 90 units of 100- and 200-level courses, at least 54 units of which should be outside the geology division. The same courses can be presented to satisfy the requirements for a minor. A proficiency in mathematics equivalent to AM 113 (Engineering Mathematics) is desirable.

Geophysics: In addition to the general Institute and basic division requirements, the Ph.D. candidate in Geophysics must successfully complete a minimum of 81 units of 100-200 level courses chosen from the three categories listed below. At least 18 units must be completed in each group.

Group A. Courses in mathematics and applied mathematics: Ph 129, AMa 101, AMa 110, AMa 151, AMa 201, AMa 204, Ma 142, Ma 143, Ma 205, AM 113, AM 141, EE 161, EE 255. A minimum proficiency in basic mathematical methods at the level of Ph 129 or AMa 101 and AMa 201 is required.

Group B. Courses in physics, applied physics, and chemical physics: Ph 106, Ph 125, APh 114, APh 120, APh 214, Ph 127, Ph 205, Ph 236, MS 205, EE 133, Ch 125, Ch 226. Geophysics courses cannot be substituted for courses in this group.

Group C. Courses in geophysics: Ge 160, Ge 166, Ge 176, Ge 177, Ge 260, Ge 261, Ge 264, Ge 265.

The recommended courses in these three categories are representative of the required level, but the list is not exhaustive. Substitutions can be made upon consultation with the student's adviser. Students with an exceptionally strong background in one or more of the areas represented by these groups may, upon petition to the option representative, be excused from up to 18 units of the overall 81 unit requirement. Research and reading courses cannot be used to satisfy these requirements but are highly recommended as preparation for the oral qualifying examination.

Planetary Science: In addition to general Institute and basic division requirements the candidate for a Ph.D. degree in planetary science shall acquire at least a minimum graduate background in each of three categories of course work: (1) The Earth Sciences, (2) Physics, Mathematics, Chemistry, and Astronomy, and (3) Planetary Science.

These requirements may be met by successful completion of at least 45 units of suitable course work at the 100 or higher level in each category. The requirements in the first category are coincident with the basic division requirement. Reading and research courses may not be used, although students are expected to take such courses and to devote each summer to research in planetary science. Planetary Science Seminar (Ge 225 abc) is required each year for all planetary science students.

The student shall demonstrate professional competence in a second scientific field distinct from his specialization within planetary science. This may be accomplished either by: (1) satisfactory completion of a subject minor or (2) submission of publications which demonstrate an equivalent competence. A distributed minor is not an acceptable means of satisfying this requirement. Courses used to satisfy this secondary requirement may also be used to satisfy the requirements in one of the 45-unit categories.

Four academic years should normally be adequate for completion of the Ph.D. in planetary science. Accordingly, the student is expected to meet the following schedule unless specific written waivers are obtained by him from the academic officer or planetary science option representative.

End of 2nd academic year: 1) satisfactory completion of divisional oral examination; 2) tentative approval of courses in the major and secondary fields; 3) tentative thesis topic in planetary science.

End of 3rd academic year: 1) satisfactory completion of major requirements; 2) satisfactory completion of secondary requirements; 3) satisfactory progress on thesis; 4) admission to candidacy.

End of 4th academic year: completion of Ph.D. thesis.

Fifth academic year or beyond: satisfactory thesis progress required each quarter.

Minor Requirement. The purpose of the minor requirement is to give diversification of training and a broadening of outlook. It should involve basic approaches, techniques, and knowledge distinct from those of the major field. The division prefers that students take a subject minor in other divisions of the Institute, but the student may take a general minor or a subject minor in the geology division in a different field from his major. A subject minor must be comprehensive enough to give the student a fundamental knowledge of the field and his diploma and degree will indicate both the major and minor fields. A general minor may consist of courses from a variety of fields constituting a broad base to the major field, but it is not indicated on the diploma or degree. A general minor consists of a least 36 units of advanced work distributed in courses not specifically required by the major field and 18 units of either advanced or undergraduate work (including language courses) taken after admission to graduate standing.

If the student takes a subject minor in the division, then he must demonstrate a competency in the minor field markedly exceeding that normally expected by his major field and markedly exceeding the undergraduate requirements in the field. Such a subject minor will normally include at least 45 units, including one or more 200-level courses as well as the 100-level supporting courses. The oral examination requirement may be met through the choice of propositions (if the major field is within the division) or a special examination may be held.

A proposed minor program should be discussed with the adviser and the option representative and submitted to the staff for preliminary evaluation before the end of the 6th term of residence. Final approval will be given only after completion of all courses.

Language Requirement. Due to the diversity of fields within geological and planetary sciences, the division does not have a uniform language requirement. All entering graduate students are expected to have some knowledge of French, German, or Russian. (Other languages may be acceptable in particular cases.) A student who has not had either one year of college study in one of these languages or the equivalent thereof will be expected to make up this deficiency in his first two years. In some fields of study, additional linguistic skills are important and may be required by a student's thesis adviser in consultation with the student. However, the division *strongly encourages* the acquisition of additional language skills and such courses will be accepted as part of a general minor.

Oral presentation (Ge 102) is required of all candidates for degrees in the division.

Thesis and Paper for Publication. The doctoral candidate must complete his thesis in his option and submit it in final form by May 10 of the year in which the degree is to be conferred. A first draft of the thesis *must* be submitted to the division chairman by March 1 of the year in which it is proposed to take the degree.

The candidate is expected to publish the major results of his thesis work. The manuscript should be reviewed by the member of the staff supervising the major research before being submitted for publication. The published paper should have a California Institute of Technology address and a Division of Geological and Planetary Sciences Contribution Number, and five reprints should be sent to the division.

Final Examination. The final oral examination for the doctorate will be scheduled following submission of the thesis and, in conformity with an Institute regulation, it must be scheduled at least two weeks before the degree is to be conferred.

Subject Minor in Geological and Planetary Sciences

A student majoring in another division of the Institute may, with the approval of the Division of Geological and Planetary Sciences, elect a subject minor in any one of the major subjects listed above. Such a subject minor will normally include at least 45 units, including one or more 200-level courses as well as the 100-level supporting courses. The student should consult the division graduate representative on the choice of courses and on the scheduling of the required oral examination.

INFORMATION AND COMPUTER SCIENCE

General Scope of Graduate Study

A number of distinct subject areas form the core of theoretical subjects for this discipline. These include computer structure, programming methodology, formal theory of languages, algorithms and machines, analysis and modeling of data, theory of information processes, pattern recognition and artificial intelligence. Since these subjects have strong foundations in formal mathematics and applied mathematics, opportunities are provided for combining related course work and research from these options.

Also, a substantial number of the Information and Computer Science faculty have a deep involvement in cognitive processes, living nervous systems and social science research and have cooperative research ties with the Divisions of Biology and of the Humanities and Social Sciences. This provides for additional related course material and research that can be pursued by majors in this option.

The extremely rich experimental data bases resulting from the experimental programs greatly enhance the possibility of relevant theoretical research in pattern recognition, theory of cognitive processes and the analysis and modeling of data.

A special committee coordinates the graduate program and provides overall guidance to students.

Courses Offered

Since the opportunity exists for combining studies in information and computer science with other related disciplines, those basic courses which are expected to form the principal part of the student's program are divided into categories as follows:

A. *Courses in Information and Computer Science*

Examples of these include:

IS 110 abc	Principles of Digital Information Processing
IS 130 a	Language Systems
IS 137 a	Systematic Computer Programming
IS 138 a	Data Structures and Algorithms
IS 139 a	Operating System Principles
IS 140 ab	Programming Laboratory
IS 141 a	Formal Models of Computations
IS 142 abc	Computer Modeling and Data Analysis
IS 203 ab	Analysis and Modeling of Nervous Systems
IS 230 abc	Advanced Programming Systems
IS 240 abc	Digital Image Processing
IS 250 abc	Mathematical Linguistics
IS 260 abc	Artificial Intelligence

B. *Related Courses in Mathematics, Applied Mathematics, and Communication Theory*

Examples of these include:

AMa 104	Matrix Theory
AMa 105 ab	Introduction to Numerical Analysis
AMa 153 abc	Stochastic Processes
AMa 204 abc	Numerical Solution of Differential and Integral Equations
Ma 108 abc	Advanced Calculus
Ma 116 abc	Mathematical Logic and Axiomatic Set Theory
Ma 120 abc	Abstract Algebra
Ma 121 abc	Combinatorial Analysis
Ma 125 abc	Analysis of Algorithms
Ma 144 abc	Probability Theory
Ma 205 abc	Advanced Numerical Analysis
Ma 216 abc	Advanced Mathematical Logic

C. Related Courses in Electrical Engineering

EE 161 abc	Mathematical Theory of Information, Communication and Coding
EE 281	Semiconductor Devices

D. Related Courses in the Life and Social Sciences

Examples of these include:

IS/Bi 121 abc	Biosystems Analysis
Bi 129 ab	Biophysics
Bi 151	Neurophysiology
Bi 152	Behavioral Biology
Bi 153	Brain Studies of Motivated Behavior
Bi 155	Psychobiology
Bi 208	Selected Topics in Neurobiology
Bi 260	Advanced Physiology

Master's Degree in Information and Computer Science

The program for graduate study in information and computer science is designed primarily for the Ph.D. degree. Entering graduate students are only admitted to this degree. The master's degree may be awarded in exceptional cases. However, at least 81 units of the general master's requirement of 135 graduate units must be from the above information science courses (Group A).

Degree of Doctor of Philosophy in Information and Computer Science

Placement Examination. Each new graduate student admitted to work for the Ph.D. will be given an informal interview on Thursday or Friday of the week preceding instruction for the fall term. This interview will establish the student's background for his course of study.

Oral Candidacy Examination. In order to be recommended for candidacy the student must, in addition to satisfying the general Institute requirements, pass an oral candidacy examination. This examination will normally be given during the first term of the second graduate year. It will be based upon one year's work in selected courses from all of the above categories as determined by an option committee.

Further Requirements. In order to be recommended for the Ph.D. in information and computer science, the student must do satisfactory work in a program containing at least 90 units of work in courses of the type indicated in Groups A, B, C and D as approved by the Faculty Option Committee.

The Minor. Students majoring in information and computer science must satisfy the minor requirements of the Institute. A proposal for a general minor must involve fields of study sufficiently far removed from the student's major field and is subject to approval by the Committee on Information and Computer Science. In accordance with Institute requirements, candidates who elect a subject minor must pass a special examination in this subject. It is the responsibility of the candidate to arrange for this examination, which should be taken as soon as possible after completion of course work in the minor field.

Submission of Thesis. On or before the first Monday in April of the year in which the degree is to be conferred, a candidate for the degree of Ph.D. in Information and Computer Science must deliver a typewritten or printed copy of his completed thesis to his research supervisor.

Final Examination. The final oral examination will be held as nearly as possible four weeks after the submission of the thesis. The examination will cover the thesis and related areas.

Subject Minor in Information and Computer Science

Students majoring in other fields may take a subject minor in information and computer science provided the program consists of 45 units sufficiently far removed from their major program of study and is approved by the Information and Computer Science Committee.

MATERIALS SCIENCE

Master's Degree in Materials Science

Study for the degree of Master of Science in Materials Science ordinarily will consist of three terms of course work totaling at least 135 units. Each student is assigned to a member of the faculty, who will serve as the student's adviser and who will assist the student in planning his course of study. The program of study must be approved by the adviser, and any subsequent changes must also have the adviser's approval.

The schedule of courses is given below:

		Units per term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
MS 101 abc	Introduction to Crystal Kinetics (3-0-6)	9	9	9
MS 102 abc	Introduction to Crystal Structure and Diffraction Techniques (3-0-6)	9	9	9
MS104 abc	Materials Science Laboratory (0-6-3)	9	9	9
	Electives as below*	Minimum	24 for year	
	Free electives**	Minimum	27 for year	
	Total	Minimum	135 for year	

Approved Electives

		1st	2nd	3rd
Ae 102 abc	Basic Solid Mechanics (3-0-6)	9	9	9
Ae 213	Fracture Mechanics (3-0-6)	.	9	.
Ae 221	Theory of Viscoelasticity (3-0-6)	Any term.		
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AM 112 abc	Structural Mechanics (3-0-6)	9	9	9
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 140 abc	Plasticity (3-0-6)	9	9	9
AM 141 abc	Wave Propagation in Solids (3-0-6)	9	9	9
AM 151 abc	Dynamics and Vibrations (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
APh 101	Topics in Applied Physics (2-0-4)	6	6	6
APh 105 abc	States of Matter (3-0-6)	9	9	9
APh 114 abc	Solid-State Physics (3-0-6)	9	9	9
APh 153 abc	Modern Optics (3-0-6)	9	9	9

*Elective units may be divided among the three terms in any desired manner. Students who have not had the equivalent of AMa 95 abc are required to take AM 113 abc, which *must* be included in the free electives and *cannot* be included in the nonfree electives. Substitution for electives given below may be made with the approval of the student's adviser and the faculty in Materials Science.

**Students are urged to consider including a humanities course in the free electives.

APh 161 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
APh 181 abc	Physics of Semiconductors and Semiconductor Devices (3-0-6)	9	9	9
ChE 107 abc	Polymer Science (3-0-6)	9	9	9
MS 105	Mechanical Behavior of Metals (3-0-6)	.	9	.
MS 110	Special Topics in Physical Metallurgy (3-0-6)	.	.	9
MS 205 ab	Dislocation Mechanics (3-0-6)	.	9	9
Ma 112 ab	Elementary Statistics (3-0-6)	9 or	9	9
ME 101 abc	Advanced Design (1-6-2)	9	9	9
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ph 113 abc	Introduction to Solid-State Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (4-0-5)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9

Degree of Doctor of Philosophy in Materials Science

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

Upon admission to work toward the Ph.D. degree in Materials Science, a counselling committee of three members of the faculty is appointed to advise the student on his program. One member of the committee who is most closely related to the student's field of interest serves as the adviser and the chairman.

To be recommended for candidacy for the Ph.D. degree in Materials Science, the student must, in addition to the general Institute requirements:

a. complete 12 units of research;
b. complete at least 50 units of advanced courses arranged by the student in conference with his adviser and approved by his counselling committee and the faculty in materials science;
c. pass with a grade of at least C an advanced course in mathematics or applied mathematics, such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the student's committee and the faculty in materials science. The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward the minor requirement;
d. complete the required number of units for either a subject or a general minor, as arranged by the student in conference with his adviser and approved by his counselling committee, the faculty in materials science, and the faculty concerned with the subject minor. While foreign languages are not required, the student is encouraged to discuss with his adviser the desirability of taking foreign languages, which may be included in a general minor or a subject minor with the proper approvals;
e. pass an oral examination on the major subject, and if the student has a subject minor, examination on the subject of that program may be included at the request of the discipline offering that subject minor.

A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his specialized field of research.

Subject Minor in Materials Science

A student majoring in another branch of engineering, or another division of the Institute may, with the approval of the faculty in materials science and the faculty in his major field, elect materials science as a subject minor. The group of courses shall differ markedly from the major subject of study or research.

MATHEMATICS

Aims and Scope of Graduate Study in Mathematics

The principal aim of the graduate program is to equip the student to do original research in mathematics. Independent and critical thinking are encouraged by participation in seminars and by direct contact with faculty members; an indication of the current research interests of the faculty are found on page 147. In order to enable each student to acquire a broad background in mathematics, individual programs of study and courses are mapped out in consultation with faculty advisers. The normal course of study leads to the Ph.D. degree.

Admission

Each new graduate student admitted to work for an advanced degree in mathematics will be given an interview on Thursday or Friday of the week preceding the beginning of instruction in the fall term. The purpose of this interview is to ascertain the preparation of the student and assist him in mapping out a course of study. The work of the student during the first year will include independent reading and/or research.

Course Program

The graduate courses which are offered are listed in Section V. They are divided in three categories. The courses numbered between 100 and 199 are basic graduate courses open to all graduate students. The course Ma 108 is the fundamental course in analysis. It is a prerequisite to most courses, and its equivalent is expected to be part of the undergraduate curriculum of the entering graduate student. The basic course in algebra, Ma 120, presupposes an undergraduate introductory course in modern algebra similar to Ma 5 abc. Particular mention is made of Ma 190. It is a seminar required of all first-year graduate students and restricted to them. It is intended to stimulate independent work, to train students in the presentation of mathematical ideas, and to develop an independent critical attitude.

The courses in the second category are numbered between 200 and 290. They are taken normally by second-year and more advanced graduate students. They are usually given in alternate years. The 300 series includes the more special courses, the research courses, and the seminars. They are given on an irregular basis depending on demand and interest.

The first-year graduate program, in addition to the elementary seminar Ma 190, will consist as a rule of two or three 100-series courses.

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

Master's Degree in Mathematics

Entering graduate students are normally admitted directly to the Ph.D. program, since the Institute does not offer a regular program in mathematics leading to the master's degree. This degree may be awarded in exceptional circumstances either as a terminal degree or as a degree preliminary to the Ph.D. degree.

The recipient of a master's degree will be expected to have acquired, in the course of his studies as an undergraduate or graduate student, a comprehensive knowledge of the main fields of mathematics comparable to 180 units of work in mathematics at the Institute with course numbers greater than 90.

The general Institute requirements specify that the recipient of a master's degree must have taken at least 135 units of graduate work as a graduate student at the Institute, including at least 81 units of advanced graduate work in mathematics. This advanced work is interpreted as work with a course number greater than 115 and may include a master's thesis.

Degree of Doctor of Philosophy in Mathematics

Candidacy Examination. Before being admitted to candidacy for the Ph.D. in mathematics the student is expected to acquire an understanding of the main fields of modern mathematics and to demonstrate ability to do competent research in a particular field. The purpose of the candidacy examination is to determine as early as possible the candidate's progress toward these objectives.

The first graduate year is usually spent in acquiring basic background knowledge in the several fields of mathematics. Comprehensive written examinations will be given toward the end of the third term of the first year of graduate study. These examinations will consist of two 3-hour papers, one covering the field of algebra, the other real and complex analysis. They will not be concerned with detailed technical results and the reproduction of proofs but will emphasize the ability to use the basic concepts and to relate various mathematical ideas. A syllabus is available to graduate students describing the topics on which the examinations are based.

During the summer following the first year of graduate work, each graduate student in mathematics is expected to plan a program of independent study and research work under the guidance of some member of the mathematics staff. This summer program should provide the student with an opportunity to acquire new mathematical knowledge and to generate new mathematical ideas. Shortly after the beginning of the fall term, the faculty will make an overall evaluation of the progress and research potential of these graduate students. This evaluation will be based upon the performance in course work during the first year of study, the results of the comprehensive examinations, and a report on the summer's independent work. The results of this evaluation will be reported to the student and will be used in consultation with the student to plan his subsequent academic program. At this time each student is expected to arrange with a member of the faculty to act as his research adviser. A form to be filled out by the student and his adviser will be provided for this purpose.

Language Requirement. The language requirement for mathematics may be satisfied by demonstrating a good reading knowledge of at least two foreign languages or an extensive knowledge of at least one foreign language, chosen among French, German, and Russian. Credit will be given for previous language study.

Thesis and Final Examination. On or before the first Monday in April of the year in which the degree is to be conferred, a candidate for the degree of Doctor of Philosophy must deliver a typewritten or reproduced copy of his thesis to his supervisor. This copy must be complete and in the exact form in which it will be presented to the members of the examining committee. The candidate is also responsible for supplying the members of his examining committee, at the same time or shortly thereafter, with reproduced copies of his thesis. The department will assign to the candidate, immediately after the submission of his thesis, a topic of study outside his field of specialization. During the next four weeks the candidate is expected to assimilate the basic methods and the main results of the assigned topic with the aim of recognizing the direction of further research in this field.

The final oral examination in mathematics will be held as closely as possible to four weeks after the date the thesis has been handed in. It will cover the thesis and fields related to it and the assigned topic of study.

Subject Minor in Mathematics. Students majoring in other fields may take a subject minor in mathematics (see page 231) provided their program consists of 45 units of more advanced work in mathematics and is approved by the Mathematics Committee on Minors. The required oral examination in the subject minor will normally be a separate examination, but may be a part of one of the oral examinations in the major subject. It is the responsibility of the candidate to submit the proposed program for approval and to arrange for the examination.

MECHANICAL ENGINEERING

Master's Degree in Mechanical Engineering

Study for the degree of Master of Science in Mechanical Engineering ordinarily will consist of three terms of course work totaling at least 135 units. Each student is assigned to a member of the faculty, who will serve as the student's adviser and who will assist the student in planning his course of study. The program of study must be approved by the adviser, and any subsequent changes must also have the adviser's approval.

The schedules of courses are given below:

GENERAL MECHANICAL ENGINEERING

		Units per term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
	Electives as below*	Minimum	75 per year	
	Free electives**	Minimum	27 per year	
	Total	Minimum	135 per year	

*Elective units may be divided among the three terms in any desired manner. Students who have not had the equivalent of AMa 95 abc are required to take AM 113 abc, which *must* be included in the free electives and *cannot* be included in the nonfree electives. Substitution for electives given below may be made with the approval of the student's adviser and the faculty in mechanical engineering.

**Students are urged to consider including a humanities course in the free electives.

Approved Electives

		1st	2nd	3rd
Ae 101 abc	Basic Fluid and Gasdynamics (3-0-6)	9	9	9
Ae 102 abc	Basic Solid Mechanics (3-0-6)	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
AM 112 abc	Structural Mechanics (3-0-6)	9	9	9
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9

AM 141 abc	Wave Propagation in Solids (3-0-6)	9	9	9
AM 151 abc	Dynamics and Vibrations (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
APh 161	Nuclear Reactor Theory (3-0-6)	9	9	9
ChE 107 abc	Polymer Science (3-0-6)	9	9	9
EE 172 abc	Control Systems Theory (3-0-6)	9	9	9
APh 102 abc	Applied Modern Physics (3-0-6)	9	9	9
APh 161 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
APh 163	Nuclear Radiation Measurements Laboratory (1-4-4)	.	9	.
APh 164	Nuclear Energy Laboratory (1-4-4)	.	.	9
Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
Hy 121	Advanced Hydraulics Laboratory	6 or	6 or	6
Hy 201 abc	Hydraulic Machinery (2-0-4)	6	6	6
Hy 203	Cavitation Phenomena (2-0-4)	.	.	6
JP 121 abc	Jet Propulsion Systems and Trajectories (3-0-6)	9	9	9
JP 170	Jet Propulsion Laboratory (0-9-0)	.	.	9
MS 101 abc	Introduction to Crystal Kinetics (3-0-6)	9	9	9
MS 104 abc	Materials Science Laboratory (0-6-3)	9	9	9
MS 105	Mechanical Behavior of Metals (3-0-6)	.	9	.
Ma 112 ab	Elementary Statistics (3-0-6)	9 or	9	9
ME 101 abc	Advanced Design (1-6-2)	9	9	9
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
ME 126	Fluid Mechanics and Heat Transfer Laboratory (0-6-3)	.	.	9
ME 100	Advanced Work in Mechanical Engineering (for M.S.)	.	.	.
ME 200	Advanced Work in Mechanical Engineering	.	.	.
ME 300	Thesis Research	.	.	.
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9

JET PROPULSION

E 150 abc	Seminar (1-0-0)	1	1	1
JP121 abc	Jet Propulsion Systems and Trajectories (3-0-6)	9	9	9
	Electives as below*	Minimum 48 for year		
	Free electives**	Minimum 27 for year		
	Total	Minimum 135 for year		

*Elective units may be divided among the three terms in any desired manner. Students who have not had the equivalent of AMa 95 abc are required to take AM 113 abc which *must* be included in the free electives and *cannot* be included in the nonfree electives. Substitution for electives given below may be made with the approval of the student's adviser and the faculty in mechanical engineering.

**Students are urged to consider including a humanities course in the free electives.

Approved Electives

Ae 102 abc	Basic Solid Mechanics (3-0-6)	9	9	9
Ae 105 abc	Fluid Mechanics Laboratory (1-3-2)	6	6	6

Ae 106 abc	Solid Mechanics Laboratory (1-3-2)	6	6	6
AM 112 abc	Structural Mechanics (3-0-6)	9	9	9
AM 151 abc	Dynamics and Vibrations (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
EE 172 abc	Control Systems Theory (3-0-6)	9	9	9
Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
JP 170	Jet Propulsion Laboratory (0-9-0)	.	9	.
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
ME 126	Fluid Mechanics and Heat Transfer Laboratory (0-6-3)	.	.	9

Degree of Mechanical Engineer

Work toward the degree of Mechanical Engineer requires a minimum of two years following completion of the bachelor's degree or the equivalent. Upon admission to work toward the M.E. degree, a committee of three members of the faculty is appointed to advise the student on his program. One member of the committee who is most closely related to the student's field of interest serves as the adviser and the chairman. The student shall meet with the committee before registration for the purpose of planning the student's work.

Not less than a total of 55 units of the work shall be for research and thesis; the exact number shall be determined by the supervising committee, appointed by the Dean of Graduate Studies, which succeeds the counselling committee. The courses shall be closely related to mechanical engineering, and the specific courses to be taken and passed with a grade of C or better by the candidate shall be planned with the counselling committee and finally determined by the supervising committee. The courses must include an advanced course in mathematics or applied mathematics, such as AM 125 abc or Ph 129 abc, acceptable to the faculty in mechanical engineering. A list of possible courses from which a program of study may be organized is given below:

Suggested Courses

Ae 201 abc	Advanced Fluid Mechanics
Ae 210 abc	Advanced Solid Mechanics
Ae 213	Fracture Mechanics
Ae 232 abc	Ionized Gas Theory
Ch 226 abc	Molecular Quantum Mechanics
Ch 229	X-Ray Diffraction Methods
ChE 163 ab	Introduction to Thermodynamics
ES 201 abc	Neutron Transport Theory
Hy 200	Advanced Work in Hydraulic Engineering
Hy 201 abc	Hydraulic Machinery
Hy 203	Cavitation Phenomena
Hy 210 ab	Hydrodynamics of Sediment Transportation
Hy 300	Thesis
JP 250 abc	Turbomachines
JP 280 abc	Jet Propulsion Research (Thesis)
MS 101 abc	Introduction to Crystal Kinetics
MS 102 abc	Introduction to Crystal Structure and Diffraction Techniques

MS 104 abc	Materials Science Laboratory
MS 205 ab	Theory of Mechanical Behavior of Metals
ME 200	Advanced Work in Mechanical Engineering
ME 300	Thesis — Research
Ph 205 abc	Advanced Quantum Mechanics
Ph 227 ab	Thermodynamics, Statistical Mechanics, and Kinetic Theory

Degree of Doctor of Philosophy in Mechanical Engineering

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

Upon admission to work toward the Ph.D. degree in Mechanical Engineering, a counselling committee of three members of the faculty is appointed to advise the student on his program. One member of the committee who is most closely related to the student's field of interest serves as the adviser and the chairman.

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

a. complete 12 units of research;

b. complete at least 50 units of advanced courses arranged by the student in conference with his adviser and approved by his counselling committee and the faculty in mechanical engineering;

c. pass with a grade of at least C an advanced course in mathematics or applied mathematics, such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the student's committee and the faculty in mechanical engineering. The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward the minor requirement;

d. complete the required number of units for either a subject or a general minor as arranged by the student in conference with his adviser, and approved by his counselling committee, the faculty in mechanical engineering, and the faculty concerned with the subject minor. While foreign languages are not required, the student is encouraged to discuss with his adviser the desirability of taking foreign languages, which may be included in a general minor or a subject minor with the proper approvals;

e. pass an oral examination on the major subject, and if the student has a subject minor, examination on the subject of that program may be included at the request of the discipline offering that subject minor.

A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his specialized field of research.

Subject Minor in Mechanical Engineering

A student majoring in another branch of engineering, or another division of the Institute, may elect mechanical engineering as a subject minor, with the approval of the faculty in mechanical engineering and the faculty in his major field. The group of courses shall differ markedly from the major subject of study or research.

PHYSICS

Aims and Scope of Graduate Study in Physics

The physics department offers a program leading to the degree of Doctor of Philosophy in Physics. This program seeks to prepare students for careers in scientific research, or research combined with teaching, and independent research is an essential part of the graduate program. Courses are offered which will help a beginning graduate student prepare himself for research and provide a broad, sound knowledge of physics. These courses are not required; each student takes only those courses that he needs. Instead of formal course requirements, each student must pass a candidacy examination which seeks to determine his readiness to undertake original research on his own, and his basic knowledge of physics.

To broaden the student's experience beyond the narrow limits of his own research interest, each student is required to take 54 units (12 semester hours) of advanced physics courses selected from a variety of topics in physics. To broaden his experience outside the limits of physics, a minor program is required. This program may concentrate in a specific subject area or may range over a variety of subjects.

A Master of Science degree may be awarded upon the completion of a one-year program of courses. A student is not normally admitted to work toward the M.S. degree in physics unless he is also working for a Ph.D.

Admission

Application blanks for admission to graduate standing and for assistantships should be obtained from the Dean of Graduate Studies, California Institute of Technology, Pasadena, California 91109, and submitted as early as convenient. While late applications will be considered, applications should whenever possible reach the Graduate Office by February 15, 1974. Special inquiries will be welcomed by Professor R. W. Kavanagh, Chairman, Physics Graduate Admissions Committee. It is strongly recommended that applicants take the Graduate Record Aptitude Test and Advanced Physics Test, by November at the latest. Information may be obtained from the Educational Testing Service, 20 Nassau Street, Princeton, New Jersey 08540.

Placement Examinations

On the Thursday preceding the beginning of instruction for his first term of graduate study, a student admitted to work for an advanced degree in physics is required to take placement examinations to be used as a guide in selecting the proper course of study. These examinations will cover material in mechanics and electromagnetism, atomic and nuclear physics, quantum mechanics, and mathematical physics, approximately as covered in Ph 106, Ph 112, Ph 125, and Ph 129. In general, they will be designed to test whether the student possesses an understanding of general principles and the ability to apply these to concrete problems, rather than detailed informational knowledge. In cases in which there is a clear basis for ascertaining the status of the entering graduate student, the placement examinations may be waived.

Physics Course List

The following courses are referred to several times in the regulations below. These courses are described fully on pages 287-388.

Ph 127	Statistical Physics
Ph 129	Methods of Mathematical Physics

Ph 203	Nuclear Physics
Ph 205	Advanced Quantum Mechanics
Ph 209	Electromagnetism and Electron Theory
Ph 213	Nuclear Astrophysics
Ph 221	Topics in Solid-State Physics
Ph 224	Space Physics
Ph 230	Elementary Particle Theory
Ph 231	High-Energy Physics
Ph 234	Topics in Theoretical Physics
Ph 236	Relativity
Ph 237	Theoretical Nuclear Physics
APh 140	Cryogenics
APh 156	Plasma Physics
APh 214	Solid-State Physics
Ay 131	Astrophysics I or Ay 132, Astrophysics II
Ay 133	Radio Astronomy

Master's Degree in Physics

A student is not normally admitted to work toward the M.S. degree in physics unless he is also working for a Ph.D.

A Master of Science degree in Physics will be awarded upon satisfactory completion of a program approved by the departmental representative that fulfills the following requirements:

Ph 125 abc .... 27 units

(If this course was taken as part of an undergraduate program or an equivalent course was taken elsewhere and a satisfactory score made on the placement examination, it may be replaced by 27 units of any graduate courses.)

Physics electives .... 81 units

These must be selected from Ph 127 abc, Ph 129 abc, Ph 203 ab, Ph 205 abc, Ph 209 abc, Ph 213 ab, Ph 221, Ph 224 abc, Ph 230 abc, Ph 231 abc, Ph 236 abc, Ph 237 abc.

Non-physics electives .... 27 units

These must be graduate courses from any option, including humanities, except physics.

With the approval of the departmental representative, a student who has the proper preparation may substitute other graduate courses in science or engineering for some of those listed above.

Doctor of Philosophy Degree in Physics

Requirements for the Ph.D. include passing a written candidacy examination, typically taken in the first or second year, covering basic material in physics; an oral candidacy exam in the area in which the student proposes to do research; 54 units (equivalent to 12 semester-hours) of advanced electives in physics; writing a thesis which describes the results of independent research, and passing a final oral examination based on this thesis and research.

A minor is also required. The requirements are discussed on page 231.

Graduate students working toward the Ph.D. degree should complete the requirements for admission to candidacy for the doctor's degree as soon as possible. No courses are specifically required for candidacy, but the average student will profit from taking several of the basic graduate courses, such as Ph 129, Ph 205, and Ph 209.

Course Requirements. In order to be recommended for the Ph.D. degree, each candidate must, in addition to the requirements for candidacy and the general Institute requirements for a Ph.D. degree, pass satisfactorily a total of 54 units from the courses enumerated in the above Physics Course List. Ph 129, Ph 205 and Ph 209 are excluded from the list. These three courses will presumably be of use to the student in preparing for the written candidacy examination, but are not required, nor may they be counted toward course requirements. The purpose of course requirements is to broaden the student's knowledge of physics and acquaint him with material outside his own field of specialization; for this reason, no more than 18 units of any given course in the above list may be counted toward any requirements for these courses. In addition to these requirements, the student will normally take other advanced courses, particularly in his field of specialization. In general a student will find it desirable to continue his graduate study and research for two years after admission to candidacy.

The student is expected to obtain a grade of C or better in each of his courses. If he obtains grades below C in his courses, or an unsatisfactory grade on his written or oral candidacy examination, the Physics Graduate Committee will review the student's entire record, and if it is unsatisfactory will refuse permission for him to continue work for the Ph.D.

Candidacy Examinations. A written candidacy examination, in several parts and requiring a total of about twelve hours, is given each year in the third term. Each student must pass this examination before being permitted to register for his third year of graduate study. The examination covers that body of knowledge felt to be essential no matter what the candidate's ultimate field of specialization may be.

An oral candidacy examination is also required. This examination may be taken no sooner than one month after the written examination is passed, and is primarily a test of the candidate's suitability for research in his chosen field. The candidate must have passed at least 15 units of Ph 171, Ph 172, or Ph 173 before taking his oral candidacy examination. A student who is admitted to work toward the Ph.D. degree and who does not pass both these examinations before the end of the second term of his third year of graduate study at the Institute will not be permitted to register for a subsequent academic year.

The written and oral candidacy examinations are the only departmental requirements for admission to candidacy, beyond the general Institute requirements enumerated on page 232.

Research Requirements. There is no specific requirement, but in general a substantial effort is required to master the research techniques in a given field and carry out a significant piece of original research. Each student is strongly advised to start research as soon as possible and carry it on in parallel with course work.

The Minor. There are no departmental requirements in addition to the general requirements listed on page 231.

Language Requirements. There are no language requirements for a Ph.D. in physics, but mastery of one or more foreign languages will be highly advantageous.

Thesis and Final Examination. A final oral examination will be given not less than two weeks after the thesis has been presented in final form. This examination will cover the thesis topic and its relation to the general body of knowledge of physics. The candidate himself is responsible for completing his thesis early enough to allow the fulfillment of all division and Institute requirements, having due regard for possible conflicts in the scheduling of more than one final oral examination per day.

Subject Minor in Physics

A subject minor in physics (see page 231) will be approved by the minor division if it includes at least 18 units of physics courses, chosen from the courses in the Physics Course List, but excluding Ph 129, all Ay and APh courses, and any specific courses in physics required for the student's major program. Physics courses with numbers over 100 will be allowed for the subject minor, but, where reduced credit is given to physics graduate students, will count at the same reduced rate toward the required total of 45 units. The required oral examination in the subject minor will normally be a separate examination but may be part of one of the oral examinations in the major subject if sufficient time is made available. It is the responsibility of the candidate to make arrangements for this examination with the chairman of the Physics Graduate Committee.

SOCIAL SCIENCE

Aims and Scope of Graduate Study in Social Science

The Division of the Humanities and Social Sciences offers a program leading to the degree of Doctor of Philosophy in Social Science. The focus of the program is on social change, and it is highly analytical. The program is designed to prepare students to assume senior staff positions in policy-making organizations where they will be able to conceive and execute complicated research projects and to utilize the products of their research to provide the basis for actual policy decisions. It is also anticipated that over the next few years there will be an increasing demand in colleges and universities for people who are trained more broadly than in a single social science. Depending on their individual orientation, students graduating from the program will also be qualified to take positions in departments of economics or political science.

Admission

The only specific requirements for admission to the graduate program in social science are in the field of mathematics. Mathematical requirements consist of (1) courses in calculus at the levels of Ma 1 abc and Ma 2 abc; (2) a course in linear algebra and/or matrix algebra at the level of AMa 104; (3) courses in elementary mathematical statistics at the level of AMa 112 ab. The completion of courses in advanced calculus or applied mathematics is also recommended. Under certain circumstances, students may be permitted to complete some of the mathematical requirements after entering the program. Students will find that courses in abstract algebra, functional analysis, topology, and probability theory will be of significant help in their graduate work, and they will be expected to take whatever courses in mathematics are directly relevant to their research after entering the program.

Placement Examinations

Entering students will take placement examinations in social science and mathematics to determine their level of attainment. Required remedial work, if any, will be determined by the option committee in consultation with the student and will be based primarily on the results of the placement examinations and review of the student's undergraduate program. In cases where there is a clear basis for ascertaining the status of entering students, the placement examinations may be waived.

Course Program

No graduate courses in social science are specifically required for an advanced degree in social science. However, a student will, in consultation with the option committee and his research adviser, develop a program which will allow him to prove his competence in three major areas.

1. *Theory:* Since the basic commitment of the entire program will be the application of theory to applied problem areas, the central core of the course offerings is designed to provide the student with a substantial knowledge of existing theory that is relevant to those problems and to introduce him to the revisions that must be effected if he is to work across disciplines. The areas of competence must include microeconomics, analytical political science, and social psychology.
2. *The Testing of Theory:* Students must know how to test theory as they attempt to use it to predict or explain phenomena of the real world. Such tests involve the generation of relevant data, the manipulations that are required to compare the data with the predictions yielded by the theory, and the techniques needed to handle data efficiently. Here the areas of competence must include econometrics and computer modeling and data analysis.
3. *Applications of Methodology to the Problems of Social Change:* Neither the theory nor the problems of measurement are relevant unless they are related to actual problems of policy. Thus a substantial part of the Ph.D. program will be devoted to attempts at solutions of some of these problems. Opportunities for applied research will vary according to the work being carried on in various parts of the Institute and at the Jet Propulsion Laboratory. Of prime importance to this phase of the program will be the research seminar which all graduate students will be expected to attend.

Master's Degree in Social Science

Entering graduate students are admitted for the Ph.D. program. The M.S. degree is awarded in exceptional cases. Of the 135 units of graduate work required by Institute regulations, at least 81 units of advanced work should be in social science.

Degree of Doctor of Philosophy in Social Science

Requirements for the Ph.D. include passing a written and oral candidacy examination covering basic material in social science (to be taken before the close of the sixth quarter of residency), the writing of a thesis which describes the results of independent research, and the passing of a final oral examination based on the thesis and research. Students will be expected to have completed all requirements for the Ph.D. degree no later than the end of their fourth year of residency.

A minor is also required, the requirements for which are discussed on page 231.

Subject Minor in Social Science

Graduate students taking social science as a subject minor shall complete a program of no less than 45 units in social science approved by the option committee.

Graduate Expenses

The tuition charge for all students registering for graduate work is currently $2,886 per academic year, payable in three installments at the beginning of each term. Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Students desiring permission to register for fewer than 36 units should petition therefor on a blank obtained from the Registrar. If reduced registration is permitted, the tuition for each term is at the rate of $28 a unit for fewer than 36 units with a minimum of $280 a term. Adjustments of tuition charges may be arranged for changes in units if reported during the first three weeks of a term. Additional tuition will be charged to students registering for special courses made available to them which are not part of the normal educational facilities of the Institute.

The payment of tuition by graduate students is required (a) without reference to the character of the work of the student, which may consist in the prosecution of research, in independent reading, or in the writing of a thesis or other dissertation, as well as in attendance at regular classes; (b) without reference to the number of terms in which the student has already been in residence; and (c) without reference to the status of the student as an appointee of the Institute, except that members of the academic staff of rank of Instructor or higher are not required to pay tuition.

A yearly health fee of $84 is charged to every student. This fee is applied to provide medical services; for details, see page 178. A summer fee of $21 must be paid by students who register for summer work, and who have not paid the $84 health fee during the preceding academic year.

Each graduate student is required to make a general deposit of $25 to cover loss of, or damage to, Institute property used in connection with his work in regular courses of study. Upon completion of his graduate work, or upon withdrawal from the Institute, any remaining balance of the deposit will be refunded.

Unpaid Bills: All bills owed the Institute must be paid when due. Any student whose bills are delinquent may be refused registration for the term following that in which the delinquency occurs. No degrees are awarded until all bills due the Institute have been paid. Transcripts cannot be released until all bills due the Institute have been paid or satisfactory arrangements have been made with the business office for repayment.

Information regarding fellowships, scholarships, and assistantships is discussed on pages 284-285 of the catalog. Students of high scholastic attainment may be awarded graduate scholarships covering all or a part of the tuition fee. Loans also may be arranged by making an application to the Scholarships and Financial Aid Committee.

EXPENSE SUMMARY 1973-74

General:	
General Deposit	$ 25.00[1]
Tuition	2,886.00
Health Fee	84.00
	$2,995.00
Other:	
Books and Supplies (approx.)	$200.00

Graduate House Living Expenses (see page 284 for details)
Room — $549.00 to $612.00 per academic year[2]
(Room rates are subject to change.)
Meals — Available at Chandler Dining Hall or
the Athenaeum (members only)

[1]This charge is made only once during residence at the Institute (see page 181).

The following is a list of graduate fees at the California Institute of Technology for the Academic Year 1973-74, together with the dates on which they are due. Charges are subject to change at the discretion of the Institute.

	First Term	
September 24, 1973	General Deposit (see page 181)	$ 25.00
	Tuition	962.00
	Health Fee	28.00
	Second Term	
January 7, 1974	Tuition	962.00
	Health Fee	28.00
	Third Term	
April 1, 1974	Tuition	962.00
	Health Fee	28.00
Summer Accident Insurance Fee		21.00[1]
Tuition fees for fewer than normal number of units.		
	Over 35 units	Full Tuition
	Per unit per term	28.00
	Minimum per term	280.00
	Auditor's Fee (p. 171) $40.00 per term per lecture hour.	

[1]An Accident Insurance Fee of $21.00 will be charged to all students taking summer research who were not enrolled during the previous academic year.

Associated Student Body Dues. Graduate students are eligible for membership in the Associated Students of Caltech, pursuant to by-laws thereof. Dues are $22 annually (see page 181).

Room Deposit. A $50 deposit must accompany each room application and is subject to refund upon termination of the contract. (This deposit should not be confused with the General Deposit of $25.)

Winnett Student Center. A charge of $1 a year is made to each student who is provided a key to the Winnett Student Center game room, to help defray the expenses.

Graduate Student Council Dues. Annual dues of $1 are currently charged to each graduate student. The council uses the dues to support a program of social and athletic activities, and of other activities it deems beneficial to graduate student life.

Refunds. Students withdrawing from the Institute or reducing their number of units during the first three weeks of a term, for reasons deemed satisfactory to the Institute, are entitled to a refund of tuition less a pro rata charge. Computation of this charge is based on the period elapsed, from the beginning of the term to:

a. the date the request is made to the Dean of Students for *Withdrawals;*
b. the date the petition is presented to the Office of the Registrar for *Leave of Absence;*
c. the date that registration for the reduced units is approved by the Dean of Graduate Studies or the date that drop cards are filed in the Registrar's Office, whichever is later for *Reduction in Units* (there is a minimum charge for 10 units).

Living Accommodations for Graduate Students

Housing Facilities. The Institute has four residence houses providing single rooms for 167 graduate students. These handsome and comfortable residences, located on campus, were donated by William M. Keck Jr., Samuel B. Mosher and Earle M. Jorgensen, David X. Marks Foundations, and the family of Carl F. Braun. The rates per academic year vary depending upon the accommodations and services provided. During the summer only, rooms may be rented on a month-to-month basis. Complete information may be obtained and reservations made by writing to the Office of Residence and Dining Halls, California Institute of Technology.

A limited number of rooms are available for women graduate students. Information about membership and rates may be obtained from the same office as above.

The Institute owns three apartment buildings and a limited number of houses for exclusive rental to married students and families.

The Off-Campus Housing Office also maintains a current file of available rooms, apartments and houses in the Pasadena area. The Institute cannot make negotiations for individual housing off campus but will be glad to furnish detailed information. Address: California Institute of Technology, Off-Campus Housing Office 111-6.

Dining Facilities. Graduate students are privileged to join the Athenaeum (faculty club), which affords the possibility of contact with fellow graduate students and with others using the Athenaeum, including the Associates of the Institute, distinguished visitors, and members of the professional staffs of the Mount Wilson Observatory, the Huntington Library, and the California Institute.

The Chandler Dining Hall, located on the campus, is open Monday through Friday and most weekends when the Institute is in session. Breakfast, lunch, dinner, and snacks are served cafeteria style.

Health Services. The health services available to graduate students are explained in Section III under Student Health (pages 178-179).

The International Desk. The International Desk is maintained to help foreign students and visiting scholars with non-academic problems. They will find the services of the desk very helpful, particularly when they first arrive on campus. The International Desk operates with the advice of the Faculty Committee on Foreign Students and Scholars.

Financial Assistance

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

A request for financial assistance is included on the application for admission to graduate standing. These applications should reach the Institute by February 15. Appointments to fellowships, scholarships, and assistantships are for one year only; and a new application must be filed with option representatives each year by all who desire appointments for the following year, whether or not they are already holders of such appointments.

In addition, loans are available to graduate students who need such aid to continue their education. They are made upon application, subject to the approval of the Scholarships and Financial Aid Committee, and the extent of the available funds. In addition to loans, the Deferred Payment Plan is also available to graduate students.

Graduate Assistantships

Graduate assistants devote, during the school year, not more than 20 hours a week to teaching, laboratory assistance, or research of a character that affords them useful experience. This time includes that required in preparation and in marking notebooks and papers, as well as that spent in classroom and laboratory. The usual assistantship assignment calls for 20 hours per week at most and ordinarily permits the holder to carry a full graduate residence schedule at well.

Graduate Scholarships, Fellowships, and Research Funds

The Institute offers a number of tuition awards to graduate students of exceptional ability who wish to pursue advanced study and research. Several of these funds also provide a monthly stipend for living expenses.

Work-Study Programs

Limited opportunities are available for work-study programs in certain areas of interest. At the present time the sponsors of such programs are the Hughes Aircraft Company, Scientific Education Office, World Way, P.O. Box 90515, Los Angeles, California 90009, and the Jet Propulsion Laboratory of the California Institute of Technology. Potential students wishing to consider participation in the Hughes program may make inquiry to the address above or through the appropriate option at this Institute. Those wishing to be considered for the JPL program should inquire through their option. In general such programs require some part-time employment during the academic year, as well as full-time work during the summer.

Postdoctoral Fellowships

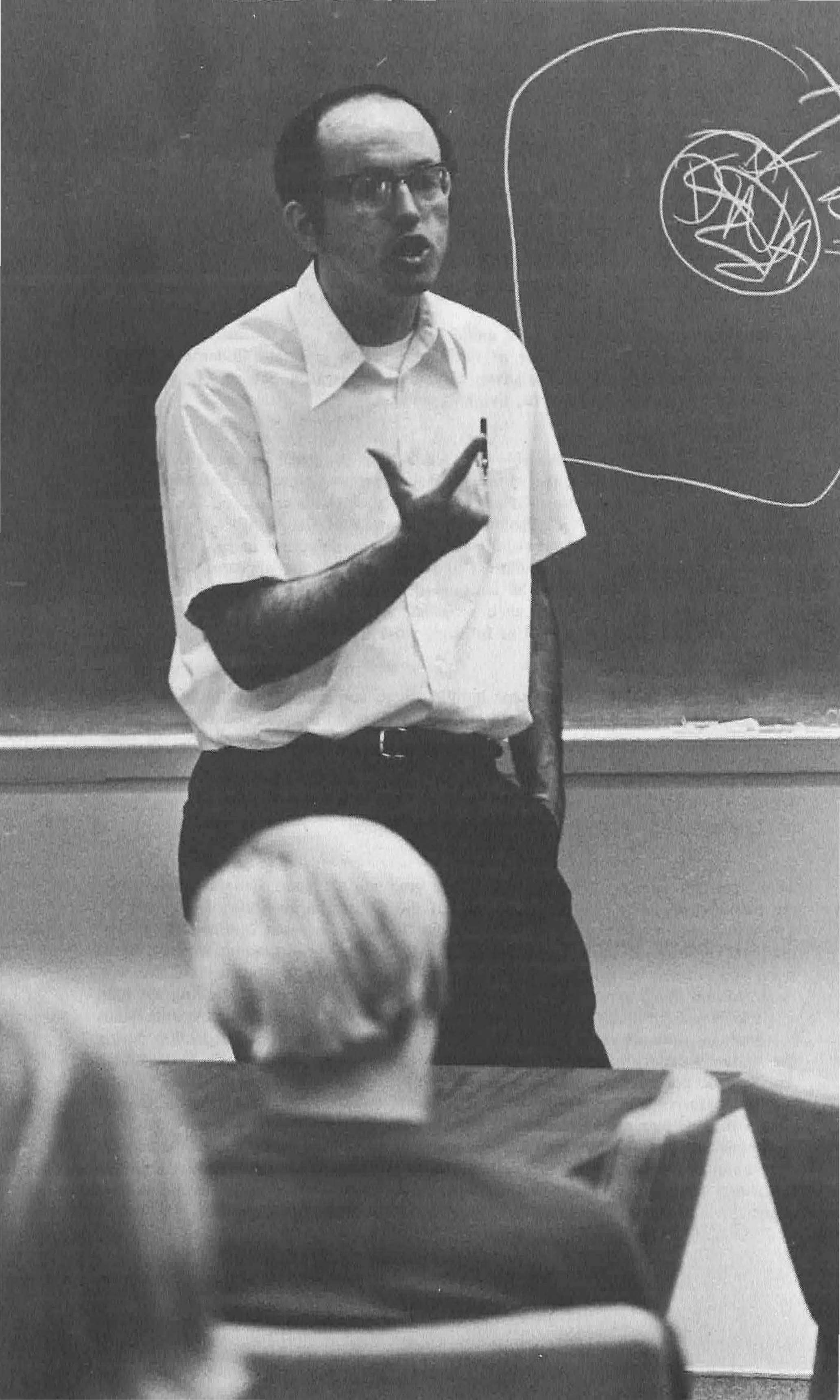
It is frequently advantageous for individuals to continue their training programs for a limited period of time after receiving their doctoral degrees and before seeking regular employment. To this end, the Institute appoints each year a number of Postdoctoral Fellows. The postdoctoral program consists, generally, of fundamental research in one of the Institute laboratories in close association with one or more regular faculty members. At the end of a period of postdoctoral training, a certificate of completion will be issued to the Fellow upon request.

Loans and Deferred Payments

There are two sources of loans available to graduate students: Federal loans under the NDEA and loans from special funds of the California Institute of Technology. The terms and conditions for these loans are the same as those outlined for undergraduate students on pages 184-185, except that the maximum amount which may be borrowed in one year under the NDEA by a qualified graduate student is $2,500. The total of loans made to such a student from this source for all years, including any loan made to him as an undergraduate, may not exceed $10,000. Loans from Institute funds for graduate students are limited to $1,000 per year and cannot exceed $9,000 during the student's undergraduate and graduate study; loans from these funds for graduate students will be subject to interest charges from the time the loan is made.

The Deferred Payment Plan is also available to graduate students and the conditions for this plan are outlined on page 185.

Loans and the deferred payment plan may also be used in combination, but the total amount from all sources may not exceed $2,500 in any one year of graduate study and cannot exceed $14,000 during the student's undergraduate and graduate study.



Section V

SUBJECTS OF INSTRUCTION

The school year is divided into three terms. The number of units assigned in any term to any subject represents the number of hours spent in class, laboratory, and preparation per week. In the following schedules, figures in parentheses denote hours in class (first figure), hours in laboratory (second figure), and hours of outside preparation (third figure).[1]

Aeronautics

ADVANCED COURSES

Ae 101 abc. Fluid Mechanics. *(Same as APh 120.) 9 units (3-0-6); each term.* Definition, classification and properties of fluids. Thermodynamics of fluid flow; compressibility, real gas effects. Acoustic waves, shock waves, gravity waves. Euler equations. Vorticity. Subsonic and supersonic flow fields. Nonstationary flows. Stress-strain relations. Viscosity and heat conduction effects at low and high Reynolds numbers. Boundary layers. Turbulent shear flows. Additional topics will be selected from subjects such as: heat flow and diffusion in gases; dynamics of rarefied gases; plasma flow and magnetohydrodynamics; super fluid flow; rotating fluids. Instructor: Roshko.

Ae 102 abc. Basic Solid Mechanics. *9 units (3-0-6); each term. Prerequisites: AMa 95, AM 97 or equivalent (AM 113 may be taken simultaneously).* An introduction to the study of deformable solids covering the subjects necessary for the systematic development of the analysis of the behavior of solids under load. Governing equations for various classes of solids. Elastic, plastic, and time dependent materials will be treated. Applications to engineering problems with a critical evaluation of available methods of solution. Instructor: Babcock.

Ae 103 abc. Vehicle Performance and Dynamics. *9 units (3-0-6); each term. Prerequisite: AMa 95.* Performance and dynamic behavior (stability and control) of vehicles moving in a continuum (air or water) will be discussed in a unified way. Examples to be discussed will include the dynamics and performance of vehicles such as submarines, surface effect machines, VTOL and STOL aircraft, subsonic and supersonic aircraft and rockets. Topics include speed performance, climb and descent, range, take-off and landing distances, static longitudinal and lateral stability, equations of unsteady motion, dynamic stability, responses to controls and disturbances. Instructors: Kubota, Behrens.

Ae 105 abc. Experimental Methods. *9 units (3-0-6 first term; 2-3-4 second and third terms).* First term: Properties of materials and of mechanical, electrical and electronic devices; design and use of instruments, with emphasis on digital methods. Examples of instrumentation (hot wire, strain gages, etc.) with demonstrations. Large experimental facilities, including GALCIT Hypersonic and 10 ft. Wind Tunnels and Water Tun-

[1]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.

nels. Second, third terms: Laboratory in solid and fluid mechanics. Emphasis on broad coverage of instrumentation and subject areas, particularly areas not ordinarily treated in analytical course work. Low-speed aerodynamics, turbulence, steady and non-steady gasdynamics, vibrations, flutter, photoelasticity. Instructors: Staff.

Ae 150 abc. Aeronautical Seminar. *1 unit (1-0-0); each term.* Speakers from campus and outside research and manufacturing organizations discuss current problems and advances in aeronautics. Graded pass/fail only. Instructor: Sturtevant.

Ae 172 abc. Optimal Control Theory. *(Same as ChE 172 abc and EE 172 abc.) 9 units (3-0-6); each term.* Linear feedback control systems; frequency and time domain analysis; stability, controllability, and observability; synthesis using bode plots, Nyquist diagrams, and root loci; optimization problems for dynamic systems with terminal and path constraints (calculus of variations); optimal feedback control (dynamic programming); terminal controllers and regulators; numerical methods for synthesizing optimal paths and optimal feedback controllers. Optimal control in the presence of noise; recursive filtering, smoothing, and interpolation for linear systems with additive Gaussian noise. Singular optimization problems and differential games. Instructor: Wood.

Ae 200 abc. Research in Aeronautics. *Units to be arranged.* Theoretical and experimental investigations in the following fields: aerodynamics, compressibility, fluid and solid mechanics, supersonic and hypersonic flow, aeroelasticity, structures, thermoelasticity, fatigue, photoelasticity. Instructors: Staff.

Ae 201 abc. Advanced Fluid Mechanics. *9 units (3-0-6); each term. Prerequisites: Ae 101 or Hy 101; AM 125 or AMa 101 (may be taken concurrently).* Foundations of the mechanics of real fluids. Basic concepts will be emphasized. Subjects covered (not necessarily in the order listed) include: physical properties of real gases; the equations of motion of viscous and inviscid fluids; the dynamical significance of vorticity; exact solutions; motion at high Reynolds number emphasizing boundary layer concepts and their mathematical treatment; inviscid compressible flow theory; shock waves; similarity for subsonic, transonic, supersonic and hypersonic flows. In addition, topics will be selected from the following subjects: low Reynolds number approximate solutions; hypersonic aerodynamics; acoustics; flow of mixtures with chemical changes and energy transfer; stability and turbulence; rotating and stratified fluids. Offered in odd-numbered years. Instructor: Coles.

Ae 202 abc. Advanced Solid Mechanics. *9 units (3-0-6); each term. Prerequisite: Ae 102 or equivalent.* Solution methods in the linear theory of elasticity: potentials in two or three dimensions; Kolosov-Muskhelishvili method of complex variables; integral transforms and integral equation methods. Anisotropic and non-simple materials. Introduction to wave mechanics. Variational methods. Principles of potential and complementary energy; Reissner's and Hamilton's principles. Application to the derivation of plate and shell equations, to discrete element methods and structural stability. Deformation and incremental theories of plasticity. Problems in large deformations, involving kinematic and material non-linearities. Instructor: Knauss.

Ae 203 abc. Applied Aerodynamics and Flight Mechanics. *9 units (3-0-6); each term. Prerequisites: Ae 102, Ae 103, AM 113.* Atmospheric flight mechanics, controlled motion of airplanes and rockets, atmospheric perturbation effects, gyroscopic coupling effects. Orbital flight mechanics, launching trajectories, space trajectories, orbital perturbations. Multi-stage rocket performance. Re-entry mechanics and aerodynamic heating. Special topics in wing theory, linearized incompressible and supersonic lifting surface theory and non-stationary wing theories. Reverse flow theorems and minimum drag theorems for incompressible and supersonic flow. Instructor: Stewart.

Ae 204 abc. Technical Fluid Mechanics. *6 units (2-0-4); each term. Prerequisites: Ae 101, Hy 101 or equivalent.* The aim is to acquaint students with a class of problems frequently encountered in engineering but for which complete theoretical methods do not exist. Typically these include flows with turbulence, separation, instability, etc. Topics will include turbulent shear flows, separated flows, effects of laminar to turbulent transition, three-dimensional and nonstationary effects, and will be used to discuss such engineering problems as mixing devices, diffusers, stall, buffeting, aerodynamics of non-aeronautical shapes such as building structures and vehicles. Offered in even-numbered years.

Ae 207 Case Histories in Aerospace Engineering. *9 units (3-0-6); each term.* The characteristic features of current large engineering developments in aeronautics and space will be treated by examining a case history of a project which has recently completed the primary engineering cycle. The information will be developed through a series of interlinked seminars, primarily presented by persons discussing their part of the project. The series will start with the economic, political and technological environment in which the concept originated, proceed to project initiation, detailed engineering, manufacturing and operations. Finally, a summary of project successes and difficulties and suggestions for future work will be presented. 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.

> **Note:** The following group of courses, Ae 212 to 225, represents a series of one-term courses in Advanced Solid Mechanics. They will be given as student demand requires and staff facilities permit.

Ae 212. Shell Theory. *9 units (3-0-6); second 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: Babcock.

Ae 213. Fracture Mechanics. *9 units (3-0-6); one term. Prerequisite: Ae 210 or equivalent.* An advanced course stressing the interdisciplinary approach to the fracture of material, both metallic and non-metallic. The Griffith macroscopic theory of brittle fracture and its extension to ductile and viscoelastic materials. Mechanics of crack propagation including dynamic effects of running cracks. Not offered 1973-74.

Ae 214. Special Problems of Space Environment. *9 units (3-0-6); third term.* The effect of space environment on living bodies, materials, and structures. Hard vacuum, ionizing and particle radiation. Micrometeoroid impact, damage, and protection. Radiation shielding. Differences between short-time and long-time missions. Solar radiations, flares, and storms. Not offered 1973-74.

Ae 217 ab. Aero- and Hydroelasticity. *9 units (3-0-6); second and third terms.* General formulation of aeroelastic and hydroelastic problems. Aeroelastic oscillations of cylinders, transmission lines and suspension bridges. Steady state problems; divergence, loss of control. Flutter of airfoils with nonlinear stiffness and damping characteristics. Instability of hydrofoils. Not offered 1973-74.

Ae 221. Theory of Viscoelasticity. *9 units (3-0-6); one term. Prerequisite: Ae 210 or equivalent.* Material characterization and thermodynamic foundation of the stress-strain laws. Correspondence rule for viscoelastic and associated elastic solutions and integral formulation for quasi-static boundary value problems. Treatment of time-varying boundary conditions such as moving boundaries and moving loads. Approximate methods of viscoelastic stress analysis and discussion of the state-of-the-art failure analysis and nonlinear viscoelasticity. Not offered 1973-74.

Ae 225 c. Special Topics in Solid Mechanics. *9 units (3-0-6); third term.* In 1973-74 the subject matter will be Numerical Methods in Structures. Topics are selected from: linear and nonlinear stress analysis of two- and three-dimensional bodies, large deformations and stability analysis of plates and shells, linear and nonlinear vibration of continuous systems. Whenever applicable the finite difference and finite element approach will be investigated. Instructors: Sechler, Arbocz.

Note: The following group of courses, Ae 231 to Ae 250, includes one-term advanced courses in Fluid Mechanics and Flight Mechanics which will be offered from time to time as demand warrants and staff availability permits.

Ae 231. Wing Theory. *9 units (3-0-6); second term. Prerequisites: Ae 101, AM 113.* Application of potential flow theories to flows around airfoils and wings. Topics are selected from: two-dimensional airfoil theories, thin airfoil theory, numerical methods for thick airfoils, ground effects, cascade of airfoils, airfoil with cavitation, nonstationary flow, compressibility effects; three-dimensional wings, lifting-line theory, slender-wing theory, lifting-surface theories, ground effects, wind-tunnel wall effects; supersonic-wing theories, conical-flow theory. Evvard's integral solution. Not offered 1973-74.

Ae 232. Numerical Methods in Fluid Mechanics. *9 units (3-0-6); third term. Prerequisites: Ae 101, AM 113 or equivalents.* Problem-oriented review of numerical methods and solutions in fluid mechanics. Ordinary differential equations, shock-wave structure, one-dimensional flow, boundary layers. Classification of partial differential equations. Numerical methods for elliptic problems, potential flow around finite bodies. Finite difference methods for parabolic problems, laminar and turbulent boundary layers. Hyperbolic problems, method of characteristics, finite-difference methods. Supersonic blunt-body problems. Non-steady flow equations. Free-surface problems. Numerical modeling. Not offered 1973-74.

Ae 233. Topics in High-Temperature Gasdynamics. *9 units (3-0-6); one term. Prerequisites: Ae 101, Ae 201, AM 113, or AM 125 or AMa 101.* Some aspects of the effects of gasdynamics of chemical reactions and departures from local thermodynamic equilibrium at high temperatures and low densities. Flow around bodies and in wakes at hypersonic speeds; importance of energy transfer by diffusion and by radiation. Ionized gases at low density. Not offered 1973-74.

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 experiment. Text: *Hypersonic Flow Theory,* Hayes and Probstein. Not offered 1973-74.

Ae 235. Acoustical Problems in Fluid Mechanics. *9 units (3-0-6); first term.* Fundamental principles. Geometrical acoustics. Standing waves. Cavities. Diffraction. Sound in moving media. Aerodynamic noise. Nonlinear acoustics. Focusing. Shock diffraction. Not offered 1973-74.

Ae 237 ab. Non-Steady Gasdynamics. *9 units (3-0-6); two terms. Prerequisites: Ae 101, AMa 95 or AM 113.* Review of shock waves in moving coordinate systems, in real and perfect gases. Simple expansion waves. Basic shock-tube equation. Reflected shock waves. Wave interactions and geometrical effects. Shock-tube applications; non-ideal behavior in shock tubes, diaphragm opening effects, boundary layer effects. Shock-tube techniques and measurements. Driver types and characteristics. Illustrations of shock-tube applications; shock-wave structure, shock-wave interactions, experiments on chemical and physical properties of gases, reaction rates, aerodynamic experiments, light gas guns, etc. Not offered 1973-74.

Ae 240 abc. Special Topics in Fluid Mechanics. *9 units (3-0-6); each term.* Subject matter will change from term to term depending upon staff and student interest. Enrollment is by permission of the instructor. Not offered in 1973-74.

Ae 250 abc. Special Topics in Flight Mechanics. *9 units (3-0-6); each term.* Subject matter may change from term to term and from year to year depending upon staff. It is planned to invite senior personnel from universities, research laboratories, and industry to give courses in such subjects as design, control systems, and systems engineering for both aircraft and spacecraft systems. Not offered 1973-74.

Aeronautics — Jet Propulsion

(For Jet Propulsion see page 357)

Air Force — Aerospace Studies

AS 1. Communicative Skills. *1 unit (1-0-0); first term. Prerequisites: enrollment in AS 30a and AS 10a or instructor's permission.* Provides students with a common foundation in basic communicative skills. Students learn general techniques of good speaking, how to present informative speeches and briefings, how to prepare and use visual aids, how to write effectively, and other related skills. Instructor: Smith

AS 10 abc. Introductory Air Force Management Laboratory. *1 unit (0-1-0); each term. Prerequisite: Enrollment in AS 30 abc or instructor's permission.* A practical study in group interaction from the point of view of a staff member in a typical Air Force organization. Students perform staff tasks under the direction and supervision of AS 20 abc students. Students are rotated throughout the staff agencies of the organization in order that they may encounter the maximum number of management problems and become thoroughly familiar with the entire organization. The organization is given various tasks to perform and its performance is analyzed with emphasis upon determining where and how breakdowns in communications, organization, etc. occur. Instructor: Smith.

AS 20 abc. Advanced Air Force Management Laboratory. *1 unit (0-1-0); each term. Prerequisites: AS 10 abc and enrollment in AS 40 abc or instructor's permission.* A continuation of AS 10 abc, the AS 20 course allows students to work within an Air Force organization as supervisors. They learn the practical aspects of the functions of management (planning, organizing, coordinating, directing and controlling) in supervising the accomplishment of tasks assigned the organization. As with the staff functions in AS 10, the AS 20 students are rotated throughout the supervisory levels of the organization in order to insure maximum exposure to management problems. The accomplishment of tasks is analyzed to provide practical lessons in management to all students. Instructor: Smith.

AS 30 abc. Growth and Development of Aerospace Power. *6 units (3-0-3); each term. Prerequisite: AS 1 (normally taken concurrently) or instructor's permission.* AS 30 a deals with the History of Aerospace Power, a course tracing the development of the Air Force from the days of balloons to the Space Age. AS 30 b is concerned with Aerospace Power Today, a study of the theory and practice of employment of aerospace power and of the existing and planned aerospace systems in the United States and abroad. AS 30 c is a survey of astronautics and space operations, dealing with the evolution of the national space program, planned capabilities for space operations, and the operating principles, characteristics and problems of space vehicles systems. Instructor: Smith.

AS 40 abc. Air Force Management. *6 units (3-0-3); each term. Prerequisite: AS 30 abc or instructor's permission.* The course begins with a study of leadership, with emphasis on human behavioral and group interactional patterns affecting leadership, and some of the distinctive variables affecting leadership in the Air Force. This is followed by a study of management with its primary units the management functions of planning, organizing, coordinating, directing, and controlling. Within these functions there is a development of normal command and staff functioning in problem solving, advising, and decision-making situations. Instructor: Bendel.

Anthropology

An 11. Race, Language and Culture. *9 units (3-0-6); first term.* Human and cultural evolution. Descriptive analysis of hunting and gathering societies in the Old and New Worlds. The development of racial, linguistic and cultural diversity. The agricultural revolution and the rise of the preindustrial city. Instructor: Scudder.

An 101 abc. Selected Topics in Anthropology. *9 units (3-0-6).* Collective action and collective decision-making. Not offered 1973-74.

An 123 ab. The Anthropology of Development. *9 units (3-0-6); second, third terms.* Social change in contemporary tribal and peasant societies. Emphasis will be placed on the impact of modernization, especially through urbanization, industrialization and the intensification of agriculture, and of revitalization on the social organization of selected societies in Latin America, Europe, Africa and elsewhere over the past half century. Instructor: Scudder.

Applied Mathematics

UNDERGRADUATE COURSES

AMa 90 abc. Topics in Applied Mathematics. *9 units (3-0-6); three terms. Prerequisites: Ma 2 abc, Ph 2 abc, or equivalent.* An introductory course, ranging over a variety of applications to show typical problems, concepts and methods of applied mathematics. Topics will be chosen from the areas of random processes, combinatorial analysis, numerical analysis, computer science, continuum mechanics and transport theory. The aim is to show the interplay between mathematics and applications on topics which do not require a large detailed background in either mathematical methods or in the particular subject area of the application. For the academic year 1973-74 the topics will be: First term — traffic flow, shock waves, sonic booms, boundary layer phenomena. Second term — fast computations, computer algebraic manipulation, Monte Carlo methods. Third term — birth and death processes, epidemics, random walks, Brownian motion. Instructors: Whitham, Keller, Grünbaum.

AMa 95 abc. Introductory Methods of Applied Mathematics. *12 units (4-0-8); three terms. Prerequisites: Ma 1 abc, Ma 2abc or equivalent.* A course in the mathematical treatment of problems arising in applied mathematics, engineering, and physics. The topics studied include: vector analysis as applied to formulation of field theory problems; a basic introduction to analytic functions of complex variables; special functions such as the Bessel functions and Legendre functions; series of orthogonal functions; partial differential equations and boundary value problems, and an introduction to integral transforms. Instructor: Caughey.

ADVANCED COURSES

AMa 101 abc. Methods of Applied Mathematics I. *9 units (3-0-6); three terms. Prerequisite: AMa 95 or Ma 108.* Review of basic complex variable analysis; analytic continuation; ordinary linear differential equations with applications to special functions; asymptotic expansions; integral transforms. Applications to boundary value problems and integral equations. Instructor: Nicolaides.

AMa 104. Matrix Theory. *9 units (3-0-6); first term. Prerequisite: AMa 95 abc or equivalent.* Matrices as linear transformations, theory of linear vector spaces, matrix operations. Eigenvalue-eigenvector theory, canonical forms, variational principles, inverses, pseudo-inverse. Matrix and vector norms, matrix calculus and applications to systems of ordinary differential equations. Introduction to computational linear algebra. Instructor: Weiss.

AMa 105 ab. Introduction to Numerical Analysis. *11 units (3-2-6); second and third terms. Prerequisites: Ma 108 or AMa 104 or equivalent; ability to use digital computer by middle of first quarter.* Solution of linear systems by direct and iterative methods; eigenvalue-eigenvector computation; iterative solution of greater nonlinear systems. Approximation theory, least squares, interpolation, splines, quadrature. Numerical methods for initial value and boundary value problems in ordinary differential equations. Introduction to methods for partial differential equations. Instructor: Weiss.

AMa 110 abc. Introduction to the Calculus of Variations. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* The first variation and Euler's equation for a variety of classes of variational problems from mathematical physics. Natural boundary conditions. Subsidiary conditions. The theory of extremal fields for single-variable variational problems. Conjugacy and the second variation. Hamilton-Jacobi theory. An introduction to the direct methods of Rayleigh, Ritz, and Tonelli and their application to equilibrium and eigenvalue problems. Some simple aspects of control problems. Offered second and third terms, 1973-74. Instructor: Whitham.

AMa 151 abc. Perturbation Methods. *9 units (3-0-6); three terms. Prerequisite: AMa 101 or equivalent.* The course discusses uniformly valid approximations in various physical problems. Generalized boundary layer technique. Coordinate straining techniques: Poincare's method. Problems with several time scales; averaging techniques; method of Krylov-Bogoliubov. Eigenvalue problems. Examples taken from linear and nonlinear vibrations, orbital problems, viscous flow, elasticity. Not offered in 1973-74.

AMa 152 abc. Linear and Nonlinear Wave Propagation. *9 units (3-0-6); three terms. Prerequisite: AMa 101 or equivalent.* Mathematical formulation, hyperbolic equations, characteristics, shocks. Combined effect of nonlinearity and diffusion. Wave propagation with relaxation effects. Dispersive waves, group velocity, geometry of waves, nonlinear dispersive waves. Diffraction theory. The emphasis is on solving physical problems and the mathematical theory is developed through a wide variety of problems in gasdynamics, water waves, plasma physics, electromagnetism. Instructor: Saffman.

AMa 153 abc. Stochastic Processes. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or AMa 95.* An introductory course designed to proceed from an elementary and often heuristic discussion of a variety of stochastic processes to a unified mathematical treatment of the subject. Topics will include: Basic probability, random walks, concepts of power spectra and correlation functions and their use in problems like shot effect, Brownian motion, wave propagation in media with random inhomogeneities, turbulence, etc. Response of systems of oscillators to random inputs. Fokker-Planck equation and its application to nonlinear oscillator problems. General theory of Markov processes. Not offered in 1973-74.

AMa 161 abc. Mathematical Theory of Information, Communication and Coding. *9 units (3-0-6); three terms. Prerequisite: Ma 5 abc or instructor's permission.* The Shannon theory of information is presented for discrete channels. Source coding, synchronization coding, and elementary cryptography are discussed, as well as linear (group) codes, algebraic codes, cyclic codes, and other error detecting and correcting codes. The underlying algebra of finite fields is developed, typical devices for encoding and decoding are described, and applications to actual communication systems are presented.

AMa 181 abc. Mathematical Programming and Game Theory. *9 units (3-0-6); three terms. Prerequisite: Some knowledge of linear algebra.* Theory of linear and nonlinear programming. Simplex algorithm. Integer programming and network flows. Zero-sum, two-person games. Linear models of exchange and production. Kakutani fixed-point theorem. Theory of n-person games. Applications to engineering and economics. Instructor: Franklin.

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

AMa 201 abc. Methods of Applied Mathematics II. *9 units (3-0-6); three terms. Prerequisite: AMa 101 or equivalent.* First-order partial differential equations; classification of higher-order equations; well-posed problems. Fundamental solutions and Green's functions; eigenfunction expansions; solution by integral transforms. Singular integral equations. Instructor: Kinnersley.

AMa 204 abc. Numerical Solution of Differential and Integral Equations. *9 units (3-0-6). Prerequisites: AMa 101 and AMa 104 or some familiarity with elementary numerical methods, as in AMa 105 a, digital computing techniques, partial differential equations.* A study of practical methods for "solving" various linear and nonlinear, ordinary and partial differential and integral equation problems with the aid of modern digital computers. The theory of stability, convergence and accuracy of methods will be stressed. Computations on some nontrivial problems from each student's area of specialization will be undertaken. Complementary material is given in Ma 205. Not offered in 1973-74.

AMa 251 abc. Applications of Group Theory. *9 units (3-0-6). Prerequisite: some knowledge of linear algebra.* Applications of group theory to differential equations and to physics, in particular quantum mechanics, will be discussed. Mathematical topics to be covered include: Basic concepts of group theory. Infinitesimal transformations and Lie algebras. General notions of group representations. Detailed discussion of classical groups (symmetric, orthogonal, unitary, Lorentz, etc.) and of their representations. Instructor: Lagerstrom.

AMa 252. Exterior Differential Forms. *9 units (3-0-6); third term. Prerequisites: AMa 101, 104 and some knowledge of partial differential equations (or consult instructor).* A review of non-metric tensor calculus will first be given, introducing modern index-free symbolism for vectors and forms. Lie differentiation, exterior differentiation, contraction and integration of forms. Use of this geometric calculus to discuss, from a unified standpoint, Hamiltonian dynamics, Riemannian geometry, and the theory of sets of first-order partial differential equations. Applications to examples from electrodynamics, fluid dynamics, plasma theory, etc. Not offered in 1973-74.

AMa 253 ab. Topics in Applied Probability Theory. *9 units (3-0-6); first and second terms. Prerequisite: AMa 153 or equivalent.* Stochastic differential and integral calculus, Wiener-Hermite analysis with applications, prediction and filtering, Markov fields, Boltzmann equation. Instructor: Grünbaum.

AMa 260 abc. Special Topics in Continuum Mechanics. *9 units (3-0-6); three terms. Prerequisites: Some knowledge of elasticity or fluid mechanics and instructor's permission.* A course designed to reflect recent and current research interests of the staff and students working on mathematical problems in the areas of elasticity, fluid mechanics and related fields. Instructor: Keller.

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

AMa 291. Seminar in Applied Mathematics. *Units by arrangement.*

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

Other courses particularly suitable in making up a program in Applied Mathematics include:

Ma 109	Delta Functions and Generalized Functions
Ma 141	Ordinary Differential Equations
Ma 143	Introduction to Functional Analysis
Ma 144	Probability
Ma 205	Advanced Numerical Analysis

AM 135	Mathematical Elasticity Theory
AM 136	Advanced Mathematical Elasticity Theory
AM 175	Advanced Dynamics
ES 131 abc	Thermodynamics and Statistical Mechanics
ES 204	Hydrodynamics of Free Surface Flows
Ph 125	Quantum Mechanics
Ph 209	Electromagnetism and Electron Theory
Ph 227	Statistical Physics

Applied Mechanics

UNDERGRADUATE COURSE

AM 97 abc. Analytical Mechanics of Deformable Bodies. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 1 abc and Ma 2 abc.* Basic principles of stress and strain, displacements and strains in a continuum, stress-strain relations, strain energy methods, and stress failures. Equations of the Theory of Elasticity, uniqueness, and St. Venant's principle. Applications to beams, elastic instability, axially symmetrical problems, stress concentrations, torsion, plates and shells, wave propagation and plastic and inelastic behavior, stresses and strains as tensors, numerical methods and experimental methods in stress analysis, variational methods. Instructors: Housner, Hudson, Jennings.

ADVANCED COURSES

AM 112 abc. Structural Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 97 abc or equivalent.* Static and dynamic analysis of structures and structural elements to determine stresses, forces, strains, displacements, and stability in continuous and discrete systems. Systems such as beams, columns, plates, shells, and framed structures with elastic and inelastic properties will be studied. A variety of methods, including energy and variational techniques, relaxation methods, and finite element analysis, will be used to develop solutions to specific problems. Instructors: Housner, Jennings.

AM 113 abc. Engineering Mathematics. *12 units (4-0-8); first, second, third terms. For graduate students only. Prerequisite: Ma 1 abc, Ma 2 abc, or equivalent.* A course for graduate students who have not had the equivalent of AMa 95 abc. Emphasis is placed on the setting up of problems as well as their mathematical solution. The topics studied include: vector analysis; analytic functions of a complex variable and applications; ordinary differential equations, emphasizing power series solutions; special functions such as the Bessel and Legendre functions; partial differential equations and boundary-value problems, with emphasis on applications of series of orthogonal functions; and an introduction to transform methods. Instructors: Wayland, Miklowitz.

AM 125 abc. Engineering Mathematical Principles. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or AM 113 abc, or Ma 108, or equivalent.* Nonlinear first-order ordinary differential equations; ordinary linear differential equations of second order, Sturm-Liouville theorems, Green's functions, asymptotic expansions and method of steepest descent; integral transform theory; partial differential equations of first and second order; applications to vibrations, elasticity, acoustic and electromagnetic wave propagation, kinetic theory, and fluid mechanics problems. Instructor: Iwan.

AM 135 abc. Mathematical Elasticity Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: suitable background in advanced calculus.* Foundations and applications of linear elasticity theory. Elements of cartesian tensor analysis. Kinematics of deformation, analysis of stress, stress-strain relations, strain-energy. Alternative formulations of boundary-value problems in elastostatics and elastodynamics. Reciprocal and uniqueness theorems, and variational principles. Theory of stress functions. Orthogonal curvilinear coordinates. Basic problems in elastostatics: fundamental singular solutions, problems of the half space, torsion and bending, plane problems. Instructor: Knowles.

AM 136 abc. Advanced Mathematical Elasticity Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 135 abc or equivalent.* Special topics in the advanced linear theory and the nonlinear theory of elasticity; specific content may vary from year to year. Representative topics include: theory of Green's functions, mean value theorems, and St. Venant's principle in the linear theory; linear thermoelasticity; integral transform and complex-variable methods in classical elasticity. Shell theory and problems of boundary-layer type in elasticity; elastic instability. Introduction to the nonlinear theory and applications. Instructor: Sternberg.

AM 140 abc. Plasticity. *9 units (3-0-6); first, second, third terms. Prerequisites: AMa 95 abc and AM 112 abc or instructor's permission.* Yield criteria and stress-strain relations for perfectly plastic and strain-hardening materials; stable materials; uniqueness theorems. Plastic torsion and bending. Plane strain theory and problems of incipient flow for metals and soils. Axially symmetric problems. Limit analysis theorems and applications. Plasticity theories for beams, plates, and shells. Minimum weight design. Not offered in 1973-74.

AM 141 abc. Wave Propagation in Solids. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or AM 113 abc, or instructor's permission.* Theory of wave propagation in solids with applications to problems. Waves in the infinite and semi-infinite elastic medium. Problems of wave scattering and diffraction. Dispersion of waves in bounded, elastic solids. Exact and approximate linear elasticity theories governing waves in rods, beams, plates, and shells. Use of integral and multi-integral transforms and related techniques, to derive exact and approximate transient elastic wave solutions. Introduction to theory of waves in viscoelastic and plastic media. Not offered in 1973-74.

AM 151 abc. Dynamics and Vibrations. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc, or instructor's permission.* The mechanics of particles, groups of particles and rigid bodies is studied within the framework of Hamilton's principle and Newton's laws of motion. Topics considered include: conservation principles, Lagrange's and Euler's equations, central force field problems, resonant vibration theory, response of systems to periodic and transient excitation, random vibration theory, general normal mode theory, matrix methods for vibration problems, vibration of continuous systems, and methods of nonlinear analysis. Instructors: Hudson, Jennings.

AM 155. Dynamic Measurements Laboratory. *9 units (1-6-2); first term.* Experimental studies of the behavior of dynamic systems. Theory and practice of dynamic instrumentation. Dynamic tests of mechanical systems including steady state and transient excitation. Analog techniques applied to random load problems. Instructors: Caughey, Hudson, Iwan.

AM 160. Vibrations Laboratory. *6 units (0-3-3); second term. Prerequisite: AM 151 abc or instructor's permission.* Experimental analysis of typical problems in structural dynamics and mechanical vibrations. Measurement of strains, accelerations, frequencies, etc., in vibrating systems, and the interpretation of the results of such measurements. Consideration is given to the design, calibration, and operation of the various types of instruments used for the experimental study of dynamics problems. Instructors: Caughey, Hudson, Iwan.

AM 175 abc. Advanced Dynamics. *9 units (3-0-6); first second, third terms. Prerequisites: AM 125 abc and AM 151 abc or equivalents.* A lecture course dealing with the theory of dynamical systems. Topics considered will include linear and nonlinear vibrations of discrete and continuous systems, stability and control of dynamical systems, and stochastic processes with applications to random vibrations. Instructor: Caughey.

AM 200. Special Problems in Advanced Mechanics. Dynamics of solid and deformable bodies, fluids, and gases; mathematical and applied elasticity. By arrangement with members of the staff, properly qualified graduate students are directed in independent studies. Hours and units by arrangement.

AM 250 abc. Research in Applied Mechanics. Research in the field of applied mechanics. By arrangement with members of the staff, properly qualified graduate students are directed in research. Hours and units by arrangement.

Applied Physics

UNDERGRADUATE COURSES

APh 3. Introduction to Solid-State Electronics. *6 units (3-0-3); first term.* An introduction to the significant concept of most modern electronic devices such as diodes, junction and field effect transistors, etc. Topics will include: electronic conduction in metals and semiconductor materials, energy barriers, junctions, carrier recombination and light emission, operating principles of transistors and transistor-like devices. Graded pass/fail. Instructor: Mayer.

APh 4. Introduction to Materials Science. *(Same as MS 4.) 6 units (2-0-4); third term.* Selected engineering systems, such as jet engines, superconducting transmission lines and nuclear reactors, are discussed in terms of the critical role played by materials in their construction and performance. Those material properties of greatest significance are explored to show how they are governed by the structure and basic physics and chemistry of the material. Graded pass/fail. Instructor: Wood.

APh 9. Solid-State Electronics Laboratory. *6 units (1-3-2); second, third terms. Prerequisite: APh 3. Six units credit allowed toward freshman laboratory requirement.* An introductory non-structured project laboratory design to provide an opportunity for projects related to the course APh 3. All of the facilities used for demonstrations in APh 3 are available as well as general semiconductor device fabrications facilities. The student is expected to design and carry out his own project either as an extension of one of the APh 3 demonstrations or fabricating and characterizing a device. Typical devices possible with facilities available: junction transistor, junction FET, MOSFET, light-emitting diode, solar cell, tunnel diode. Graded pass/fail. Instructor: Mayer.

APh 17 abc. Thermodynamics. *(Same as ME 17 abc.) 9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* An introduction to the laws governing the properties of matter in equilibrium and some aspects of non-equilibrium behavior. Definition and scales of temperature. The laws of classical thermodynamics. Thermodynamic potentials, Maxwell's relations, calculation of thermal properties, and applications to various homogeneous systems. First-order changes of phase and the Clausius-Clapeyron equation. Analyses of energy conversion cycles. General conditions for thermodynamic equilibrium, extremum properties of the thermodynamic potentials, and the thermodynamic inequalities. Chemical potential, mixtures of gases and vapors, solutions, basic chemical thermodynamics. Elementary statistical mechanics, ensembles, and statistical thermodynamics. Introduction to non-equilibrium thermodynamics, thermoelectric effects, and problems of heat conduction in solids. Thermodynamics of fluid flow. Some aspects of the kinetic theory of gases, calculation of transport properties by mean-free path methods and simplified forms of the Boltzmann equation. Instructor: Liepmann.

APh 50 abc. Applied Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc, Ma 2 abc, or equivalents.* Application of quantum mechanics to problems of the three states of matter: solids, gases, and liquids. Starting point will be the free and bound particle, the one-electron atom, and quantum statistics. Additional topics will be selected from electron transport in solids, plasma physics, kinetic theory, and other topics in physics depending on the instructor and interests of the students. Instructor: Villagrana.

APh 91 abc. Experimental Projects in Applied Physics. *Units by arrangement. 6 units minimum each term. Prerequisite: Ph 7 or EE 90 abc or equivalent; open to seniors upon acceptance by the instructor of a suitable proposal.* A non-structured project laboratory designed to give the student an opportunity to do original experiments in applied physics. Emphasis is placed upon the selection of significant projects, the formulation of the experimental approach and the interpretation of data as well as upon the use of modern laboratory techniques. Facilities are available for experiments in cryogenics, lasers, quantum electronics, ferromagnetism, optics, microwaves, plasma physics, and semiconducting solid state. Text: Literature references. Instructor: Humphrey.

ADVANCED COURSES

APh 100. Advanced Work in Applied Physics. Special problems relating to applied physics will be arranged to meet the needs of students wishing to do advanced work. Primarily for undergraduates. Students should consult with their advisers before registering for this course. Graded pass/fail.

APh 101. Topics in Applied Physics. *2 units (2-0-0); first, second, third terms.* A course designed to acquaint first-year graduate students with the various research areas represented in the option. Lecture each week given by a different faculty member of the option. Graded pass/fail. Instructors: Staff.

APh 105 abc. States of Matter. *9 units (3-0-6); first, second, third terms.* A survey of current ideas about the states of matter emphasizing unifying concepts, such as order parameters, scaling laws, quasi-particle excitations and correlation functions. Topics will include long-range ordered states such as crystals, superfluids and ferromagnets, phase transitions of first and higher orders, critical phenomena, band theory of solids, liquids, and ideal classical and degenerate gases. Instructor: Goodstein.

APh 114 abc. Solid-State Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 50 or Ph 102 abc or equivalent.* A lecture and problem course dealing on an introductory level with experimental and theoretical problems in solid-state physics. The topics to be discussed include: crystal structure, lattice vibrations, Fermi electron gas, semiconductors, superconductivity, magnetic resonance, ferroelectricity, linear and nonlinear optical phenomena in insulators. Instructor: McGill.

APh 120 abc. Fluid Mechanics. *(Same as Ae 101) 9 units (3-0-6); first, second, third terms.* Definition and classification of fluids. Kinematics of fluid flow, vorticity. Stress tensor and heat flux vector. Equations of motion. Dynamics of ideal and real fluids, the limiting cases of small and large Reynolds number flows, boundary layer theory. Laminar stability and turbulence. Gravity waves, acoustic waves, shock waves. Additional topics will be selected from subjects such as: heat flow and diffusion in gases; dynamics of rarefied gases; plasma flow and magnetohydrodynamics, super fluid flow; rotating fluids. Text: *Fluid Mechanics.* Instructor: Roshko.

APh 140 abc. Cryogenics. *9 units (3-0-6); first, second, third terms.* An introductory course on the behavior of condensed matter at low temperatures. Topics include superfluidity, superconductivity, quantum phase coherence, liquid He^3, ultralow temperature experiment, cryogenic techniques, and macroscopic quantum devices. Instructor: Mercereau. APh 140 c not offered in 1973-74.

APh 141. Superconductivity and Its Applications. *9 units (3-0-6); third term. Prerequisite: APh 114 abc.* A course on the basic principles and the engineering applications of superconductivity. After a review of basic properties of superconductors, phenomenological treatment and microscopic theory of superconductivity, the topics covered include: magnetic properties of type II superconductors, proximity effect, superconducting compounds, alloys and composites, high field superconducting magnets, magnetic suspensions for high-speed transportation, superconductive power transmission and rotating machines. Instructor: Tsuei.

APh 153 abc. Modern Optics. *(Same as EE 113 abc.) 9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc.* The analysis of optical systems based on electromagnetic theory. Mode theory and functions for optical resonators and transmission structures, image formation and spatial filtering with coherent light, partial coherence and partial polarization, theory of dielectrics, theory and applications of holography and selected topics of research importance. Text: Class notes and selected references. Instructor: George.

APh 154. Modern Optics Laboratory. *(Same as EE 197) 9 units (1-4-4); second term. Prerequisite: APh 153 or APh 190 (may be taken concurrently).* Primarily for graduate students. Laboratory experiments to acquaint students with the contemporary, yet basic, aspects of modern optical research and technology. Experiments encompass holography and interferometry, single-mode and mode-locked lasers, nonlinear optics, acousto-optic interactions, coherence, diffraction, optical data processing, photosensitive materials, liquid crystals, and ferroelectric ceramics. Instructor: George.

APh 156 abc. Plasma Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* An introduction to the principles of plasma physics. Topics presented will include: orbits of charged particles in electric, magnetic, and gravitational fields; elementary processes in the production and decay of ionized gases; continuum magnetohydrodynamics and elementary stability theory; transport processes such as conductivity and diffusion; waves, oscillations, and radiation in plasmas. Examples from physics, engineering, and astrophysics will be discussed. Instructor: Gould.

APh 161 abc. Nuclear Reactor Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or equivalent.* Fission and fusion systems; steady-state and transient chain reactions; the criticality condition; slowing down and diffusion of neutrons in multiplying and non-multiplying systems; effects of lattice structure; and reflectors; theory of control rods; elements of the rigorous theory of neutron transport. Instructors: Staff.

APh 163. Nuclear Radiation Measurements Laboratory. *9 units (1-4-4); second term. Prerequisite: Ph 2 abc.* A one-term laboratory course designed to familiarize students with basic nuclear detecting and measuring techniques. The instruments are used to determine the properties of various types of radiation and to observe the nature of their interaction with matter. Not offered in 1973-74.

APh 175 abc. Electromagnetic Fields. *(Same as EE 155 abc). 9 units (3-0-6); first, second, third terms. Prerequisite: EE 151 abc or Ph 106 abc.* An advanced course in classical electromagnetic theory and its application to guided waves, cavity resonators, antennas, artificial dielectrics, propagation in ionized media, propagation in anisotropic media, magnetohydrodynamics, and to other selected topics of research importance. Text: Course notes. Instructor: Papas. Not offered in 1973-74.

APh 181 abc. Physics of Semiconductors and Semiconductor Devices. *9 units (3-0-6); first, second, third terms.* Introduction to the concepts of semiconductor devices based on underlying physical properties of semiconductors. Electronic and chemical equilibrium in the bulk semiconductor and near interfaces, e.g., p-n junctions, surfaces. Kinetics of carrier generation-recombination and transport to first order. Applications will be made to a wide variety of devices and attention given to feasible schemes for device construction. Instructor: McCaldin.

APh 185 abc. Ferromagnetism. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 50.* Review of current theories of ferromagnetism. Phenomenological treatment of magnetization using the Landau-Lifshitz equation to treat flux reversal, spin wave resonance and micromagnetics. Relaxation mechanisms. Applications of magnetic materials in modern technology. Not offered in 1973-74.

APh 190 abc. Quantum Electronics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125, or equivalent.* This course is concerned with generation, manipulations, propagation, and applications of coherent radiation. Starting with the basic theory of the interaction of electromagnetic radiation with resonant atomic transitions, the course takes up the subjects of laser oscillation, important laser media, Gaussian beam modes, the electro-optic effect, nonlinear-optics theory, second harmonic generation, parametric oscillation, stimulated Brillouin and Raman scattering. Other topics include: Light modulation, diffraction of light by sound and quantum noise theory. Text: *Quantum Electronics* by Yariv, class references and research literature. Offered in alternate years. Not offered in 1973-74.

APh 195 ab. Molecular Gas Lasers. *(Same as JP 130 ab.) 9 units (3-0-6); first, second terms.* An introduction to gas lasers based on transitions involving molecular degrees of freedom. Some acquaintance with fluid mechanics, and knowledge of electromagnetic theory and quantum mechanics at the advanced undergraduate level will be assumed. Background material on the interaction of radiation and matter, and optical resonators will be included, but the emphasis will be on processes particular to molecular lasers. Examples of electrical discharge, gas dynamics, and chemical lasers will be discussed. Instructor: Culick.

APh 200 Applied Physics Research. *Units in accordance to work accomplished.* Offered to Ph.D. candidates in applied physics for research leading directly towards a Ph.D. degree. Students should consult their adviser before registering for the course.

APh 214 abc. Advanced Solid-State Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 114 abc and Ch 125 abc or Ph 125 abc.* A course in experimental and theoretical solid-state physics. Topics include: phonons; electronic excitation in solids; electron-phonon interactions; optical transport, and magnetic properties; superconductivity; ferroelectricity. The emphasis will be mainly theoretical with frequent comparison between theoretical predictions and experimental results. Instructor: McGill. Offered in alternate years. Not offered in 1973-74.

APh 224 abc. Magnetic Resonance. *(Same as Ch 224 abc.) 9 units (3-0-6); first, second, third terms. Prerequisite: background in elementary statistical and quantum mechanics, and some familiarity with elementary magnetic resonance.* The principles of nuclear magnetic resonance and electron paramagnetic resonance will be discussed. The theoretical background behind the various types of magnetic resonance experiments will be developed. Methods for the analysis of spectra will be treated as well as the theory of interaction between nuclear spins, electron spins, nuclear-electronic coupling and the dynamic coupling of spins to lattice degrees of freedom. Applications of magnetic resonance to current research will be discussed with illustrations taken from problems in chemistry, physics, and biology. Instructors: Chan, Vaughan.

APh 250 Advanced Topics in Applied Physics (Seminar). *Units, offering date, and duration by arrangement.* Consideration of selected topics in applied physics. Instructors: members of the staff and guest lecturers.

APh 261 abc. Theory of Particle Transport. *9 units (3-0-6). Prerequisite: instructor's permission.* The formulation and solution of the transport equation for neutrons, photons and simple gases, transport in dense fluids. Instructor: Corngold. Not offered in 1973-74.

APh 281 Advanced Theory of Semiconducting Solid State. *9 units (3-0-6); first, second, third terms.* Selected areas in the theory of the solid state relevant to semiconductors will be developed in detail. Emphasis will be placed on areas of current research interest in the field. Topics include: electronic and vibrational spectra, optical properties, electron phonon interactions, transport phenomena, disordered semiconductors, impurities, defects, and interfaces. Instructor: McGill. Not offered in 1973-74.

Art

Art 101. Topics in Art. *9 units (3-0-6).* Instructors: Staff.

Art 102 ab. Introduction to the Visual Arts. *9 units (3-0-6); first, second terms.* First term concentrates upon the vocabularies of analysis for the study of painting, sculpture, and architecture; approaches to study of art history, and case studies of selected art forms. The second term concentrates upon twentieth-century developments. Instructors: Price, Wark.

Astronomy

UNDERGRADUATE COURSES

Ay 1. Introduction to Astronomy. *9 units (3-1-5); third term.* This course, primarily for freshmen, surveys astronomy, radio astronomy and astrophysics. Reading in an elementary text is supplemented by lectures on current topics, emphasizing the application of physics in astronomy. Instructor: Cohen.

Ay 20. Basic Astronomy and the Galaxy. *11 units (3-2-6); first term. Prerequisites: Ma 1 abc, Ph 1 abc.* Astronomical terminology. Stellar masses, distances and motions. Star clusters and their galactic distribution. Stellar spectra, magnitudes and colors. Structure and dynamics of the galaxy. Laboratory exercises including double star orbits and the use of an astrograph. Instructor: Schmidt.

Ay 21. Galaxies and Radio Sources. *9 units (3-0-6); second term. Prerequisite: Ay 20.* The masses, sizes and luminosities of galaxies. Space density of galaxies. Stellar populations, integrated spectra and forms of galaxies. The local group. The extragalactic distance scale. Clusters of galaxies. Peculiar and interacting galaxies. Introduction to cosmology. Galactic and extragalactic radio sources. The physics of radiation mechanisms. Source counts and cosmology. Instructor: Sargent.

Ay 22. Solar System Astronomy. *9 units (3-0-6); third term.* The surface of the sun. Active regions: flares, the chromosphere and corona. Sunspots and the solar magnetic field. The solar cycle. Convection: granulation and supergranulation. The solar wind. The dynamics of the planetary system. The compositions, surface characteristics, structures, and atmospheres of the planets and their satellites. Comets, asteroids, and interplanetary matter. Instructor: Münch.

Ay 30. Current Trends in Astronomy. *3 units (2-0-1); second term.* Weekly seminar designed for sophomore astronomy majors; to be held, where possible, in faculty homes, in the evening. Purpose is to introduce the students to the faculty and their research. Graded pass/fail. Instructors: Greenstein and staff.

Ay 42. Research in Astronomy, Radio Astronomy, and Astrophysics. *Units in accordance with work accomplished.* Properly qualified undergraduates may, in their senior year, undertake independent or guided research with the goal of preparing a senior thesis. Subject matter must be arranged with instructor before registering. Graded pass/fail. Instructors: Staff.

Ay 43. Reading in Astronomy, Radio Astronomy, and Astrophysics. *Units in accordance with work accomplished.* Student must have a definite reading plan and obtain permission of instructor before registering. Graded pass/fail. Instructors: Staff.

ADVANCED COURSES*

Ay 100. Astronomical Measurements and Instruments. *12 units (3-3-6); first term.* Pho-

*See also Ge 152.

tographic plates and techniques. Photomultipliers and pulse counters. Modern television systems. The theory of optical instruments; spectrographs; the schmidt and other wide-field telescopes. Laboratory instruments. Interference filters and etalons. Radio telescopes, radiometers and interferometers. Filters and line receivers. Techniques and detectors in infrared and x-ray astronomy. Magnetic field measurements in astronomy. The effects of the earth's atmosphere. Laboratory exercises. Instructors: Oke, Moffet.

Ay 101. The Physics of Stars. *11 units (3-2-6); second term. Prerequisite: Ay 20.* The physics of stellar atmospheres and interiors. Stellar spectroscopy and radiative transfer theory. The Boltzmann and Saha equations and the spectral sequence. Sources of opacity, formation of absorption lines and the analysis of stellar compositions. The equations of stellar structure. Nuclear energy generation and nucleosynthesis. Polytropic stellar models. Stellar evolution and age determination. The end points of stellar evolution. Laboratory exercises on spectral classification and stellar interiors. Instructor: Greenstein.

Ay 102. Plasma Astrophysics and the Interstellar Medium. *9 units (3-0-6); third term. Prerequisite: Ay 20.* An introduction to fluid mechanics; sound waves and shock waves. The physics of ionized gases. Introduction to magnetohydrodynamics; Alfven waves and plasma waves with applications to the interstellar medium. Supernova remnants. Magnetic fields of stars and their origin. The interstellar magnetic field. The physics of H I and H II regions. Stromgren spheres. Planetary nebulae. Interstellar dust. The two-phase theory of the interstellar medium. Instructor: Sargent.

Ay 110. Senior Seminar in Astrophysics. *6 units (2-0-4); second term.* Designed for Ay seniors. Seminar on astrophysical topics of current interest. The lectures will be given by the students. The emphasis will be on topics which require a synthesis of previous formal course work. Instructors: Münch, Zirin.

Ay 120. Basic Astronomy and Astrophysics from an Advanced Viewpoint. *9 units (1-0-8); first term.* A lecture-reading course open to graduate students with deficient undergraduate background in astronomy and astrophysics. Content tailored to needs of students. Instructor: Münch.

Ay 131. Stellar Atmospheres. *9 units (3-0-6); first term. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) and Ph 92 abc or equivalents.* General survey of the methods for studying the structure and composition of stellar atmospheres. Radiative transfer. Sources of opacity. Convection. The construction of models. The line spectrum of normal stars. Coarse and fine analysis of stellar spectra. Composition and nucleosynthesis theory. Instructors: Zirin, Münch.

Ay 132. Stellar Interiors. *9 units (3-0-6); first term. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) and Ph 92 abc or equivalents.* Polytropes, opacity and energy generation. Stellar models and evolution. White dwarfs. Pulsating stars. Problems of stellar rotation, convection, and stability. Instructor: Gunn.

Ay 133 abc. Radio Astronomy. *9 units (3-0-6); first, second, third terms. For seniors and graduate students only. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) or equivalents.* Principles of radio receivers and telescopes. Noise and fluctuations. Aperture synthesis instruments. Observations and theory of galactic and extragalactic radio sources. Radiative transfer. Theory of bremsstrahlung and synchrotron emission. Discrete sources and their identification. Radio galaxies and quasi-stellar sources. Radiation from the sun, geophysical effects. Microwave spectroscopy. The 21-cm hydrogen line and galactic structure. Interstellar molecules. Instructors: Cohen, Moffet.

Ay 134. The Sun. *9 units (3-1-5); second term.* The physical state of the sun as derived from observations from the ground and from space. The structure of the quiet sun, the corona and chromosphere. Development of solar magnetic fields and the sunspot cycle. Solar flares, x-rays and radio bursts; cosmic rays from flares. The solar wind and other solar-terrestrial effects. Students will have the opportunity to do a small research topic with materials from the Big Bear Solar Observatory. Given in alternate years. Offered in 1973-74. Instructor: Zirin.

Ay 136. Solar System Astrophysics. *9 units (3-0-6). Prerequisites: Ay 22 or Ge 155.* A seminar-type course designed to fit the interests of students specializing in planetary astronomy. Current research topics on the composition and evolution of solar system bodies will be discussed and related to the understanding of the processes which gave origin to the solar system as a whole. Given in alternate years. Not offered in 1973-74.

Ay 138. Interstellar Matter. *9 units (3-0-6); first term. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) or equivalents.* 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. Given in alternate years. Not offered in 1973-74.

Ay 139. Stellar Dynamics and Galactic Structure. *9 units (3-0-6); third term. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) or equivalents.* 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. Given in alternate years. Offered in 1973-74. Instructors: Schmidt, Goldreich.

Ay 141 abc. Research Conference in Astronomy. *2 units (1-0-1); first, second, third terms.* These conferences consist of reports on investigations in progress at the Hale Observatories and the Owens Valley Radio Observatory, and on other researches which are of current interest. Graded pass/fail.

Ay 142. Research in Astronomy, Radio Astronomy, and Astrophysics. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of research outlined with him. Approval of the instructor and the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy. Graded pass/fail.

Ay 143. Reading and Independent Study. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of reading and independent study outlined with him. Approval of the instructor and the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy. Graded pass/fail.

Ay 152. Advanced Stellar Interiors. *9 units (3-0-6); first term.* Computation of stages of stellar evolution; nucleosynthesis; planetary nebulae; mass exchange in binaries; evolution toward the white dwarfs; thermal instabilities. The course is a logical but advanced continuation of our regular course, Ay 132, on stellar interiors. Instructor: Paczynski.

Ay 201 ab. Astronomical Instruments and Radiation Measurement. *9 units (3-1-5), (3-2-4); second, third terms. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) or equivalents.* The use of the photographic plate as a scientific instrument; quantitative techniques in laboratory photography. Astronomical optics. Theory of reflectors, schmidts and spectrographs. Photoelectric detectors, photometric systems and their applications. Given in alternate years. Not offered in 1973-74.

Ay 204. Advanced Spectroscopy. *9 units (2-2-5); third term. Prerequisite: Ay 131.* Spectroscopy of normal and peculiar stars; identification problems; the effect of the stellar atmosphere on the spectrum observed; effective temperatures and surface gravity; coarse and fine analyses and deviations from local thermodynamic equilibrium; the compositions of stars and nucleosyntheses. The class will measure and analyze a stellar spectrum. Instructor: Greenstein.

Ay 207 abc. Galaxies and the Universe. *9 units (3-0-6); first, second, third terms. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) or equivalents.* Structure, stellar content, and evolution of normal galaxies. Galaxies of the Local Group. Mass determinations. The luminosity function. Seyfert and compact galaxies, QSO's, and other peculiar objects. Dynamics of galaxies, clusters and small groups. The third term, which may be taken independently, will cover topics in observational cosmology, including dynamics, the microwave, and x-ray background, and the formation of galaxies and clusters. Given in alternate years. Not offered in 1973-74.

Ay 208. Modern Observational Astronomy. *6 units (1-0-5); second term. Prerequisite: instructor's permission.* An observational course for graduate students in astronomy in which modern astronomical techniques are used in conjunction with the various telescopes and auxiliary instruments on Mount Wilson and Palomar Mountain. Students will be permitted to register for only one term. Given in alternate years. Offered in 1973-74. Instructor: Oke.

Ay 215. Seminar in Theoretical Astrophysics. *9 units (3-0-6). Prerequisite: instructor's permission.* Seminar on recent developments for advanced students. The current theoretical literature will be discussed by the students. Given in alternate years. Not offered in 1973-74.

Ay 217. Theoretical Astrophysical Spectroscopy. *9 units (3-0-6). Prerequisite: Ph 125, or equivalent.* The analysis of radiation from astronomical sources not in thermodynamic equilibrium. Special attention to the formation of lines in atmospheres, and the calculation of excitation and ionization equilibria as well as individual atomic processes. Emission of radiation in dynamic plasmas; radiation and transition processes. Given in alternate years. Not offered in 1973-74.

Ay 218 ab. High-Energy Astrophysics. *9 units (3-0-6); second, third terms. Prerequisites: Ph 106 and Ph 92 or Ph 112 or equivalent, including a solid understanding of electromagnetic theory, special relativity, and quantum mechanics.* Equation of state and physical processes at high densities ($\rho \approx 10^5$ to 10^{15} g/cm^3), and at high temperatures (T $\approx$ 10^9 to 10^{11} K). Hydrodynamics; shock waves, magnetohydrodynamics. Radiation processes (thermal, synchrotron, bremsstrahlung, inverse Compton, and coherent). Relativistic gravity. Applications to final stages of stellar evolution (white dwarfs, supernovae, neutron stars, pulsars, black holes); to massive objects (supermassive stars, galactic nuclei, quasars); and to sources of high-energy radiation (x-ray sources, gamma-ray sources, cosmic-ray sources, gravitational-wave sources). Given in alternate years. Offered in 1973-74. Instructors: Goldreich, Gunn.

Ay 234. Seminar in Radio Astronomy. *6 units (2-0-4). Prerequisite: Ay 133 abc.* Recent developments in radio astronomy for the advanced student. Current publications and research in progress will be discussed by students and staff. Given in alternate years. Not offered in 1973-74.

The following courses will be offered from time to time by members of the Institute and Observatories staffs:

Ay 135. Topics in Modern Astronomy.
Ay 137. Topics in Space Astronomy and Physics.
Ay 151. Seminar in Stellar Atmosphere Theory.
Ay 203. Cosmical Electrodynamics.
Ay 206. Variable Stars.
Ay 213. Selected Topics in Observational Cosmology.
Ay 214. Theoretical Cosmology.
Ay 216. Dynamics and Formation of Galaxies and Clusters.

Biology

UNDERGRADUATE COURSES

Bi 1. Introduction to Biology. *9 units (distribution to be arranged); second term.* A course of lectures, discussion and laboratory opportunities designed to permit a relatively free exploration of biological topics. Individual arrangements are made to determine the number of laboratory units counting toward freshman laboratory requirements. Graded pass/fail. Instructors: McMahon and staff.

Bi 2. Current Research in Biology. *6 units (2-0-4); first term. An elective course, open only to freshmen.* Current research in biology will be discussed, on the basis of reading assigned to students in advance of the discussions, with members of the divisional faculty. Graded pass/fail. Instructors: Owen and staff.

Bi 3. Biology and Social Problems. *6 units (2-0-4); third term.* The relation of biological knowledge to major social problems. Topics may include over-population, environmental pollution, distribution of limited medical resources, "genetic engineering," biological warfare, the ethics of human medical research, etc. Instructor: Sinsheimer.

Bi 7. Organismic Biology. *12 units (3-5-4); first term. Prerequisite: Bi 1.* A survey of the principal kinds of organisms and the problems they have solved in adapting to various environments. Instructors: Brokaw and McMahon.

Bi 9. Cell Biology. *9 units (3-3-3); third term.* Studies of life at the cellular level: nature, functions, and integration of ultrastructural components; physical and chemical parameters; influences of external agents and internal regulation. Instructors: Bonner and staff.

Bi 22. Special Problems. *Units to be arranged; first, second, third terms.* Special problems involving independent research in fields represented in the undergraduate biology curriculum; to be arranged with instructors before registration. Graded pass/fail. Instructors: Staff.

Bi 23. Biology Tutorial. *Units (up to 6 maximum) to be arranged; first, second, third* *terms.* Study and discussion of special problems in biology involving regular tutorial sessions with instructors. To be arranged through the Undergraduate Adviser before registration. Graded pass/fail. Instructors: Wood and staff.

Bi 27. Biology Scholars Program. *Units to be arranged.* A program providing, by arrangement, a flexible combination of course work and independent study in biology for selected students in the junior and senior years. Pass-fail grading may be permitted. Instructors: Wood and staff.

ADVANCED COURSES

[A] Subjects intended for graduate students but open to qualified undergraduates.

Bi 101. Invertebrate Biology. *12 units (2-6-4); second term. Recommended prerequisites: Bi 7 and Bi 9.* A survey of the invertebrates, with emphasis on physiological functioning. Will include laboratory work at the Kerckhoff Marine Laboratory in Corona del Mar. Offered alternate years. Not offered in 1973-74. Instructor: Brokaw.

Bi 102. Vertebrate Biology. *12 units (2-5-5); second term. Recommended prerequisites: Bi 7 and Bi 9.* A survey of structure, function, and development in vertebrates, with emphasis on physiology. Offered alternate years; offered in 1973-74. Instructors: Brokaw and staff.

Bi 106. Developmental Biology of Animals. *9 units (2-3-4). Recommended prerequisite, Bi 9.* A lecture and discussion course dealing with various aspects of embryological development. Areas to be covered include cytoplasmic localization and cell interaction in early development, gene function and oogenesis, the role of accessory cells, gene regulation, the evolution of developmental processes and patterns of macromolecular syntheses in early embryological life. Laboratory optional. Instructor: Davidson.

Bi 110 ab. Biochemistry. *12 units (4-0-8); first, second terms. Prerequisite: Ch 41 or instructor's permission.* A lecture and discussion course on the molecular basis of biological structure and function. The first term emphasizes the chemical mechanisms by which living cells store and utilize energy and information. The second term includes selected topics in biochemistry of higher organisms, including chromosome structure, hormone action, differentiation, molecular evolution, and disease. Instructors: Wood, Hood, and staff.

Bi 111. Biochemistry Laboratory. *10 units (0-8-2); second term. Open to students enrolled in Bi 110; others require consent of instructor.* An introduction to current methods in biochemical research, through laboratory projects suggested by the lecture and seminar material of Bi 110. Instructors: Mitchell and staff.

Bi 114. Immunology. *7 units (3-0-4); first term. Prerequisite: Bi 122 or equivalent.* A course on the principles and methods of immunology and their application to various biological problems. Instructors: Owen, Hood.

Bi 115. Virology. *10 units (3-4-3); third term. Prerequisite: Bi 110 or instructor's permission.* An introduction to the chemistry and biology of bacterial, plant, and animal viruses. The subject matter will include viral structure, the biochemistry and regulation of virus replication, viral genetics, and virus-induced changes in the host cell. Instructor: Strauss.

Bi 116. Immunology Laboratory. *5 units (0-5-0); first term. Open to students enrolled in Bi 114; others require consent of instructor.* Laboratory research projects serve primarily as a means of acquiring experience with some of the methods and problems of immunology. Instructors: Owen, Hood, and staff.

Bi 119. Advanced Cell Biology. *9 units (3-0-6); third term. Prerequisites: Bi 9, Bi 110 or instructor's permission.* This course covers the principles of general microbiology and of the growth and differentiation of the cells of higher organisms. Regulatory circuits in nucleic acid and protein synthesis; mechanisms of control of enzyme activity; regulation of cell multiplication; surface properties of cells. Instructor: Attardi.

Bi 121 abc. Biosystems Analysis. *6 units (2-0-4); first, second, third terms. Same as IS 121 abc.* This course presents a systematic consideration and application of the methods of systems analysis, information theory and computer logic to problems in neurobiology. The subjects to be considered include the mechanical properties of striated muscle, the analysis of neuronal integrative mechanisms and reflex behavior in terms of logical net theory. The course will seek to describe some aspects of human cortical activity in terms of information theory and conceptual modeling. The course will be conducted as a research seminar and the detailed subject matter will change from year to year. Instructors: Fender and staff.

Bi 122. Genetics. *12 units (3-3-6); third term. Prerequisite: Bi 1 or Bi 9, or instructor's permission.* A lecture, discussion, and laboratory course covering the basic principles of genetics. Instructors: Lewis, Horowitz, and staff.

Bi 129. Biophysics. *6 units (2-0-4); second term.* The subject matter to be covered will be repeated approximately in a three-year cycle. The subject matter will be organized according to various biological functions, such as replication, contractility, sensory processes, endogenous rhythms, etc. Each function will be discussed in its various biophysical aspects. This course together with Bi 132 constitutes an integrated program covering the physical and physicochemical approaches to biology. Instructor: Delbrück.

Bi 132 ab. Biophysical Chemistry of Macromolecules. *(Same as Ch 132 ab.) 9 units (3-0-6); first, second terms. Prerequisite: Ch 21 or equivalent.* A study of the structure and properties of biological macromolecules. Emphasis is placed on both the methods of investigation and the results. The first term will cover topics in the physical chemistry of nucleic acids, and the study of biological macromolecules by ultracentrifugation methods. The second term will emphasize the properties of proteins, structural chemistry of biological molecules in general, the biophysics of membrane and cell surface phenomena, and applications of magnetic resonance spectroscopy to biological problems. Instructors: Chan, Davidson, Sinsheimer, Stroud, and Vinograd. Offered alternate years; offered in 1973-74.

Bi 133. Biophysics of Macromolecules Laboratory. *14 units (0-10-4); second, third terms.* A laboratory course designed to provide an intensive training in the techniques for the characterization of biological macromolecules. Open to selected students. Instructor: Vinograd. Offered alternate years; offered in 1973-74.

Bi 134. Advanced Research Techniques in Molecular Biology. *14 units (0-10-4); first term.* A laboratory course designed to provide research experience in utilizing important, new methods in molecular biology as they become available. Open to selected students. In charge: Dreyer and staff. Offered alternate years; offered in 1973-74.

Bi 135. Optical Methods in Biology. *6 units (2-0-4); first term. Prerequisite: Ph 1 or instructor's permission.* The course will present principles and practice of the operation of various types of light and electron microscopes including phase contrast and interference microscopes as well as transmission electron microscopes and scanning electron microscopes of various types. Specimen preparation will be discussed and the interpretation of electron micrographs analyzed. Instructor: Revel. Offered in alternate years; not offered in 1973-74.

Bi 136. Optical Methods in Biology Laboratory. *8 units (0-6-2); first term.* Laboratory accompanying Bi 135. Enrollment limited. Instructor: Revel. Offered in alternate years; not offered in 1973-74.

Bi 137. Multicellular Assemblies. *8 units (2-2-4); third term. Prerequisite: Bi 1.* The course will deal with the structural organization of tissues viewed as basic cellular assemblies common to all of the organs. Emphasis will be placed on correlation between morphology and function. Instructor: Revel.

Bi 141. Selected Topics in Evolution Theory. *9 units (3-0-6); third term. Prerequisite: Bi 110 or Bi 122.* Lectures and seminars on subjects of current interest, with emphasis on genetic and molecular processes in evolution. Topics to be treated include modern experiments on the origin of life, biological aspects of planetary exploration, the evolution of protein structure, and mathematical models of evolution. Instructors: Horowitz, Dickerson, Hood.

Bi 151. Neurophysiology. *9 units (3-0-6); first term.* A lecture course on fundamental aspects of nervous system structure and function. Lectures will include mechanisms of nervous excitation and conduction, synaptic transmission, inhibition, muscle contraction, sense organ physiology, etc. Instructors: Lester, Van Harreveld, Wiersma.

Bi 152. Behavioral Biology. *6 units (2-0-4); second term.* The behavior of organisms, including lower forms. Emphasis is placed on molecular, genetic, and developmental mechanisms. Instructor: Benzer.

Bi 153. Brain Studies of Motivated Behavior. *9 units (3-0-6); third term. Prerequisite: instructor's permission.* A lecture course concerned with the anatomical and physiological bases of drives, arousal, rewards, and learning. Emphasis is placed on the mammalian brain, particularly the midbrain, hypothalamus, and paleocortex with reference to the effects of lesions and electric stimulation upon physiological and behavioral activity. Instructor: Olds.

Bi 155. Psychobiology. *6 units (2-0-4); second term.* An introduction to the study of neural mechanisms of behavior with emphasis on development, circuitry and the problem of correlating brain processes with psychological functions. Instructor: Sperry.

Bi 156. Neurochemistry. *9 units (3-0-6); third term. Prerequisite: Bi 151 or instructor's permission.* A lecture and discussion course covering chemical aspects of synaptic transmission, impulse conduction, axonal transport, neuroendocrine control mechanisms, and control of nerve cell differentiation, growth, and systemic organization. Instructor: Russell.

Bi 161. Neurophysiology Laboratory. *6 units (0-4-2); first term. Open to students enrolled in Bi 151; others require instructor's permission.* A laboratory course in neurophysiology to accompany Bi 151. Instructors: Lester, Van Harreveld, Wiersma.

[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: Hood, Russell.

Bi 202 Biochemistry Seminar. *1 unit; all terms.* A seminar on selected topics and on recent advances in the field. In charge: Mitchell.

Bi 204. Genetics Seminar. *2 units; all terms.* Reports and discussion on special topics. In charge: Lewis, Russell.

Bi 207. Biophysics Seminar. *1 unit; all terms.* A seminar on the application of physical concepts to biological problems. Reports and discussions. In charge: Delbrück.

Bi 208. Selected Topics in Neurobiology. *Units to be arranged with the instructor; second, third terms.* Lectures and seminars on neurophysiology, neurochemistry, and animal behavior. In charge: Strumwasser, Van Harreveld, Wiersma, and invited lecturers.

Bi 209. Psychobiology Seminar. *Units to be arranged; all terms. Prerequisite: Instructor's permission.* An advanced seminar course in brain mechanisms and behavior. In charge: Sperry.

Bi 220. Advanced Seminar in the Molecular Biology of Development. *4 units (1-0-3); all terms.* Discussion of current papers on various pertinent topics including: nucleic acid renaturation and hybridization studies; transcription level regulation of gene function; evolutionary change in developmental processes; molecular aspects of differentiation in certain more intensively studied systems, etc. In charge: Davidson.

Bi 241. Advanced Topics in Molecular Biology. *6 units (2-0-4); third term. Prerequisite: Instructor's permission.* Reading and discussion of new areas in molecular biology. Instructor: Dreyer.

Bi 260. Advanced Physiology. *Units to be arranged; second, third terms.* A project laboratory using advanced techniques of physiology. Instructors: Lester, Van Harreveld, Wiersma.

Bi 270. Special Topics in Biology. *Units to be arranged; first, second, third terms.* Students may register with permission of the responsible faculty member.

Bi 280-291. Biological Research. *Units to be arranged; first, second, 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), developmental biology (283), genetics (284), immunology (285), marine zoology (286), plant physiology (287), biophysics (288), psychobiology (289), cell biology (290), physiological psychology (291).

Business Economics and Management

ADVANCED COURSES

BEM 100 abc. *9 units (3-0-6); first, second, third terms. Open to graduate students.* This course endeavors to bridge the gap between engineering and business. It is primarily intended for technically trained students who wish, sooner or later, to take advantage of opportunities in industry beyond their strict technical fields. The broad assumptions in the course are that technical training is an excellent approach to positions of general responsibility in business and industry, and that technically trained men going into industry can make significant contributions to the improved functioning of the economy. The principal divisions of the subject matter of the course are: 1) managerial accounting and information flows; 2) business finance; 3) quantitative technique and business decisions; 4) economic applications to business; and 5) systems analysis. This treatment provides a description of the industrial economy about us and of the latest management techniques. The points of most frequent difficulty are given special study. Instructor: Morrisroe.

BEM 106 abc. Business Economics (Seminar). *Units by arrangement; first, second, third terms. Prerequisite: instructor's permission.* 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. Instructor: Gray.

BEM 110. Personnel Problems of Management. *9 units (3-0-6); first, second, third terms.* This course stresses the personnel functions and responsibilities of supervisors and managers in working with professional and technical employees. The roles of unions and government, including collective bargaining and labor legislation, are covered. The relationships of a supervisor or manager with his employer, his associates, and his superiors are analyzed, and the services which he may receive from the personnel department are discussed. The processes of decision-making and communication are applied to specific supervisory responsibilities such as interviewing and selection, appraisal of performance, salary administration, benefit plans and development of individuals. Instructor: Gray.

BEM 132. The Management of an Enterprise. *9 units (3-0-6); third term.* The managerial aspects of supervision and the basic decision-making functions of management, excluding employee relations, will be covered. Specific topics include selection of plant location, plant layout, production and inventory controls, purchasing, and similar problems related to equipment and materials. The concepts of operations research and systems management are stressed. Instructor: Gray.

Chemical Engineering

UNDERGRADUATE COURSES

ChE 10. Chemical Engineering Systems. *9 units (3-3-3); third term.* Basic concepts in transport phenomena and chemical kinetics are discussed with respect to problems of current interest to society. Topics from fields such as artificial organs, air pollution, water pollution will be used to study principles of engineering and elucidate the relationships among engineering principles, chemistry, and economics and their application to the needs of society. Students participate in open-ended term projects. Instructors: Shair and staff.

ChE 63 abc. Chemical Engineering Thermodynamics. *9 units (3-0-6); first, second, third terms.* Basic thermodynamic laws and relations for one-component closed systems and for simple steady-flow systems; the treatment includes imperfect substances and frictional processes. Introduction to the thermodynamics of chemical equilibria and phase equilibria; in the third quarter, applications to the equilibrium of chemical reactions under practical conditions, and to separation processes involving equilibrium staged operations. Instructors: Pings (ab), Gavalas (c).

ChE 80. Undergraduate Research. *Units by arrangement.* Research in chemical engineering and industrial chemistry offered as an elective in any term. If ChE 80 units are to be used to fulfill elective requirements in the chemical engineering option, a thesis approved by the research director must be submitted in duplicate before May 10 of the year of graduation. The thesis must contain a statement of the problem, appropriate background material, a description of the research work, a discussion of the results, conclusions, and an abstract. The thesis need describe only the significant portion of the research. Graded pass/fail.

ChE 81. Special Topics in Chemical Engineering. *Units by arrangement.* Occasional advanced work involving reading assignments and a report on special topics. Permission of the instructor is required. No more than 12 units in ChE 81 may be used to fulfill elective requirements in the chemical engineering option. Graded pass/fail.

ADVANCED COURSES

ChE 101 ab. Applied Chemical Kinetics. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 abc or the equivalent.* A study of kinetics with application of combined kinetics and transport processes to the analysis and synthesis of chemical systems. Elementary reactions, mechanisms, and rates. Analysis and design of plug flow and stirred tank reactors. Determination of kinetic parameters by statistical techniques. Mass transfer and chemical reaction in heterogeneous systems including solid-fluid, gas-liquid and liquid-liquid systems. Diffusion and reaction in porous catalysts. Residence time distribution and mixing. Analysis and design of fixed bed catalytic reactors, including reactor stability analysis. Fluidized bed reactors. Collision and transition theory of reaction rates. Reactions in solution. Chain reactions and combustion. Instructor: Gavalas.

ChE 103 abc. Transport Phenomena. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or AM 113 ab, or concurrent registration in either.* A study of transfer of momentum, energy, and material in situations of practical interest, particularly those including chemical reaction and those involving staged and continuous unit operations. Derivation of applicable differential equations and their solution to determine distributions of velocity, pressure, temperature, and composition, and the fluxes of momentum, energy, and material in fluid systems. Brief treatment of the molecular theory of transport phenomena. Turbulent as well as laminar flow systems are considered. Instructors: Leal (a), Seinfeld (bc).

ChE 110 abc. Optimal Design of Chemical Systems. *9 units (3-0-6); first, second, third terms. Prerequisites: ChE 63 ab, ChE 103 abc or equivalent, or enrolled in ChE 103 concurrently.* Applications of the principles of chemical engineering and general engineering to the study of systems involving chemical reactions. Topics of current interest will be drawn from the chemical and petroleum industries, the environment, and biomedicine. Techniques of numerical analysis and the digital computing facility will be used to simulate and optimize. Principles of transport phenomena, chemical kinetics, chemical equilibria, and economics along with the elements of applied mechanics, machine design, strength and properties of materials will be employed. Instructor: Corcoran.

ChE 126 abc. Chemical Engineering Laboratory. *(Same as ME 126.) Units to be arranged; first, second, third terms.* Seniors taking this course are introduced to some of the basic techniques of laboratory measurements. Several short projects, illustrative of problems in transport phenomena, unit operations, chemical kinetics, and reactor control, are performed. Master's degree students are introduced to advanced experimental techniques involving energy transport and reactor kinetics and control during the first term; during the second and third terms, each student works on an individual research project under the direction of a staff member.

Experiments in energy transport may be chosen from those available in ME 126. These include solid-state and solar-energy conversion, conduction, free and forced convection, radiation, nucleate and stable film boiling, free surface and supersonic flows. Experiments in chemical systems include projects in homogeneous gas-phase kinetics using a microreactor with gas chromatography, homogeneous liquid-phase kinetics and control using a stirred-tank reactor for the study of the multiplicity of steady states. Instructors: Shair, Sabersky, Zukoski.

GRADUATE AND ADVANCED UNDERGRADUATE COURSES

ChE 157. Fundamentals of Air Pollution Engineering. *(Same as Env 157.) 9 units (3-0-6); third term. Prerequisite: Open to graduate students and seniors with instructor's permission.* The course presents the basic concepts necessary for understanding the origins, atmospheric behavior and control of air pollutants. Sources, quantities, and nature of pollutants; air pollution standards; aerosol physics; chemistry of pollutant gases; gas sampling; design of control technology; urban basin modeling and control, air environment monitoring systems. Instructors: Friedlander, Seinfeld.

ChE 162. Catalysis and Surface Chemistry. *9 units (3-0-6); third term. Prerequisite: Ch 21 abc or the equivalent.* Thermodynamics of two-dimensional systems. Physical adsorption and the BET theory. Chemical adsorption and the Langmuir isotherm. General theories of heterogeneous catalysis by metals, semiconductors and insulators. Homogeneous catalysis. Instructor: Weinberg.

ChE 164. Introduction to Statistical Thermodynamics. *9 units (3-0-6); first term. Prerequisite: Ch 21 abc or the equivalent.* Ensembles and a statistical mechanical formulation of the second and third laws of thermodynamics. Classical statistical mechanics and an introduction to quantum statistics. The ideal monatomic, diatomic and polyatomic gas-translational, rotational, vibrational and electronic partition functions. Chemical equilibria. Real gases. The ideal crystal lattices. Instructor: Weinberg.

ChE 165 ab. Applied Chemical Thermodynamics. *9 units (3-0-6); second, third terms. Prerequisite: ChE 63 abc or equivalent.* The first term consists of a rigorous development of the concepts and formalisms of thermodynamics, while in the second term these principles are applied to problems of chemical interest. They include ideal and real behavior of single and multicomponent systems and treatment of multi-phase equilibria both with and without simultaneous chemical reactions. Instructor: Vaughan.

ChE 167 abc. Polymer Science. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 or equivalent.* The first term covers polymer chemistry: the nature and classification of polymers, methods of synthesis, polymerization kinetics and molecular weight distribution, copolymerization, and cross-linking. During the second term attention is focused on the physical characterization of polymers by solution methods and by physical methods in bulk. A detailed treatment of polymer properties is the subject of the third term which includes a discussion of the principles of polymer technology. Throughout the course the emphasis is on an understanding of polymer properties in terms of polymer structure. Not offered in 1974-75.

ChE 168. Polymer Science Laboratory. *9 units (0-7-2); third term. Prerequisite: ChE 167 ab or equivalent.* An introduction to some of the basic techniques employed in the polymerization and characterization of synthetic polymeric materials. The reaction kinetics of a free-radical polymerization are studied, and the reaction product is collected for characterization. The characterization experiments include the determination of number average and viscosity average molecular weights and the glass transition temperature. Mechanical properties are studied in tensile stress relaxation. Instructors: Tschoegl and staff. Not offered in 1974-75.

ChE 172 abc. Optimal Control Theory. *(Same as Ae 172 abc and EE 172 abc.) 9 units (3-0-6); first, second, third terms.* Linear feedback control systems; frequency and time domain analysis; stability, controllability, and observability; synthesis using bode plots, Nyquist diagrams, and root loci; optimization problems for dynamic systems with terminal and path constraints (calculus of variations); optimal feedback control (dynamic programming); terminal controllers and regulators; numerical methods for synthesizing optimal paths and optimal feedback controllers. Optimal control in the presence of noise; recursive filtering, smoothing, and interpolation for linear systems with additive Gaussian noise. Singular optimization problems and differential games. Instructor: Wood.

ChE 173 ab. Advanced Transport Phenomena. *9 units (3-0-6); second, third terms. Prerequisites: ChE 103 a or equivalent, AM 113 or AMa 95, or concurrent registration in either, or instructor's permission.* Application of the principles of transport phenomena to the solution of advanced problems in heat, mass, and momentum transfer. Topics to be discussed will be chosen from: laminar flow of incompressible fluids at high and low Reynolds number, including the motion of bubbles, drops and other small particles; forced and free convection heat and mass transfer, including the effects of simultaneous chemical reaction; transport processes in suspensions, packed beds and porous media; mixing processes such as Taylor diffusion; selected topics in hydrodynamic stability theory with emphasis on buoyancy and surface tension driven instabilities; and an introduction to the motion of non-Newtonian liquids. The relation of the topics covered to practical engineering systems will be emphasized throughout the course. Instructor: Leal.

ChE 191 abc. Chemical Engineering Conference. *2 units (1-0-1); first, second, third terms.* Oral presentations on problems of current interest in chemical engineering and industrial chemistry with emphasis on the techniques of effective oral communication with groups. Graded pass/fail for undergraduates. Instructors: Seinfeld and staff.

ChE 203 ab. Interfacial Phenomena. *9 units (3-0-6); second, third terms. Prerequisite: ChE 103 abc, or instructor's permission.* Review of the theory of the Brownian motion and irreversible thermodynamics, structure of the interface, absorption and monomolecular layers, membrane transport, facilitated transport, active transport, convective diffusion, concentration boundary layers, current flow through electrolytic solutions, interfacial turbulence. Instructor: Friedlander.

ChE 206 abc. Molecular Theory of Fluids. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 21 abc, AM 113 ab, ChE 103 abc, or their substantial equivalents.* A study of the models and mathematical theories of the liquid and gaseous states, including plasmas. Some emphasis is placed on the prediction and correlation of macroscopic properties and phenomena from molecular parameters. Rigorous kinetic theory of equilibrium and transport properties of dilute gases; statistical mechanics and kinetic theory of equilibrium and nonequilibrium behavior in dense gases and liquids; study of intermolecular forces and potentials in neutral and ionized systems; treatment of plasma, with special emphasis on problems of chemical interest. Instructors: Gavalas, Pings, Shair. Not offered in 1973-74.

ChE 207 abc. Mechanical Behavior and Ultimate Properties of Polymers. *9 units (3-0-6); first, second, third terms. Prerequisite: ChE 107 or equivalent.* The course begins with an introduction to the theory of viscoelastic behavior. The discussion centers on material functions and their interconversion, model representation, time-temperature equivalence, and the molecular theories of polymer behavior. During the second term consideration is given to the mechanical behavior of various polymeric systems including amorphous, crystalline, and cross-linked polymers, copolymers, elastomers, filled and plasticized systems, blends and melts. The third term is devoted to a discussion of the phenomenology and the molecular and statistical theories of rupture in polymeric materials. Special attention is given to the controlling molecular parameters. Instructors: Tschoegl, Landel. Not offered in 1973-74.

ChE 280. Chemical Engineering Research. *Offered to Ph.D. candidates in Chemical Engineering.* The main lines of research now in progress are:

Transport in biomedical systems, including arteries and artificial kidney.

Air-pollution control and simulation, including atmospheric fluid mechanics and chemistry. Application of tracer techniques to environmental problems.

Chemistry and physics of aerosols.

Theoretical and experimental fluid mechanics. Rheology and flow of suspensions and emulsions, mechanics of non-Newtonian fluids.

Liquid-state physics including studies of structure and intermolecular forces.

Mechanical behavior and ultimate properties of polymers.

Plasma chemistry and engineering.

Kinetics and mechanism of homogeneous reaction, including pyrolysis and oxidation of hydrocarbons.

Studies of industrial catalysts by controlled poisoning.

Adsorption and catalysis on well-characterized solid surfaces.

Chemistry and physics of solids and solid surfaces.

Chemistry

UNDERGRADUATE COURSES

Ch 1 abc. General and Quantitative Chemistry. *6 units (3-0-3); first, second, third terms.* Lectures and recitation dealing with general principles of chemistry. Fundamental laws and theories of chemistry are discussed and illustrated by factual material. Text: *Chemical Principles*, Dickerson, Gray, and Haight. Instructors: Dickerson, Kuppermann.

Ch 2 abc. Advanced Placement in Chemistry. *9 units (3-0-6): first, second, third terms. Prerequisite: instructor's permission.* Ch 2 will be taught at a more advanced level than Ch 1 and will assume that the student already has a strong background in science and mathematics. Attention will be focused on a detailed consideration of properties of atoms important in describing chemical bonding and hence molecular structure and properties, and the energetic changes associated with chemical reactions. Stress is placed on understanding current research involving chemical systems with emphasis on reactions of biological significance. Instructors: Beauchamp, Richards, Stroud.

Ch 3 abc. Experimental Chemical Science. *First term, 6 units (0-6-0); second, third terms, 3 units (0-3-0) or 6 units (0-6-0). Either 3 or 6 units may be elected the second or third term or both terms.* An introductory laboratory course in basic experimental chemistry with experiments involving quantitative and qualitative analysis, synthesis, chemical dynamics and the correlation of structure with physical properties. Many modern tools and techniques, such as digital computers, radioactive tracers, infrared, visible and ultraviolet spectrometry, gas chromatography, spectrophotometry and couleometry, are applied to the solution of chemical problems. Instructors: Gordon and other staff members and assistants.

Ch 14a. Chemical Equilibrium and Analysis. *6 units (2-0-4); first term.* A systematic treatment of association equilibria, including ions and neutral ligands in solution. Illustrative examples relevant to biochemistry and to chemical analysis will be emphasized. Topics treated include acid-base equilibria, solubility, complex ions and chelation, binding of ligands by macromolecules, cooperative binding equilibria, oxidation-reduction reactions and some aspects of reaction. Instructors: Anson, Raftery.

Ch 15. Chemical Equilibrium and Analysis Laboratory. *10 units (0-6-4); first term. Prerequisites: Ch 1 abc, Ch 14 (may be taken concurrently).* A choice of laboratory experiments is offered to illustrate some of the modern instrumental techniques that are currently employed in industrial and academic research. Emphasis will center on determinations of chemical composition, measurement of equilibrium constants, and trace-metal analysis. Instructors: Anson, Beauchamp, Gordon, Raftery.

Ch 21 abc. The Physical Description of Chemical Systems. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 abc, Ph 2 abc, Ma 2 abc.* A lecture and recitation course. The main emphasis is on atomic and molecular theory, quantum mechanics, statistical mechanics, thermodynamics, and chemical kinetics. Instructors: Chan, Waser.

Ch 24 abc. Elements of Physical Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 abc, Ma 2 abc, Ph 2 abc.* A course in physical chemistry with emphasis on topics relevant to biochemistry, geochemistry, and environmental chemistry. Topics covered include: ionic and other equilibria in solution, thermodynamics, transport properties, and chemical kinetics. Atomic and molecular chemical physics are covered but with only limited emphasis on rigorous quantum mechanical derivations. The course will consist of three lectures or recitations per week and appropriate homework and study assignments. During the first term, Ch 14, a two-lecture-a-week course, and Ch 24, a three-lecture-a-week course, are combined. The third lecture and assigned study material of Ch 24 each week will deal with topics not covered in Ch 14. Not offered in 1973-74.

Ch 26 ab. Physical Chemistry Laboratory. *10 units (0-6-4); second, third terms. Prerequi-*

sites: Ch 1 abc and Ch 21 a are required; previous experience with electronic circuitry is desirable. Laboratory exercises which provide illustrations of the principles of physical chemistry, an introduction to problems of current interest, and techniques of contemporary research. Instructor: Robinson.

Ch 41 abc. Chemistry of Covalent Compounds. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 1 abc.* The study of the chemical reactions of covalent compounds and the mechanisms of these transformations. Emphasis will be on the study of the molecules formed from the first- and second-row elements and the transition metals. Instructors: Bergman, Ireland.

Ch 46 ab. Experimental Methods of Covalent Chemistry. *9 units (1-6-2); second, third terms. Prerequisite: Ch 1 abc.* Laboratory accompaniment to Ch 41 abc. Experiments stressing modern techniques for investigating the structures and dynamic behavior as well as synthesis, purification, and characterization of covalent compounds both organic and inorganic. Instructor: Dervan.

Ch 80. Chemical Research. *Offered to B.S. candidates in chemistry. Prerequisite: consent of research supervisor.* This course is intended to provide experimental and theoretical research experience in the Division of Chemistry and Chemical Engineering. No credit will be awarded for research work performed as Ch 80 without an appropriate written report prepared by the student and approved by the research supervisor. This report must contain a statement of the problem, appropriate background material, a description of the research work or a portion of the research work, a discussion of the results, conclusions, and an abstract. No more than 60 units of Ch 80 credit for undergraduate research may be accumulated as chemistry electives without special permission. Graded pass/fail.

Ch 81. Special Topics in Chemistry. *Prerequisite: instructor's permission.* Occasional advanced work involving reading assignments and a report on special topics. No more than 12 units in Ch 81 may be used as electives in the chemistry option. Graded pass/fail.

Ch 90. Oral Presentation. *2 units (1-0-1); third term.* Training in the techniques of oral presentation of chemical topics. Practice in the effective organization and delivery of reports before groups. Instructors: Beauchamp, Dickerson.

Ch 92 ab. Chemical Education. *6 units (2-0-4); second, third terms. Prerequisite: Ch 1 abc or Ch 2 abc.* Preliminary examination of some elements of both educational and psychological learning theories will be made by way of reading, discussion, and lecture. Attempts will then be made to consider application of those concepts to a specific body of subject matter where goals and practices are at least partially dictated by disciplinary tradition and a complex curriculum context. Although chemistry will be chosen as a familiar example, emphasis will be placed upon disciplinary goals. Not offered in 1973-74.

ADVANCED COURSES

Ch 112 abc. Advanced Inorganic Chemistry. *9 units (2-0-7); first, second, third terms. Prerequisite: Ch 21 abc or concurrent registration.* The course features a treatment of the structures and mechanisms of inorganic compounds with particular emphasis on transition metal complexes. The second term is devoted to structural, spectroscopic, and magnetic properties and includes some discussion of minerals, organometallic complexes, and bioinorganic problems. The third term takes up the mechanisms of inorganic reactions in detail. Instructor: Gray.

Ch 113 abc. Advanced Ligand Field Theory. *12 units (1-0-11); first, second, third terms. Prerequisite: Ch 21 abc or concurrent registration.* A tutorial course which involves problem solving in the more advanced aspects of ligand field theory. This course is recommended only for students interested in detailed theoretical work in the inorganic field. Instructors: Gray and staff.

Ch 114 a. Chemical Equilibrium and Analysis. *6 units (2-0-4); first term.* A systematic treatment of association equilibria, including ions and neutral ligands in solution. Illustrative examples relevant to biochemistry and to chemical analysis will be emphasized. Topics treated include acid-base equilibria, solubility, complex ions and chelation, binding of ligands by macromolecules, cooperative binding equilibria, oxidation-reduction reactions and some aspects of reaction kinetics in solution. Instructors: Anson, Raftery.

Ch 117. Introduction to Electrochemistry. *6 units (2-0-4); second term.* A discussion of the structure of the electrode-electrolyte interface, the mechanism by which charge is transferred across it, and of the experimental techniques used to study electrode reactions. The topics covered change from year to year but usually include diffusion currents, polarography, coulometry, irreversible electrode reactions, the electrical double layer, and the kinetics of electrode processes. Instructor: Anson. Given in alternate years.

Ch 118 ab. Experimental Electrochemistry. *Units by arrangement; second, third terms.* Laboratory practice in the use of selected electrochemical instruments and techniques. The student may pursue a set of expository experiments or elect to carry out a research project in electrochemistry. Instructor: Anson.

Ch 120 ab. The Nature of the Chemical Bond. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 a or an equivalent brief introduction to quantum mechanics.* Modern ideas of chemical bonding will be discussed with the emphasis on the qualitative concepts and how they are used to predict:

(a) Molecular geometries and the energy ordering of the excited states of molecules;
(b) Electric and magnetic properties of ground and excited states of molecules;
(c) Selection rules for chemical reactions.

Heavy use will be made of the recent advances in understanding of the chemical bond resulting from the application of *ab initio* quantum mechanical techniques. However, the main objective of the course is to enable the student to build a conceptual understanding sufficient for him to reliably apply the ideas and make predictions on his own. As such, the main emphasis will be nonmathematical and will not require an extensive understanding of the esoteria of formal quantum mechanics.

The emphasis will be upon polyatomic molecules of various types (including transition metal compounds), but discussions will also include such topics as antiferromagnetism (origin of superexchange), impurity states in solids, and the bonding and reactions at surfaces of solids. Instructor: Goddard.

Ch 122 ab. The Structure of Molecules. *6 units (2-0-4); first, second terms.* A discussion of the arrangement of atoms in molecules and crystals, of the experimental methods used to determine these arrangements, and of the various types of interatomic forces and their relationships to the chemical and physical properties of substances. Instructor: Marsh.

Ch 124 abc. Elements of Physical Chemistry. *6 units (3-0-3); first, second, third terms.* This course is the same as Ch 24 abc with reduced credit for graduate students. Not offered in 1973-74.

Ch 125 abc. The Elements of Quantum Chemistry. *9 units (3-1-5) first, second, third terms. Prerequisite: Ch 21 abc or an equivalent brief introduction to quantum mechanics.* A first course in molecular quantum mechanics consisting of a quantitative treatment of quantum mechanics with applications to systems of interest to chemists. The course includes:

1. Basic foundations of quantum mechanics and group theory, angular momentum, hydrogen atom, perturbation and variational methods, the interaction of matter with electromagnetic radiation.
2. Electronic structure and reactions of atoms and molecules, for both ground and excited states. π-Electron states of conjugated systems. Electronic structure of transition metal complexes.
3. Born-Oppenheimer approximation and nonadiabatic effects, predissociation, nonadiabatic transitions, etc. Rotational and vibrational states of diatomic and polyatomic molecules.
4. Interaction of matter with electric and magnetic fields. Nuclear magnetic resonance and electron spin resonance.
5. Basic elements of scattering theory, including potential and nonpotential scattering and resonances.
6. Basic aspects of the electronic structure of solids.

This course is designed to be a terminal course in molecular quantum mechanics for nonchemical physicists and an introductory course in quantum mechanics for chemical physicists. Instructor: Kuppermann.

Ch 127 ab. Nuclear Chemistry. *9 units (3-0-6); first, second terms. Prerequisite: instructor's permission.* An introductory course concerned with the properties of nuclei and their application to chemical problems. Topics to be discussed include: production and decay of radioactive nuclei; the interaction of radiation with matter; nuclear masses and energy; alpha and beta decay; emission of gamma-radiation; nuclear fission; nuclear reactions; chemical applications of radioactivity. Given in alternate years. Instructor: Burnett.

Ch 129 abc. The Structure of Crystals. *9 units (3-0-6); first, second, third terms.* The nature of crystals and X-rays and their interaction. The various diffraction techniques. The theory of space groups and the use of symmetry in the determination of the structures of crystals. The detailed study of representative structure investigations. The quantitative treatment of X-ray diffraction. Fourier-series methods of structure investigation. Given in alternate years. Instructor: Waser.

Ch 130. Fundamentals of Photochemistry and Photobiology. *6 units (3-0-3); third term. Prerequisite: Ch 21 ab or equivalent.* A discussion of radiative and radiationless processes associated with problems in photochemistry and photobiology. Topics in photochemistry to be discussed are: chromophores, energy levels, absorption and emission of radiation, Förster transfer and other types of intermolecular excitation transfer, electronic and vibrational relaxation, time scales for competing processes, and excitonic phenomena in aggregate systems. About half the time will be devoted to discussions of the role that these photochemical events play in photosynthesis, animal vision, phototropism, and radiation biology. Not offered in 1973-74.

Ch 132 ab. Biophysical Chemistry of Macromolecules. *(Same as Bi 132 ab.) 9 units (3-0-6); first, second terms. Prerequisite: Ch 21 or the equivalent.* A study of the structure and properties of biological macromolecules. Emphasis is placed on both the methods of investigation and the results. The first term will cover topics in the physical chemistry of nucleic acids, and the study of biological macromolecules by ultracentrifugation methods. The second term will emphasize the properties of proteins, structural chemistry of biological molecules in general, the biophysics of membrane and cell surface phenomena, and applications of magnetic resonance spectroscopy to biological problems. Offered in 1973-74. Instructors: Chan, Davidson, Sinsheimer, Stroud, Vinograd.

Ch 133. Biophysics of Macromolecules Laboratory. *(Same as Bi 133.) 14 units (0-10-4); offered in both second and third terms.* A laboratory course designed to provide an intensive training in the techniques for the characterization of biological macromolecules. Open to selected students. Instructor: Vinograd. Given in alternate years.

Ch 135 ab. Chemical Dynamics. *9 units (3-0-6); second, third terms. Prerequisites: Ch 21 abc and Ch 41 abc or equivalent.* A general introduction to the interrelation of rates, energetics and mechanisms of chemical reactions both in solution and the gas phase. Topics covered include general kinetic methods, theories of elementary reactions and their extensions to the treatment of complex processes, organic and inorganic reaction mechanisms, and enzyme kinetics. Not offered in 1973-74.

Ch 140 abc. Special Topics in Organic Chemistry. *4 units (2-0-2); first, second, third terms. Prerequisite: Ch 41 abc or equivalent.* Lectures on a series of subjects of current interest at the frontiers of organic chemistry. Not offered in 1973-74.

Ch 144 ab. Organic Chemistry. *9 units (3-0-6); second, third terms. Prerequisite: Ch 41 abc or equivalent.* Lectures and discussions of a number of basic unifying themes in organic chemistry. Problems in synthetic, theoretical and bio-organic chemistry with emphasis on stereochemistry. Text: *Basic Principles of Organic Chemistry,* Roberts and Caserio. Instructors: Bergman, Roberts.

Ch 145 bc. Organic Chemistry Laboratory. *3 units (0-3-0), second term; 6 units (0-6-0), third term. Prerequisites: Ch 46 ab, Ch 144 a, and concurrent registration in Ch 144 b.* An organic chemistry laboratory course that includes synthetic, kinetic, and spectroscopic techniques within the framework of preparative organic chemistry. Not offered in 1973-74.

Ch 180. Chemical Research. *Offered to M.S. candidates in chemistry.* Graded pass/fail.

Ch 223 a. Statistical Mechanics. *9 units (3-0-6); third term. Prerequisite: Ph 227 ab or an introductory course in statistical mechanics; or the consent of the instructor.* Ph 227 ab is a course in fundamental aspects of statistical mechanics which is particularly appropriate for the chemistry student. The present course assumes knowledge of that material and will direct itself to applications of chemical interest such as statistical thermodynamics, transport phenomena, gases at high pressure, and liquids, polymers, and crystals. Not offered in 1973-74.

Ch 224 abc. Magnetic Resonance. *(Same as APh 224 abc.) 9 units (3-0-6); first, second, third terms. Prerequisite: background in elementary statistical and quantum mechanics, and some familiarity with elementary magnetic resonance.* The principles of nuclear magnetic resonance and electron paramagnetic resonance will be discussed. The theoretical background behind the various types of magnetic resonance experiments will be developed. Methods for the analysis of spectra will be treated as well as the theory of interaction between nuclear spins, electron spins, nuclear-electronic coupling and the dynamic coupling of spins to lattice degrees of freedom. Applications of magnetic resonance to current research will be discussed with illustrations taken from problems in chemistry, physics, and biology. Instructors: Chan, Vaughan.

Ch 226 c. Advanced Topics in Quantum Chemistry. *9 units (3-0-6); third term. Prerequisite: Ch 125 abc (not concurrent).* This course consists of advanced topics in quantum chemistry but excludes subjects emphasizing dynamics (treated in Ch 227 c). Topics will generally include advanced methods for treating electronic wavefunctions of molecules including various methods of accounting for electron correlation. In addition, (1) advanced topics in group theory, (2) the coupling of rotational, vibrational, and electronic states of molecules, (3) spinors and double point groups, (4) electronic properties of molecules, and (5) many-body techniques will normally be included. Instructor: McKoy.

Ch 227 c. Applications of Many-Body Methods to Atomic and Molecular Problems. The theory of many-body systems provides powerful and direct methods for studying a large number of atomic and molecular phenomena. These methods, including Green's function techniques, will be applied to various problems including elastic and inelastic scattering of electrons by atoms and molecules and photoionization cross sections. Not offered in 1973-74.

Ch 229 abc. X-Ray Diffraction Methods. *6 units (2-0-4); first, second, third terms. Prerequisite: Ch 129 abc or equivalent.* An advanced discussion of the techniques of structure analysis by X-ray diffraction. Topics covered include protein crystallography, direct phase analysis methods, lattice vibrations, and refinement and assessment of accuracy of structure determination. Instructors: Dickerson, Hughes, Marsh. Given in alternate years. Not offered in 1973-74.

Ch 242 ab. Chemical Synthesis. *4 units (2-0-2); first, second terms. Prerequisite: Ch 41 abc.* The concepts of synthetic planning will be developed through the analysis of recorded syntheses. The methodology of the organization of a complex set of reactions so as to accomplish a chosen goal will be examined with the aid of examples of bio-organic, organic, and organometallic interest. Not offered in 1973-74.

Ch 244 ab. Molecular Biochemistry. *6 units (3-0-3); first, second terms.* During the first term, the chemistry of enzyme catalyzed reactions will be discussed with emphasis on modern methods for determination of structure, study of enzyme substrate isomerizations, and detection of conformation changes. In addition, an analysis of techniques which are used to detect intermediates in model reactions and in enzyme catalyzed reactions will be presented. This will be followed by a discussion of current theories regarding the origins of rate enhancement by enzymes. During the second term, topics covered will include coenzymes, metalloenzymes, and current theories of the molecular basis of enzyme regulation. In addition, studies relating to membrane-bound enzymes and other such proteins of known function will be covered. The course will include seminars and model building of macromolecules of known structure. Instructors: Raftery, Richards.

Ch 247 ab. Organic Reaction Mechanisms. *6 units (2-0-4); first, second terms.* Various tools for the study of organic reaction mechanisms will be discussed with major emphasis on kinetic methods. Not offered in 1973-74.

Ch 254 ab. The Chemistry of Amino Acids, Peptides, and Proteins. *9 units (3-0-6); second, third terms. Prerequisite: Ch 41 abc.* A discussion of the chemical reactions, structures, and functions of amino acids, peptides, and proteins. Instructor: Schroeder. Given in alternate years.

Ch 258. Immunochemistry. *8 units (0-5-3); second term. Prerequisites: Bi 114 and consent of instructor.* Essentially a laboratory course involving the basic methodology used in immunochemistry. Informal lectures and discussion will be scheduled as needed. The laboratory work will be based primarily on *Methods in Immunology*, by Campbell, Garvey, Cremer and Sussdorf, and related special selected publications. Not offered in 1973-74.

Ch 280. Chemical Research. *Offered to Ph.D. candidates in chemistry.* The main lines of research now in progress are:

In physical chemistry, chemical physics, and inorganic chemistry —

- Electronic structures of simple molecules and molecular fragments.
- Low-energy electron scattering.
- Spectroscopic studies of the chemistry of free radicals trapped at low temperatures.
- Kinetics of chemical reactions including photochemical reactions.
- Experimental and theoretical molecular kinetics.
- Reactions in crossed molecular beams.
- Determination of the structure of crystals by the diffraction of X-rays.
- Application of quantum mechanics to chemical problems.
- Molecular structure by spectroscopic methods.
- Nature of the metallic bond and the structure of metals and intermetallic compounds.
- Electron spin and nuclear magnetic resonance.
- Distribution of chemical compounds between immiscible phases.
- Kinetics and mechanics of electrode reactions.
- Inorganic and analytical methods.
- Bonding in and structures of transition-metal complexes.
- Gas-phase ion chemistry.
- Nuclear spin relaxation.

In organic chemistry —

- Mechanisms of organic reactions in relation to electronic theory.
- Structural elucidation and biosynthesis of natural products.
- Total synthesis of natural products.
- Chemistry and reaction mechanisms of metallocenes.
- Isotope effects in organic and biochemical reactions.
- Chemistry of small-ring carbon compounds.
- Application of isotopic tracer and nuclear magnetic resonance techniques to problems in organic chemistry.
- Chemistry of non-benzenoid aromatic compounds.
- Relation of structure to reactivity of organic compounds.
- Organic chemistry of metal chelates.
- Solution photochemistry.
- Reactions of free radicals in solutions.

In chemical biology —

- Molecular structure of proteins by X-ray crystallography.

Chemical studies of enzyme structure and function.
Applications of n.m.r. to chemical biology: enzyme-substrate interactions, polynucleotide interactions and structure, membrane structure.
Physical chemistry of nucleic acids; studies of gene structure and function.
Sequence determination of proteins.
Genetics and chemistry of the abnormal hemoglobins.
Chemical studies of specific biological receptors.
Mechanism of antigen-antibody reactions and the structure of antibodies.
Spectroscopic studies in photobiology.
Magnetic and spectroscopic studies of iron-containing proteins.
Structure of biological membranes.
Conformation properties of oligonucleotides and polynucleotides.
Mechanisms of ion transport.

Ch 290 abc. Chemical Research Conference. *First, second, third terms.* These conferences consist of reports of a general nature on investigations in progress in the chemical laboratories and on other researches which are of current interest. Seminars in the special fields (immunochemistry, analytical chemistry, crystal structure, chemical physics, organic chemistry, and inorganic chemistry) are also held. Consult Weekly Calendar for times and places.

Civil Engineering

UNDERGRADUATE COURSES

CE 10 abc. Structural Analysis and Design. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 97 abc.* Study and design of selected structures, such as reinforced concrete building, arch bridge, gravity dam, water transportation project, etc. Each project in the course is given broad consideration that covers the initial conception of the project, cost-benefit factors, and optimum design. Each project concludes with the actual design of a structure or portion of a structure. Instructor: Housner.

CE 17. Civil Engineering. *9 units (3-0-6); third term. Prerequisite: Senior standing.* Selected comprehensive problems of civil engineering systems involving a wide variety of interrelated factors. Instructors: Staff.

ADVANCED COURSES

CE 105. Introduction to Soil Mechanics. *9 units (2-3-4); first term. Prerequisite: AM 97.* A general introduction to the physical and engineering properties of soil, including origin, classification and identification methods, permeability, seepage, consolidation, settlement, slope stability, lateral pressures and bearing capacity of footings. Standard laboratory soil tests will be performed. Text: *Principles of Soil Mechanics*, Scott. Instructor: Scott.

CE 115 ab. Soil Mechanics. *9 units (3-0-6); first term. 9 units (2-3-4); second term. Prerequisite: CE 105, or equivalent, may be taken concurrently.* A detailed study of the engineering behavior of soil through the examination of its chemical, physical and mechanical properties. Classification and identification of soils, surface chemistry of clays, inter-particle reactions, and their effect on sediment deposition and soil structure. Permeability and steady-state water flow, transient flow and consolidation processes, leading to seepage and settlement analyses. In the second term, attention is given to stress-deformation behavior of soils, elastic stability, failure theories, and problems of plastic stability. Study is devoted to the mechanics of soil masses under load, including stress distributions and failure modes of footings, walls, and slopes. Laboratory tests of the shear strength of soils will be performed. Text: *Principles of Soil Mechanics*, Scott. Instructor: Scott.

CE 121. Analysis and Design of Structural Systems. *9 units (0-9-0); third term. Prerequisite: AM 112 ab.* The analysis and design of complete structural systems. In general, students will work on a single problem for the entire term. The problem may be primarily one of analysis or one of design. Instructors: Staff.

CE 124. Special Problems in Structures. *9 units (3-0-6); any term.* Selected topics in structural mechanics and advanced strength of materials to meet the needs of first-year graduate students. Instructors: Housner, Jennings.

CE 130 abc. Civil Engineering Seminar. *1 unit (1-0-0); each term.* Conferences participated in by faculty and graduate students of the civil engineering department. The discussions cover current developments and advancements within the fields of civil engineering and related sciences, with special consideration given to the progress of research being conducted at the Institute. Graded pass/fail.

CE 150. Foundation Engineering. *9 units (3-0-6); third term. Prerequisite: CE 115 ab.* Methods of subsoil exploration. Study of types and methods of design and construction of foundations for structures, including spread and combined footings, mats, piles, caissons, retaining walls, cofferdams, and methods of underpinning. Instructor: Scott.

CE 180. Experimental Methods in Earthquake Engineering. *9 units (1-5-3); first term. Prerequisite: AM 151 abc or equivalent.* Laboratory work involving design, calibration, and performance of basic transducer and recorder types suitable for the measurement of strong earthquake ground motion, and of structural response to such motion, including a consideration of data-processing techniques. Study of principal methods of dynamic tests of structures including generation of test forces and measurement of structural response. Instructors: Hudson, Iwan.

CE 181. Principles of Earthquake Engineering. *9 units (3-0-6); second term.* Characteristics of potentially destructive earthquakes from the engineering point of view. Includes a consideration of: determination of location and size of earthquakes; earthquake magnitude and intensity; frequency of occurrence of earthquakes; seismic risk maps, and techniques of seismic regionalization; engineering implications of geological earthquake phenomena, including earthquake mechanisms, faulting, fault slippage and the effects of local geology on earthquake ground motion; characteristics of ground motions; seismic sea waves and their damaging effects; socio-economic aspects of earthquakes such as cost factors in earthquake-resistant design, disaster planning; and the implications of earthquake prediction. Instructors: Hudson, Housner.

CE 182. Structural Dynamics of Earthquake Engineering. *9 units (3-0-6); third term. Prerequisite: AM 151 ab.* Response of structures to earthquake ground motion; influence of physical parameters on the response; spectrum techniques; influence of plastic deformations; earthquake excitation as a random process; nature of building code requirements and their relation to actual behavior of structures; observed effects of earthquakes on structures; earthquake behavior of special structures such as nuclear reactor containment structures, long-span suspension bridges, and fluids in tanks and reservoirs; earthquake design criteria. Instructors: Housner, Jennings.

CE 200. Advanced Work in Civil Engineering. *6 or more units as arranged; any term.* Members of the staff will arrange special courses on advanced topics in civil engineering for properly qualified graduate students. The following numbers may be used to indicate a particular area of study.

CE 201. Advanced Work in Structural Engineering.

CE 202. Advanced Work in Soil Mechanics.

CE 212 abc. Advanced Structural Mechanics. *9 units (3-0-6); each term. Prerequisite: AM 112 abc or equivalent.* Advanced methods of structural analysis applied to problems involving space frames, plates, shells and finite-element models of continuous structures. Instructors: Staff.

CE 300. Civil Engineering Research.

For courses in Environmental Engineering Science and Hydraulics see separate sections.

Computers and Machine Methods of Computation

(See courses listed under Information/Computer Science)

Economics

UNDERGRADUATE COURSES

Ec 11. Introduction to Microeconomics. *(Same as SS 11 a.) 9 units (3-0-6); first, third terms.* An introduction to the methodology of social science and the applications of that methodology to current social problems. This course emphasizes the role of wages, prices, and profits in a free enterprise economy and develops a theory of individual and firm decision making that can be used to analyze the behavior of business and public institutions. Subjects covered may also include financial markets, international trade, development, and alternative economic systems. Instructors: Staff.

Ec 12. Introduction to Macroeconomics: Principles and Problems. *9 units (3-0-6); second term.* Problems of inflation and depression and the tools of monetary and fiscal policy. The course stresses the analysis of money and expenditure in the income determination process as well as covering national income, economic growth and business fluctuations and international economic relations. Instructors: Staff.

Ec 13. Reading in Economics. *Units to be determined for the individual by the department. Not available for credit toward humanities-social science requirement.* Graded pass/fail.

Ec 98 abc. Senior Research and Thesis. *Prerequisite: instructor's permission.* Senior economics majors wishing to undertake a research project and to prepare a paper for presentation to interested faculty and fellow students may elect a variable number of units, not to exceed 12 in any one term, for such work under the direction of some member of the economics faculty.

HSS 99. See page 351 for description.

ADVANCED COURSES

Ec 101. Selected Topics in Economics. *9 units (3-0-6).* Instructors: Staff and visiting lecturers.

Ec 112. History of Economic Analysis. *9 units (3-0-6); first term.* An examination of the traditions, schools of thought, and controversies which have helped shape modern economic analysis. Substantial reading in Adam Smith, Ricardo, Mill, Jevons, Marshall, Keynes and other major figures will be assigned. The manner in which precise theoretical reasoning has developed will be analyzed, as will the manner in which economic analysis has been influenced by events and policy concerns. Special attention will be paid to the manner in which one method of analysis supplants another. Instructor: Montgomery.

Ec 113. Reading in Economics. *Same as Ec 13 but for graduate credit.* Graded pass/fail.

Ec 115. Population and Environment. *9 units (3-0-6); third term.* This course will be concerned with (1) the causes of rapid population growth, both in the West in the 18th and 19th centuries and in the less developed countries today; (2) the relation between population growth and economic development; (3) environmental consequences of population growth and distribution; (4) the problem of reducing the rate of growth through control of fertility. Instructors: Sweezy with Holdren.

Ec 116. Contemporary Socioeconomic Problems. *9 units (3-0-6); first term. Prerequisite: Ec 11 and Ec 12.* An analytical investigation of the economic aspects of certain current social issues. Topics to be discussed include the economics of education, medical care systems, urban affairs and the welfare system. Part of the instructional content of the course will be provided by field investigations and outside visitors. Instructors: Staff.

Ec 117. Problems of Urban Society. *9 units (3-0-6); third term.* A description of some of the significant urban problems of contemporary America and an investigation of alternative policies. The problems considered include race relations, poverty, public education, crime, housing, urban planning, the public administration of cities and local politics and finance. Stress is placed on field trips and individual student research on specific problems in the Pasadena area. This course emphasizes economic theory less than does Ec 116. Instructor: Oliver.

Ec 118. Environmental Economics. *(Same as Env 118.) 9 units (3-0-6); third term.* The methods of price and welfare theory are used to analyze the causes of air, water and other environmental pollution, to examine their impact on economic welfare, and to evaluate selected policy alternatives for managing our environment. Topics include (1) theory of externalities; (2) economic analysis of current and proposed regulatory policies to restrict pollution; (3) the application of economic planning tools such as capital budgeting, linear programming, cost-benefit analysis to specific environmental management problems (such as water supply, solid-waste disposal, smog control devices, health effects of air pollution, etc.); and (4) comprehensive environmental planning for coordinated use of environmental resources and for rational allocation of funds for environment improvement. Instructor: Montgomery.

Ec 119. Seminar in Applied Economics. *9 units (3-0-6); third term.* Applications of economic analysis to a variety of problems of contemporary interest. While the content will vary, some examples of the types of topics to be covered are: health care, urban housing, markets and transportation systems, education, discrimination, crime and poverty. Instructors: Staff. May be repeated for credit.

Ec 120. International Economic Theory. *9 units (3-0-6); first term. Prerequisite: Ec 11 and Ec 12.* An investigation of the factors affecting the exchange of goods and services and the flow of capital between markets. Major issues include the determination of international values, the gains from trade and their division among major trading areas, the theory of economic integration, and the problems of foreign-exchange-rate and balance-of-payments adjustments. Theory is stressed in this course. Instructor: Oliver.

Ec 121 ab. Price Theory and Industrial Organization. *9 units (3-0-6); first, second terms. Prerequisite: Ec 11 and Ec 12 or equivalent.* A theoretical analysis of the price system, with special reference to the nature and problems of the U.S. economy. The course includes a study of consumer preference, the structure and conduct of markets, factor pricing, measures of economic efficiency, and the interdependence of markets in reaching a general equilibrium. The second term deals with questions of industrial organization such as economics of scale, elasticity of demand, and conditions of entry in a highly quantitative way. Instructor: Quirk.

Ec 122 ab. Econometrics. *9 units (3-0-6); second, third terms. Prerequisite: Ma 112 a.* The application of statistical techniques to the analysis of economic data. The first part of this course deals with the statistical theory and methods most useful to economists and to other social scientists. The second part is a survey of important empirical studies in the estimation of functional relationships derived from economic theory, such as supply and demand functions, the behavioral relationships determining investment and personal consumption expenditures, and relationships useful for forecasting future levels of economic activity. Instructor: Grether.

Ec 125 ab. The Economics of International Relations. *9 units (3-0-6); first, second terms. No prerequisite.* An examination of the economic factors which influence relations among nations. Among the topics discussed are international banking and business, the pattern of international trade, payments and investments, economic warfare, the international gold standard, the International Monetary Fund, the World Bank, the European Common Market, the General Agreement on Tariffs and Trade, the Organization for Economic Cooperation and Development, the dollar crisis and the American Foreign Aid program. The foreign economic policy of the United States is analyzed in some detail. This course emphasizes economic theory less than does Ec 120. Instructor: Oliver.

Ec 126 ab. Money, Income, and Growth. *9 units (3-0-6); first, second terms. Prerequisite: Ec 11 and Ec 12 or instructor's permission.* This course starts with an intensive study of Keynes' *General Theory of Employment* and then goes on to post-Keynesian developments in the theory of income, consumption, investment and growth. The course also covers the theory of wages and productivity and the relation of technical progress to increases in productivity and real income. It deals with economic policy as well as economic theory, especially the application of monetary, fiscal, and other policies to problems of inflation, depression, unemployment, automation, and growth. Instructor: Sweezy.

Ec 127 abc. Problems in Economic Theory (Seminar). *Units by arrangement; first, second.*

third terms. Prerequisite: Ec 126 or its equivalent. Consideration of selected topics in economic theory. Instructors: Staff and guest lecturers.

Ec 128 abc. New Technology and Economic Change. *9 units (3-0-6); first, second, third terms.* At the macroeconomic level this course will be concerned with changes in productivity, changes in foreign trade, and the impact of environmental issues upon energy questions. At the microeconomic level it will be concerned with entrepreneurial behavior. A theory will be developed to relate macro and micro behavior. Instructor: Klein.

Ec 129 ab. Economic History of the United States. *9 units (3-0-6); second, third terms.* An examination of certain analytical and quantitative tools available to the economic historian and their application to a study of the process of American economic development. Instructor: Davis.

Ec 130 ab. Political Foundations of Economic Policy. *9 units (3-0-6); first, second terms. Ec 130 a is a prerequisite for Ec 130 b.* Mathematical theories of individual and social choice are introduced as an approach to the classic problems of welfare economics and economic policy. The design and construction at an abstract level of political-economic processes consistent with stipulated ethical postulates will be studied together with the related impossibility theorems. Instructor: Plott.

Ec 131. Mathematical Models of Political-Economic Decision Processes. *9 units (3-0-6); third term.* Selected models will be reviewed with special emphasis on behavioral interpretations. Special attention will be given to simple majority rule and spatial models of electoral processes. Instructor: Plott.

Ec 135. Marxist Economics. *9 units (3-0-6); second term.* A critical survey of the economic theory of capitalism as developed in the writings of Marx, Engels and Lenin, with emphasis upon Marx's theory of labor value, the theory of crises, and the theory of imperialism. Extensive reading of Marx, his modern supporters, e.g., Sweezy, Dobb, and Lange, and his critics is required. The Marxist theory is analyzed in terms of its place in the history of economic thought, and is contrasted with the more recent analytical approach to the study of a capitalistic price system. Instructors: Montgomery, Quirk.

Ec 150. Independent Study on Population Problems. *Units to be arranged. Prerequisite: Ec 115 or its equivalent.* This course is designed to encourage study on a broad range of problems covering the technological, economic, demographic, sociological, political, and biological aspects of population growth, movement, and density. Instructors: Sweezy, H. Brown, Bonner, Scudder, Munger. Graded pass/fail.

Electrical Engineering

UNDERGRADUATE COURSES

EE 4. Introduction to Digital Electronics. *6 units (2-0-4); second term.* An introduction to the significant concepts and techniques of modern digital integrated electronic circuitry. The formulation of logical equations and their realization in hardware. Binary arithmetic and its implementation with logical functions. The course concludes with the design and construction of a simple digital computer. Graded pass/fail. Instructor: Mead.

EE 5. Introduction to Linear Electronics. *6 units (2-0-4); third term.* An introduction to the significant concepts of modern linear electronic circuitry. A.C. circuit analysis; networks and their characterization in frequency and time domain. Amplifier, gain, frequency response. The use of operational amplifier to synthesize function of input variables. Power, dynamic range and the design of power output amplifiers. The course concludes with the design and construction of a typical Hi-Fi amplifier. Graded pass/fail. Instructor: Wilts.

EE 10. Digital Electronics Laboratory. *6 units (0-3-3); third term. Prerequisite: EE 4 and approval of project proposal. 6 units credit allowed toward freshman laboratory requirement.* An introductory nonstructured project laboratory designed to provide an opportunity for projects related to the course EE 4. The student is expected to design, build, and test his own digital system. Graded pass/fail. Instructor: Mead.

EE 13 abc. Linear System Theory. *9 units (3-0-6); three terms. Prerequisites: Ma 1 abc and Ph 1 abc.* Introduction to the analysis of linear systems in both the time and frequency domain. Topics presented include loop and node equations, two terminal pair networks, Fourier and Laplace transforms, convolution, autocorrelation, feedback systems, flow graphs, noise, and distributed linear systems. An introductory treatment of synthesis and filter theory is presented. The last term treats AM, FM, sampling theory and information theory. Computer solution of problems is presented as needed. Instructors: Staff.

EE 14 abc. Electronic Circuits. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* A course covering the general area of active devices and their circuit applications. Transistor and vacuum tube amplifiers, biasing, gain, frequency response, class A, B and C power output circuits and their limitations. Nonlinear electronics, diodes, rectifiers, mixers, switching circuits, saturation, power converters, etc. Text: *Electronics: BJTs, FETs, and Microcircuits,* Angelo. Instructor: Martel.

EE 90 abc. Laboratory in Electronics. *Units by arrangement in multiples of 3 units (0-0-3); each term.* An introductory laboratory normally taken in the sophomore and/or junior year. Experiments are available that are designed to acquaint the student with the characteristics of linear and passive electronic circuits and devices as well as the behavior of simple linear and nonlinear active elements. Individual projects may be performed, depending upon the student's interests and abilities, involving the investigation of particular circuits and circuit elements or involving electronic measurement techniques. *No more than 6 units may be used in satisfying the laboratory requirement of the Division of Engineering and Applied Science.* Text: *Electronics: BJT's, FET's, and Microcircuits,* Angelo; or *Basic Electronics for Scientists,* Brophy. Graded pass/fail. Instructor: Ingle.

EE 91 abc. Experimental Projects in Electronic Circuits. *Units by arrangement; 6 units minimum each term. Prerequisites: EE 14 abc and EE 90 or equivalent. Recommended: EE 114 abc or IS 110 (may be taken concurrently).* Open to seniors; others only with consent of instructor. A general laboratory program designed to give the student an opportunity to do original projects in electronics and electronic circuits. Emphasis is placed upon the selection of significant projects, the formulations of the engineering approach, and the demonstration of a finished product as well as the use of modern electronic techniques. The use of integrated circuit elements, digital and analogue, is encouraged. Printed circuit board facilities are available. Text: Literature references. Instructor: Humphrey.

ADVANCED COURSES*

EE 112 abc. Network Synthesis. *9 units (2-0-7); first, second, third terms. Prerequisite: AM 95 abc.* Passive network analysis and synthesis, feedback amplifiers, closed loop transfer functions, active filters. Sample data systems, digital/linear delay functions, digital filters, and digital signal processing. Second and third terms seminar format, requires extensive student participation. Instructors: Martel, Mead, Wilts.

EE 113 abc. Modern Optics. *(Same as APh 153 abc.) 9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc.* The analysis of optical systems based on electromagnetic theory. Mode theory and functions for optical resonators and transmission structures, image formation and spatial filtering with coherent light, partial coherence and partial polarization, theory of dielectrics, theory and applications of holography and selected topics of research importance. Text: Class notes and selected references. Instructor: George.

EE 114 abc. Electronic Circuit Design. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 14 abc or equivalent.* Applications of solid-state electronic devices in circuits and systems. Emphasis on methods of engineering analysis and design. Instructor: Middlebrook.

EE 116. Topics in Modern Electronics. *6 units (2-0-4). Prerequisites: Ma 2 abc and Ph 2 abc.* Selected topics in various fields of electronics will be covered utilizing guest lecturers from industry. The specific topics and scope will be announced prior to registration. A seminar format will be utilized for this course. Graded pass/fail. Offered as announced. Instructors: Staff.

EE 118 abc. Electronic Circuits and their Application to Physical Research. *(Same as Ph 118 abc.) 9 units (3-3-3); first, second, third terms.* A course on the fundamentals of analog and digital electronics with emphasis on proven techniques of instrumentation for scientific research. The first two terms will deal with the physical principles and properties of electronic components and circuits and the last will discuss the logical design of digital systems. Topics considered in the first two terms will include the theory of transient signal response in linear networks, the properties of solid state devices, basic passive and active circuit combinations, linear amplifiers, feedback theory, and the properties of currently available integrated circuits. The third term topics will include techniques of systematic logic design, Boolean algebra reductions using Karnaugh maps, the design of both synchronous and asynchronous sequential circuits, and existing computer aids for digital design. Common electronic instruments, computer interfaces, and typical digital control logic in scientific research will be used as illustrative examples. The homework will consist mostly of laboratory problems. Instructors: Gomez, Peck, Tollestrup.

EE 151 abc. Electromagnetism. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc; AMa 95 abc.* A course in theoretical electricity and magnetism, primarily for electrical engineering students. Topics covered include electrostatics, magnetostatics, Maxwell's equations, waveguides, cavity resonators, and antennas. EE 151 c will include topics on propagation in the ionosphere, propagation over the earth's surface, and modern microwave tubes. Instructor: Langmuir.

EE 155 abc. Electromagnetic Fields. *(Same as APh 175 abc.) 9 units (3-0-6); first, second, third terms. Prerequisite: EE 151 abc or Ph 106 bc.* An advanced course in classical electromagnetic theory and its application to guided waves, cavity resonators, anten-

*See also Ge 152.

nas, artificial dielectrics, propagation in ionized media, propagation in anisotropic media, magnetohydrodynamics, and to other selected topics of research importance. Text: Course notes. Not offered 1973-74. Instructor: Papas.

EE 160 abc. Topics in Communications. *6 units (2-0-4); first, second, third terms. Prerequisite: Ma 2 abc.* Selected subjects pertaining to communications systems. Topics covered will include examples from signal spectra, noise, sampling, information rate, antennas, modulation systems, etc. The approach will be presentation and discussion of relevant mathematical and engineering concepts and discussion of their applications. Instructor: Pierce.

EE 161 abc. Mathematical Theory of Information, Communication and Coding. *9 units (3-0-6); three terms. Prerequisite: Ma 5 abc or instructor's permission.* The Shannon theory of information is presented for discrete channels. Source coding, synchronization coding, and elementary cryptography are discussed, as well as linear (group) codes, algebraic codes, cyclic codes, and other error detecting and correcting codes. The underlying algebra of finite fields is developed, typical devices for encoding and decoding are described, and applications to actual communication systems are presented. Instructor: McEliece.

EE 172 abc. Optimal Control Theory. *(Same as Ae 172 abc and ChE 172 abc.) 9 units (3-0-6); first, second, third terms.* Linear feedback control systems; frequency and time domain analysis; stability, controllability, and observability; synthesis using bode plots, Nyquist diagrams, and root loci; optimization problems for dynamic systems with terminal and path constraints (calculus of variations); optimal feedback control (dynamic programming); terminal controllers and regulators; numerical methods for synthesizing optimal paths and optimal feedback controllers. Optimal control in the presence of noise; recursive filtering, smoothing, and interpolation for linear systems with additive Gaussian noise. Singular optimization problems and differential games. Instructor: Wood.

EE 191. Advanced Work in Electrical Engineering. *Units to be arranged.* Special problems relating to electrical engineering will be arranged to meet the needs of students wishing to do advanced work. Primarily for undergraduates. Students should consult with their advisers before registering for this course. Graded pass/fail.

EE 194. Microwave Laboratory. *9 units (1-4-4); third term. Prerequisite: EE 151 abc or Ph 106 abc, may be taken concurrently.* Selected laboratory experiments and related theory on microwave generation and amplification; measurements of impedance, frequency and power; properties of microwave cavities, waveguides, junctions, and irises. Open to undergraduates. Instructors: Staff.

EE 197. Modern Optics Laboratory. *(Same as APh 154.) 9 units (1-4-4); second term. Prerequisite: APh 153 or APh 190 (either may be taken concurrently).* Primarily for graduate students. Laboratory experiments to acquaint students with the contemporary, yet basic, aspects of modern optical research and technology. Experiments encompass holography and interferometry, single mode and mode locked lasers, nonlinear optics, acousto-optic interactions, coherence, diffraction, optical data processing, photosensitive materials, liquid crystals, and ferroelectric ceramics. Instructor: George.

EE 221 abc. Topics in Physical Electronics. *4 units (1-0-3); first, second, third terms.* Principles of electromagnetic interaction with solids and ionized gases and current applications. Content to vary from year to year. Typical topics are: microwave noise in electron beams, magnetic resonance and relaxation, cyclotron resonance, oscillations and waves in plasmas. Instructor: Gould

EE 243 abc. Quantum Electronics Seminar. *6 units (3-0-3); first, second, third terms.* Advanced treatment of topics in the field of quantum electronics. Each weekly seminar consists of one lecture of a series on the elements of radiation theory, partial coherence, dispersion, nonlinear optics, laser media, and spectroscopy, followed by a discussion of a current research paper. Text: Class notes and selected references. Instructor: Yariv.

EE 255 abc. Boundary-Value Problems of Electromagnetic Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 155 abc or equivalent.* This course presents the mathematical techniques (Fourier-Lamé method, integral equation method, variational principles) that are available for the solution of boundary-value problems arising from the study of antennas, waveguides, and wave propagation. Text: *Randwertprobleme Der Mikrowellenphysik,* Borgnis and Papas; also class notes. Instructor: Papas.

EE 281 abc. Semiconductor Devices. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 181 ab, its equivalent, or instructor's permission.* An advanced graduate course is the physics, design, production, and use of large-scale integrated circuits. Emphasis is placed on the engineering approach. Instructor: Mead.

EE 291. Advanced Work in Electrical Engineering. *Units to be arranged.* Special problems relating to electrical engineering will be arranged to meet the needs of students wishing to do advanced work. Primarily for graduate students. Students should consult with their advisers before registering for this course.

Engineering

E 5. Laboratory Research Methods in Engineering and Applied Science. *6 units (1-3-2); third term. 6 units credit allowed toward freshman laboratory requirement.* An introduction to experimental methods and problems typical of a variety of engineering fields. Staff members representing various areas of interest within engineering and applied science will supervise experiments related to their specialty. The experiments will be selected from such fields as fluid mechanics, elasticity and plasticity, dynamics and vibration, heat transfer, gasdynamics, combustion, materials science, environmental health, solid-state electronics, biomedical engineering, information science, chemical engineering, etc. The student is given some choice in selecting experiments of particular interest to him. Instructors: Sturtevant and staff.

E 10 ab. Technical Presentations. *2 units (1-0-1); first, second terms.* A course concerned with oral presentations of technical material. Instructors: Clark and staff.

E 150 abc. Engineering Seminar. *1 unit (1-0-0); each term.* All candidates for the M.S. degree in Applied Mechanics, Electrical Engineering, Materials Science, and Mechanical Engineering are required to attend any graduate seminar in any division each week of each term. Graded pass/fail. Instructor: Clark.

Engineering Graphics

Gr 1. Basic Graphics. *3 units (1-2-0); first term.* This course deals with the fundamental aspects of projective geometry and graphical techniques used by the scientist and engineer as an aid in spatial visualization, communication and in creative design. Emphasis is placed on the effective use of freehand sketching in perspective, orthographic projection and other useful forms of representation. The student's ability to visualize three-dimensional forms and spatial relationships is logically developed through a series of freehand problems followed by basic descriptive geometry solutions analyzing some of the general relationships which exist among points, lines, and planes. Accuracy, neatness, and clarity of presentation are encouraged throughout the course. Instructor: Welch.

Gr 7. Advanced Graphics. *Maximum of 6 units; second and third terms. Prerequisite: Gr 1.* Further study in the field of graphics as applied to engineering problem analysis and in design. Instructor: Welch.

Engineering Science

ADVANCED COURSES

ES 131 abc. Thermodynamics and Statistical Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or equivalent.* Thermodynamics; kinetic theory; classical statistical mechanics; quantum statistical mechanics; diffusion theory and transport theory. Instructors: Plesset, Wu.

ES 200. Special Problems in Engineering Science. *By arrangement with members of the staff, properly qualified graduate students are directed in independent studies in Engineering Science.* For those interested in bioengineering see also Env 206. *Hours and units by arrangement.* Instructors: Plesset, Wu.

ES 250 abc. Research in Engineering Science. *By arrangement with members of the staff properly qualified graduate students are directed in research in Engineering Science. Hours and units by arrangement.*

Environmental Engineering Science

UNDERGRADUATE COURSES

Env 1. Engineering Problems of Man's Environment. *9 units (3-0-6); third term. Prerequisites: Ph 1 ab, Ch 1 ab, and Ma 1 ab.* This course explores ways in which man is adversely changing his environment, ways in which these alterations are affecting him and other forms of life, and methods of engineering control. Typical problem areas are: air pollution, water pollution, solid and industrial wastes, harmful substances, impact of energy utilization, and land erosion. Instructors: Morgan, Friedlander, Scudder, McKee, List, Brooks.

Env 90. Undergraduate Research in Environmental Engineering Science. *Units by arrangement; any term. Approval of research supervisor required prior to registration.* Independent reseach on current environmental problems; laboratory or field work is encouraged. A written report is required for each term of registration. Seniors may elect to prepare a thesis with approval of the Environmental Engineering Science faculty at the beginning of the senior year; in this case, registration should be for at least three consecutive terms. Graded pass/fail. Instructors: Staff.

ADVANCED COURSES

Env 100. Special Topics in Environmental Engineering Science. *6 or more units as arranged. Prerequisite: instructor's permission.* Special courses of reading, problems, or research for graduate students working for the M.S. degree or qualified undergraduates. Graded pass/fail. Instructors: Staff.

Env 103 ab. Introduction to Processes of the Atmosphere and Hydrosphere. *(Same as Ge 103 ab.) 9 units (3-0-6); first and second terms.* Natural physical and chemical processes of the earth's atmosphere and hydrosphere. Emphasis will be on developing an order of magnitude understanding of the atmosphere and oceans through analysis of observations and physical reasoning. Topics covered will include the global heat balance, polar ice caps and climatic change, temperature distributions; tides, waves and currents; cloud formation; precipitation, runoff, floods, sediment transport and deposition; geochemical cycles. Instructors-in-charge: List (first term), Ingersoll (second term).

Env 112 abc. Hydrologic Transport Processes. *9 units (3-1-5), first term; 9 units (3-0-6), second, third terms. Prerequisites: AMa 95 abc or AM 113 abc (may be taken concurrently); ME 19 abc; and some knowledge of elements of hydrology (may be satisfied by special reading assignments).* A basic study of the physical processes in fresh-water bodies and the coastal waters. The hydrologic cycle and its relation to man; statistical analysis and simulation of hydrologic data; dynamic similitude in fluid mechanics; turbulent shear flow in rivers and estuaries; introduction to stratified flow, turbulent plumes and buoyant jets; experimental techniques; hydraulic models. Flow through porous media, wells, ground-water recharge, and seawater intrusion in aquifers. Transport and dispersion of solutes, sediments and heat in rivers, lakes, ground water and estuaries; heat transfer, evaporation and density stratification in natural waters. Engineering of outfalls for safe disposal of wastewater and thermal discharges. Introduction to river morphology and sediment transport. Instructor: Brooks.

Env 116. Experimental Methods in Air Pollution. *7 units (1-3-3); third term. Open to graduate students and seniors with instructor's permission.* This course covers the methods of sampling and measurement of particulate and gaseous pollutants with applications to gas cleaning equipment and smog formation. Experiments will include the use of online systems for measuring complete aerosol size spectra, and simultaneous gas-phase chemical composition and aerosol measurements in photochemical smog. The application of data acquisition and processing systems in air pollution will be treated in detail. Emphasis will be placed on understanding the physical and chemical principles on which the measurements are based. Instructors: Friedlander, staff.

Env 117. Fundamentals of Air Pollution Engineering. *(Same as ChE 157.) 9 units (3-0-6); third term. Open to graduate students and seniors with permission of instructor.* Basic concepts necessary to understanding the origins, atmospheric behavior, and control of air pollutants. Sources, quantities, and nature of pollutants; aerosol physics, chemistry of pollutant gases; gas sampling; design of control technology; absorbers, filters, inertial separators, electrical precipitators; urban basin modeling and control, air environment monitoring systems. Instructors: Friedlander, Seinfeld.

Env 118. Environmental Economics. *(Same as Ec 118.) 9 units (3-0-6); third term.* The methods of price and welfare theory are used to analyze the causes of air, water and other environmental pollution, to examine their impact on economic welfare, and to evaluate selected policy alternatives for managing our environment. Topics include: (1) theory of externalities; (2) economic analysis of current and proposed regulatory policies to restrict pollution; (3) the application of economic planning tools to specific environmental management problems (such as water supply, solid waste disposal, smog control devices, health effects of air pollution, etc.); and (4) comprehensive environmental planning for coordinated use of environmental resources and for rational allocation of funds for environmental improvement. Instructor: Montgomery.

Env 142 ab. Chemistry of Natural Water Systems. *9 units (2-3-4); first, second terms. Prerequisites: Ch 1 abc or equivalent; Ch 14 (may be taken concurrently).* The chemistry of solutions, heterogeneous processes, and oxidation-reduction reactions is applied to provide a quantitative treatment of the chemical characteristics of natural waters. The first term features acid-base systems of natural waters, carbonate equilibria, metal-ion solubility controls, metal-ion complexes in natural systems, and redox equilibria. The second term deals with chemical characteristics of lakes, streams; surface-chemical phenomena (adsorption, coagulation) in natural waters, and models (equilibrium, steady-state, dynamic) for describing the behavior of natural water systems. Laboratory sessions consider experimental techniques for measuring natural water constituents and computational methods for describing complex systems. Text: *Aquatic Chemistry*, Stumm and Morgan. Instructors: Morgan, O'Melia.

Env 144. Ecology. *6 units (2-1-3); second term.* Basic principles of ecology and ways in which human activities can influence natural populations, including the marine environment as affected by ocean waste disposal. Topics discussed include community structure, dynamics of populations, geochemical cycles, limiting factors, and microbial ecology. (May be taught in conjunction with parts of Env 145 a.) Instructor: North.

Env 145 ab. Environmental Biology. *10 units (2-4-4), second term; 9 units (3-0-6), third term. Prerequisites: Ch 41 abc or equivalent (may be taken concurrently).* An exposition of basic biological principles concerning interrelations between organisms, particularly those directly affecting man and his environment. Emphasis is placed on the influences of microorganisms as illustrative of the ways populations react on each other and condition the physical and chemical environment. Unique features of the terrestrial, freshwater, and marine environments are discussed and extensive reading is required, covering a broad scope of biological literature. Instructor: North.

Env 146 abc. Analysis and Design of Water and Wastewater Systems. *9 units (3-0-6); each term. Prerequisites: ME 17 abc, ME 19 abc, or equivalents.* A series of selected problems in the application of basic science and engineering science to water supply and treatment for municipal, industrial, and irrigation use; removal, treatment, and disposal of liquid wastes; the theory of unit operations as applied to environmental systems; the designs of works; water rights; and economic aspects of projects. Instructor: McKee.

Env 150 abc. Seminar in Environmental Engineering Science. *1 unit (1-0-0); each term.* Weekly seminar on current developments and research within the field of environmental engineering science, with special consideration to work at the Institute. Graded pass/fail.

Env 155. Special Problems in Waste Management. *9 units (2-3-4); second term. Prerequisite: instructor's permission.* Investigation of environmental pollution related to nuclear energy; the siting of steam-electric power plants; solid wastes from municipalities, industries, and agriculture; transportation and storage of hazardous materials, and similar special situations, including detailed case studies of specific problems. Field trips to illustrative examples in southern California. Instructor: McKee.

Env 156. Industrial Wastes. *9 units (3-0-6); third term. Prerequisite: Env 146 ab.* A study of the industrial processes resulting in the production of liquid wastes; the characteristics of such wastes and their effects upon municipal sewage treatment plants, receiving streams, and ground waters; and the theory and methods of treating, eliminating, or reducing the wastes. Offered only in even-numbered years. Instructor: McKee.

Env 160. Biological Fluid Flows: Hemorheology. *6 units (2-0-4). Prerequisites: AMa 95 abc, Hy 101 abc or equivalent.* The problems of measurement of bulk rheological properties of blood; the influence of the composition of the suspending medium on blood flow properties; the influence of the particulate nature of blood on its flow in narrow tubes and small blood vessels; the influence of cell deformation on flow through capillaries. Not offered in 1973-74. See Env 206. Instructor: Wayland.

Env 170 ab. Behavior of Disperse Systems in Fluids. *9 units (3-0-6); first, second terms. Prerequisites: ME 19 ab or Ch 21 abc, or equivalents.* Studies of the mechanical and physicochemical behavior of particles in fluids with applications to gas cleaning, cloud physics, emulsion stability and water treatment. The first term is concerned primarily with stochastic problems including fluctuation theories of new phase formation, the Brownian movement, and coagulation and convective diffusion. The second term deals with mechanical problems including impaction and filtration, and light scattering by clouds of particles. Instructor: Friedlander.

Env 203. Advanced Topics in Environmental Engineering Science. *Units by arrangement, any term.* Courses to explore new approaches to environmental problems. The topics covered vary from year to year, depending on the interests of the students and staff. Visiting professors may present portions of the course from time to time.

Env 206 ab. Special Problems in Biological Engineering Science. *9 units (3-0-6); second, third terms. Prerequisite: AMa 95 abc.* In 1973-74 this course will concentrate on biological fluid flows. It will first lay a background in low Reynolds number flows, particularly as applied to suspensions, including heat and mass transfer in suspensions. Application will then be made to problems in blood rheology, blood flow in living systems and motility of micro-organisms. Instructors: Wu, Leal, Wayland.

Env 214 abc. Advanced Environmental Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Hy 101 or Ae 101, AMa 101 or AM 125.* Large scale motions in the oceans and atmosphere, air-water interface, wind generation of waves and currents, stratified fluids, internal waves, blocking, stratified withdrawal, jets and plumes, stratified flows in porous media, turbulent diffusion, mixing in the oceans and atmosphere, dispersion in rivers and estuaries. Applications to engineering problems of pollution control in air and water environments. Instructors: Ingersoll (first term); List (second, third terms).

Env 250. Advanced Environmental Seminar. *4 units (2-0-2); every term. Prerequisite: instructor's permission.* A seminar course for advanced graduate students and staff to discuss current research and technical literature on environmental problems. As the subject matter changes from term to term, it may be taken any number of times. Instructors: Staff.

Env 300. Thesis Research.

Other closely related courses (listed elsewhere) are:

ChE 103 abc	Transport Phenomena
ChE 172 abc	Optimal Control Theory
ChE 173 ab	Advanced Problems in Transport
ChE 203 ab	Interfacial Phenomena
Hy 101 abc	Fluid Mechanics
Hy 111	Fluid Mechanics Laboratory
Hy 113 ab	Coastal Engineering
Hy 121	Advanced Hydraulics Laboratory
Hy 210 ab	Hydrodynamics of Sediment Transportation
Hy 211	Advanced Hydraulics Seminar
Hy 213	Advanced Coastal Engineering

Graduate students may also enroll in graduate courses offered by Scripps Institute of Oceanography under an exchange program (see page 228). Graduate students majoring in environmental engineering science should consult Professor Brooks, academic officer, for more information.

French

(See Languages)

Geological and Planetary Sciences

Geology, Geobiology, Geochemistry, Geophysics, Planetary Science

UNDERGRADUATE COURSES

Ge 1. Introductory Geology. *9 units (3-3-3); first, third terms.* This course aims to present a broad and up-to-date view of the earth by focusing upon major geological items currently of high interest, such as paleomagnetism, mid-oceanic rises, sea-floor spreading, plate tectonics, continental drift, evolution of continental plates, the earth's interior, and environmental geology. A reasonable degree of flexibility is purposely maintained, and the emphasis and topics of consideration will vary, within limits, with the individual instructor and with class interests. An acquaintance with classical geological topics such as rocks and minerals, fossils, crustal deformation, earthquakes, volcanism, geochronology, metamorphism, and processes and features of the earth's surface is obtained in association with treatment of the above listed topics, and through field trips. Classes are rigorously limited in size and individually handled by full-time faculty members. All registrants must be prepared to devote 6 weekend days to field trips. The course is planned specifically for freshmen. Instructors: Shoemaker, in charge, and staff.

Ge 2. Geophysics. *9 units (2-1-6); second term. Prerequisites: Ge 1, Ma 2a, Ph 2a.* An introduction to the physics of the earth. Topics discussed include the figure of the earth, the gravity and magnetic fields of the earth and their variation in space and time, the propagation of seismic waves and the transport of heat within the earth. Recent developments in geodynamics, including the relation of the heat flux from the interior, major gravity anomalies, paleomagnetism, and earthquake mechanisms to convection in the mantle and the new global tectonics are emphasized. Three one-day field trips to sites of geophysical interest are an integral part of the course. Text: *Physics of the Earth,* Stacey. Instructor: Ahrens.

Ge 4. Introduction to Cosmochemistry and Nuclear Geophysics. *6 units (3-0-3); third term. Prerequisite: instructor's permission.* An introductory course focusing on the information obtained by the laboratory study of natural samples, both terrestrial and extraterrestrial, using the techniques of modern chemistry and physics. Topics discussed include: the synthesis and abundances of elements; ages of the earth, the moon and the solar system; formation and chemical differentiation of objects in the early solar system; the chemical composition of lunar, terrestrial, and meteoritic material; the recent history of the moon and the meteorites as inferred by the study of the products of cosmic ray induced nuclear reactions. Instructor: Burnett.

Ge 5. Geobiology. *9 units (3-0-6); second term. Prerequisites: Ge 1, Ch 1, Bi 1, or consult instructor.* An examination, chiefly in biological terms, of processes and environments governing the origin and differentiation of secondary materials in the crust throughout the span of earth history. Consideration is given to the environmental influence of the change from a reducing to an oxidizing atmosphere upon the evolution of life processes and to the subsequent progression of organisms and organic activity throughout the oxidizing era as recorded in the sedimentary rocks of the earth's crust. Special attention is devoted to organic progression and differentiation in time and space in terms of environment. Instructor: Lowenstam.

Ge 40. Special Problems for Undergraduates. *Units to be arranged, any term.* This course provides a mechanism for undergraduates, other than freshmen, to undertake honors-type work in geologic sciences. By arrangement with individual members of the staff. Graded pass/fail.

Ge 41 abc. Undergraduate Research and Bachelor's Thesis. *Units to be arranged.* Undergraduates may undertake research in the geological and planetary sciences under the supervision of some member of the division faculty, with the aim of preparing a professional report on the accomplishments. Number of units to be arranged with the research supervisor, and is not to exceed 12 per term. Writing of a Bachelor's Thesis based on the research is encouraged, and to obtain elective credit for more than 24 units of undergraduate research, a Bachelor's Thesis accepted by the research supervisor is required. Guidance in seeking research opportunities and in formulating a research plan leading to preparation of a Bachelor's Thesis is available from the Division Undergraduate Research Counselor, Professor Epstein. Graded pass/fail.

ADVANCED COURSES

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 and planetary sciences by the students and staff of the division and by guest speakers. Generally required of all senior and graduate students in the division; optional for sophomores and juniors. Graded pass/fail. Instructor: Albee

Ge 102. Oral Presentation. *2 units (1-0-1); first term.* Training in the technique of oral presentation. Practice in the effective organization and delivery of reports before groups. Successful completion of this course is required of all candidates for degrees in the division. Instructors: Burhans, Murray.

Ge 103 ab. Introduction to Processes of the Atmosphere and Hydrosphere. *(Same as Env 103 ab.) 9 units (3-0-6); first, second terms.* Natural physical and chemical processes of the earth's atmosphere and hydrosphere. Emphasis will be on developing an order of magnitude understanding of the atmosphere and oceans through analysis of observations and physical reasoning. Topics covered will include the global heat balance, polar ice caps and climatic change, temperature distribution; tides, waves and currents; cloud formation; precipitation, runoff, floods, sediment transport and deposition; geochemical cycles. Instructors-in-charge: List (first term), Ingersoll (second term).

Ge 104 abc. Advanced General Geology. *9 units (3-4-2). Prerequisites: Ch 1 or 2, Ma 2, Ph 2.*

104 a. Minerals as Physical, Chemical, and Geological Systems. *First term.* Atomic architecture and physical properties of the solid state, with emphasis on the important naturally occurring minerals. Relations between bonding forces, structure, composition, properties, and conditions of formation of minerals. Phase stability, melting relations, and solid-state transformations in mineral systems as a function of temperature and pressure. The chemistry of mineral synthesis and breakdown in relation to chemical evolution and differentiation in the earth. Occurrence, significance, and properties of the major mineral groups that are important at the earth's surface and in the interior. Laboratory study of selected examples. Instructor: Kamb.

104 b. Igneous, Sedimentary, and Metamorphic Rocks. *Second term.* A study of rocks and the chemical and physical processes affecting their origin. Igneous phenomena, rock classification, and processes. Phase equilibria of silicate crystal-melt-fluid equilibria and the genesis of igneous rocks. Principles of physical stratigraphy. Sedimentary minerals and rocks, processes, and depositional environments. Metamorphic processes, rocks and minor structural features. Instructor: Albee.

104 c. Tectonics and Earth History. *Third term.* Major structural features and tectonic processes of the earth's crust. Principles of paleontology and animal stratigraphy. Elements of the Phanerozoic history of the earth with emphasis on both faunal and physical history. Outlines and problems of the Precambrian history of the earth. Instructors: Silver, Lowenstam.

Ge 105 abc. Geological Field Training and Problems. *6 units (0-6-0); first, second, and third terms. Prerequisite: Ge 104 abc should be taken concurrently.* Elementary field mapping techniques in stratigraphy and structural geology. Selected field problems designed to develop techniques and to establish an understanding of basic geologic relationships. Problems in structural geology are emphasized in third term. Instructors: Shoemaker, Allen.

Ge 111 ab. Invertebrate Paleontology. *9 units (2-5-2); second, third terms.* Morphology and geologic history of the common groups of the lower invertebrates, with emphasis on their evolution and adaptive modifications; consideration of the higher invertebrate groups; preparation of fossils and problems of invertebrate paleontology. Instructor: Lowenstam.

Ge 114. Optical and X-ray Mineralogy. *12 units (3-6-3); first term. Prerequisite: Ge 104 a-105 a.* Methods of optical crystallography. Measurement of optical constants with the polarizing microscope. X-ray determination of lattice parameters and space symmetry. Characterization and identification of minerals by optical and X-ray methods. Systematic application of these methods to the study of important mineral groups, including feldspars, chain silicates, and sheet silicates. Instructor: Rossman.

Ge 115. Petrology and Petrography. Systematic study of rocks and rock-forming minerals with emphasis both upon the use of the petrographic microscope and megascopic identification; interpretation of mineral assemblages, textures, and structures; problems of genesis.

115 a. Igneous Petrology and Petrography. *12 units (3-6-3); second term. Prerequisites: Ge 104 ab, Ge 114, Ch 24a or 124a or Ch 21a.* The mineralogical and chemical composition, origin, occurrence, and classification of igneous rocks considered mainly in the light of chemical equilibrium and of experimental studies. Detailed consideration of the structures, phase relations, and identification of the feldspar, pyroxene, amphibole, olivine, and feldspathoid mineral groups. Instructor: Albee.

115 b. Sedimentary Petrology and Petrography. *12 units (3-6-3); third term. Prerequisite: Ge 115 a.* The mineralogic and chemical composition, occurrence, and classification of sedimentary rocks; consideration of the chemical, physical, and biological processes involved in the origin, transport, and deposition of sediments and their subsequent diagenesis. Detailed consideration of structure, phase relations, composition and identification of clay minerals, carbonates, and Fe-Mn oxides. Laboratory study will include identification of clay minerals by X-ray diffraction. Not offered in 1973-74.

115 c. Metamorphic Petrology and Petrography. *12 units (3-6-3); third term. Prerequisite: Ge 115 a.* The mineralogic and chemical composition, occurrence, and classification of metamorphic rocks; interpretation of mineral assemblages in light of chemical equilibrium and experimental studies. Detailed consideration of structure, phase relations, composition, and determination of the major metamorphic minerals. Instructor: Taylor.

Ge 121 abc. Advanced Field Geology. *12 units (0-9-3). Prerequisites: Ge 104 abc, Ge 105 abc.* Interpretation of geologic features in the field, with emphasis on problems of the type encountered in professional geologic work. Advanced techniques of investigation are discussed. The student investigates limited but complex field problems in igneous, sedimentary, and metamorphic terranes. Individual initiative is developed, principles of research are acquired, and practice gained in field techniques, including the use of the plane table in geologic mapping. The student prepares reports interpreting the results of his investigations. Instructors: Allen, in charge, and staff.

Ge 122. Geophysical Field Studies. *10 units (3-5-2); first term. Prerequisites: Ma 2 abc, Ge 105, and instructor's permission.* This course is a field program in an area of particular geological interest, using seismic refraction, gravity, and magnetic field measurements. Students participate in all phases of the program, e.g., station surveying, geophysical equipment operation, and interpretation of data. A final report, embodying calculations and interpretations, is required. Instructor: Dix.

Ge 123. Summer Field Geology. *30 units (6 weeks). Prerequisites: Ge 104 abc, Ge 105 abc.* Intensive study of three field areas in the Rocky Mountains, Colorado Plateau, Basin and Range Province, Sierra Nevada or Coast Ranges. The work in each area is supervised by a separate staff member, and the selection of areas studied varies from year to year. Emphasis is on stratigraphic and structural interpretation, involving a wide range of sedimentary, plutonic, volcanic, and metamorphic rocks. For each area the student prepares a geologic map, stratigraphic and structural sections, and geologic report. The course is designed to complement the field training in southern California afforded by Ge 105 and Ge 121. It is required at the end of the junior year for the bachelor's degree in the geology and geochemistry options. The course begins immediately after commencement and runs for six weeks. Instructors: Allen, in charge, and staff.

Ge 126. Geomorphology. *9 units (3-0-6); second term.* Primarily a consideration of dynamic processes acting on the surface of the earth, and the genesis of land-forms. Instructor: Sharp. Offered in alternate years (1973-74).

Ge 130. Introduction to Geochemistry. *6 units (2-0-4); first term. Prerequisites: Ch 1, Ma 2 abc, Ph 2 abc, Ge 1.* A lecture and problem course on the application of chemical principles to earth problems, involving topics in stable isotopic geochemistry. Instructor: Epstein.

Ge 132. Chemistry of the Earth and Planets. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* A critical evaluation of what is known about the chemical composition of the planetary bodies in the solar system and the processes and time scales required for evolution into their present states. Topics include: survey of mechanisms of nucleosynthesis; solar system elemental abundances; formation times of planetary bodies; the chemical composition and evolution of the earth and moon; speculations on the compositions of other planets; composition and origin of planetary atmospheres. Instructor: Burnett. Offered in alternate years (1974-75).

Ge 135. Regional Geology of Southern California (Seminar). *6 units (3-0-3); second term. Prerequisites: Ge 104 abc, Ge 105 abc or equivalent.* Reading and discussion of selected topics in the geology of southern California and adjacent areas, with emphasis on outlining the important regional research problems. Instructor: Silver.

Ge 137 ab. Laboratory Techniques in the Geological Sciences. *9 units (1-4-4); second and third terms. Prerequisite: instructor's permission.* A series of laboratory experiments covering the important types of laboratory measurements made in modern geological and geochemical research. The emphasis will be placed on understanding the physical and chemical principles on which the measurements are based. X-ray, mass spectrometric, and counting techniques will be treated in detail. Instructors: Patterson, Burnett, Epstein. Offered in alternate years (1974-75).

Ge 150. The Nature and Evolution of the Earth. *6 units (3-0-3). Offered by announcement only.* Discussions at an advanced level of problems of current interest in the earth sciences. The course is designed to give graduate students in the geological sciences and scientists from other fields a broad sampling of data and thought concerning current problems. Students may enroll for any or all terms of this course without regard to sequence. Instructors: The staff and visitors.

Ge 152. Radar Astronomy. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* This course covers techniques of radar astronomy and interpretations of observational results in terms of the physics of the target planet. Radar studies of Mercury, Venus, and Mars will also be described. Additionally it will provide an introduction to the design of radar experiments. Instructor: Goldstein.

Ge 153. Planetary Radio Astronomy. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* The interpretation of radio astronomy observations of the Moon, Mercury, Venus, Mars, and Jupiter in terms of the planets' surface properties and atmospheric characteristics. Thermal and non-thermal emission mechanisms in planetary atmospheres and surfaces will be discussed with particular emphasis toward the construction of mathematical planetary models which can be tested by all possible observational techniques including radio interferometry, planetary occultation, and radar astronomy. Instructor: Muhleman. Offered alternate years (1973-74).

Ge 154. Atmospheric Physics. *9 units (3-0-6); second term.* Basic processes affecting the structure and composition of planetary atmospheres. Scattering, absorption, radiative transfer, convection, diffusion, thermal escape, atmospheric tides, geostropic motion. Observations of the earth, observations of the planets, theoretical models of planetary atmospheres. Instructor: Ingersoll. Not offered in 1973-74.

Ge 155. Introduction to Planetary Science. *9 units (4-0-5); first term.* A broad survey course for undergraduates and graduates. The planets: their probable composition, physical state, and dynamical behavior. Ground-based observations: spectroscopy, photometry, radio interferometry, radar mapping, observations from spacecraft. Theories of atmospheric structure, surface processes, internal history. Speculations on the origin and evolution of bodies in the solar system. Instructors: Muhleman and staff.

Ge 160. Introduction to Modern Geophysics. *4 units (2-0-2); first term.* Seminar on current topics in geophysics with emphasis on active research programs within the department. The course is designed to acquaint new graduate students with outstanding problems in geophysics and with current methods of investigation. Instructors: Anderson and staff.

Ge 166 a. Physics of the Earth's Interior. *9 units (3-0-6); second term. Prerequisite: AMa 95 abc or AM 113 abc, or instructor's permission.* A study of current knowledge concerning the interior of the Earth using information from various earth-science disciplines. Interpretation of the fundamental data of seismology, gravity and heat flow using available high-pressure laboratory data and equations of state with the aim of understanding the structure, composition and phase of the Earth's deep interior. Thermal history of the Earth. Internal constitution of the terrestrial planets. Suitable for students in geology and as an elective in physics, astronomy and engineering. Instructor: Anderson.

Ge 166 b. Planetary Physics. *9 units (3-0-6); first term. Prerequisites: Ph 106 abc, AMa 95 abc or AM 113 abc.* Solar system dynamics, with emphasis on slow changes in the orbit and rotation rates of planets and satellites. Topics to be discussed include tidal friction, resonant orbits and rotation rates, gravitational fields of planets and satellites, dynamics of polar wandering and continental drift. Instructor: Goldreich. Not offered in 1973-74.

Ge 176. Physics of Earthquakes. *9 units (3-0-6); first term. Prerequisites: AMa 95 abc or instructor's permission.* Study of earth structure and earthquake phenomena by application of physical principles. The emphasis will be placed on understanding complex earthquake phenomena in the light of fundamental physical and mathematical concepts. Topics to be discussed include structure of the earth in relation to propagation of earthquake waves, static and dynamic models of earthquakes, interpretation of far- and near-field phenomena, significance of earthquakes in plate tectonics and problems pertaining to earthquake prediction. Instructor: Kanamori.

Ge 177. Seismotectonics. *9 units (3-3-3); third term.* Relationship of seismicity to geologic structures and to tectonic processes: global seismicity patterns; active faults; problems of seismic zoning. Case studies of selected earthquakes with field trips to local areas of special interest. Instructor: Allen. Offered in alternate years (1973-74).

Ge 212 ab. Thermodynamics of Geological Systems. *9 units each term (3-0-6); first and second terms.*

212 a. *Prerequisite: Ch 124 ab or Ch 21 abc, Ge 115 abc or equivalent.* An advanced treatment of chemical thermodynamics, with emphasis on applications to geologic problems. Topics to be covered include heat flow and heat sources, high pressure phase transformations, silicate phase equilibria, solid solutions, the effect of H_2O in silicate melts, and equilibrium in a gravitational field. Text: *Chemical Thermodynamics,* Prigogine and Defay. Instructor: Taylor. Offered in alternate years (1974-75).

212 b. *Prerequisite: 212 a.* Lectures and problems on the chemical and physical properties of aqueous solutions, with emphasis on the thermodynamic behavior of those electrolyte solutions important in nature. Topics to be covered include the effects of solution composition on mineral equilibria, Eh-pH diagrams, extension of thermodynamic data to high temperatures and pressures, non-ideality in mixed-gas systems, and reaction kinetics in systems involving water. Results will be applied to problems of low-temperature sedimentary processes, metamorphism, and diagenesis. Text: *Solutions, Minerals, and Equilibria,* Garrels and Christ. Instructor: Epstein. Offered in alternate years. (1974-75).

Ge 213. Seminar on special topics and problems of current interest in the fields listed below. *5 units. Prerequisites dependent upon topics.* Offered by announcement only.

Ge 213 a—Mineralogy Seminar.
Ge 213 b—Petrology Seminar.
Ge 213 c—Geochemistry Seminar.
Ge 213 d—Geochronology Seminar.
Ge 213 e—Planetary Science Seminar.

Ge 214. Advanced Mineralogy. *9 units (3-3-3); third term. Prerequisite: Ge 104 a, Ge 114, Ch 21 or instructor's permission.* The origin of color, pleochroism, and luminescence in minerals, infrared absorption spectroscopy of mineral substances, the relationship of the various types of x-ray and optical spectra, and the effects of site population upon optical properties. The laboratory will deal with the measurement of the optical and infrared spectra of selected minerals. Instructor: Rossman. Offered in alternate years (1974-75).

Ge 215 abc. Topics in Advanced Petrology. *12 units each term (3-6-3); first, second, third terms. Prerequisites: Ge 115, Ch 124.*

215 a. Chemical Petrology. *First term.* Lectures, seminars, and laboratory studies of the chemical reactions that occur in rocks. Emphasis will be placed on rock-water interactions, mineral deposition, hydrothermal alteration, and the formation of ore deposits. The nature and origin of the H_2O, CO_2, and other gases that take part in these reactions will be discussed, mainly utilizing studies of mineral equilibria and the techniques of stable isotope geochemistry. Instructor: Taylor. Offered in alternate years (1973-74).

215 b. Advanced Igneous Petrology. *Second term.* Lectures, seminars, and laboratory studies on igneous petrogenesis and rocks. Emphasis is placed on a particular group of rocks, such as basalts, andesites, meteorites, layered complexes, etc. Instructor: Silver. Offered in alternate years (1973-74).

215 c. Advanced Metamorphic Petrology. *Third term.* Lectures, seminars, and laboratory studies on metamorphic petrogenesis and rocks. Emphasis is placed on the construction, based on natural assemblages, of two-variable diagrams for multicomponent systems after the method of Schreinemakers and on an understanding of the partition of elements between coexisting phases. Instructor: Albee. Offered in alternate years (1973-74).

Ge 216. Nuclear Problems in Geology. *9 units (3-0-6); third term. Prerequisite; instructor's permission.* This course will cover a variety of topical material relating to nuclear processes which are of geologic importance. Topics to be covered include introductory discussion of theories of nucleosynthesis, naturally occurring and extinct radio-activities and their daughter products, isotopic anomalies, heat generation in the earth, cosmic ray induced nuclides, methods of absolute age dating, age determinations on meteorites and rocks, the geologic time scale, element redistribution in radioactive parent-daughter systems, and residence times and mixing processes for some model systems. Instructor: Wasserburg. Offered in alternate years (1973-74).

Ge 220 ab. Lunar and Planetary Surfaces. *9 units (4-0-5); second term. Prerequisite: Ge 155.*

220 a. Geology of the Moon. A detailed examination of lunar stratigraphy, structure, surface processes and history, as well as a review of the major results obtained from investigations on returned lunar samples. Origin of the Moon and history of the Earth-Moon system. Instructor: Shoemaker. Offered in alternate years (1973-74).

220 b. Planetary Surfaces. Photographic and other remote observations of the surface of Mars are considered in terms of likely surface processes and conditions, past and present. An outline of martian history is developed. Briefer consideration is given to the surfaces of Mercury, Venus, and the satellites of Jupiter and Saturn. Instructor: Murray. Offered in alternate years (1974-75).

Ge 225 abc. Current Research in Planetary Science. Required attendance for all Planetary Science graduate students. Others welcome.

225 a. Student/Faculty Research Conference. *1 unit (1-0-0); first term.* One hour per week informal review of current research by staff and students. Instructor: Ingersoll.

225 b. Selected Topics in Planetary Science. *1 unit (1-0-0); second term.* Review of current research in selected areas of chemistry, physics, or geology of Moon, planets, or meteorites. Instructor: Muhleman.

225 c. Planetary Research with Spacecraft. *1 unit (1-0-0); third term.* Review of potential or recently completed scientific exploration of the moon or planets by means of spacecraft. Instructor: Murray.

Ge 226. Observational Planetary Astronomy. *9 units (3-0-6); first term.* Observational papers in the planetary astronomy literature will be critically analysed to introduce the use of telescopes and other optical instruments for measurement of the physical and chemical properties of the solar system. The nature of optical and infrared radiation detectors, spectrometers, polarimeters, and photometers will be discussed in the context of the observational study of the planets. Other topics will include the design of observational programs and the assessment of the reliability of data. Instructor: Westphal. Offered in alternate years (1974-75).

Ge 229. Glaciology. *9 units (3-0-6); second term.* Origin and behavior of the North American ice sheet, physical conditions and structures of existing glaciers, glacier flow, erosional and depositional processes and products. Instructors: Kamb, Sharp. Offered in alternate years (1974-75).

Ge 230. Geomorphology (Seminar). *5 units; third term.* Review and critical analysis of current research and literature in geomorphology. On occasion, activities are devoted wholly to field excursions within the southwestern U.S. Instructor: Sharp.

Ge 244 ab. Paleoecology (Seminar). *5 units; second, third terms.* Critical review of classic investigations and current research in paleoecology and biogeochemistry. Instructor: Lowenstam.

Ge 247 a. Tectonics. *9 units (3-0-6); third term. Prerequisites: Ge 104 abc, Ge 105 abc.* Structure and geophysical features of continents, ocean basins, geosynclines, mountain ranges, and island arcs. Structural histories of selected mountain systems in relation to theories of orogenesis. Instructors: Allen, Kamb. Offered in alternate years (1974-75).

Ge 247 b. Tectonophysics. *9 units (3-0-6); third term. Prerequisites: Ge 104 abc, AMa 95 abc or equivalent.* Analysis of stress and deformation in tectonic processes. Brittle failure of rocks in relation to faulting. Elastic stress distributions and fault patterns. Dislocation theory of faulting, and analysis of stress distribution around strike-slip faults. Brittle-ductile transition. Plasticity of mineral crystals and rocks in relation to structure. Non-hydrostatic thermodynamics, recrystallization, origin, and significance of structural anisotropy in rocks. Theories of plasticity and non-linear creep, with application to stress analysis in tectonic problems. Viscous buckling of layered media: theory of folding. Rheological properties of rocks at high temperatures and pressures. Viscosity of earth materials from post-glacial rebound and other evidence. Convective instability and mantle convection. Tectonic models. Instructors: Kamb, Allen. Offered in alternate years (1973-74).

Ge 260. Solid-State Geophysics. *9 units (3-2-4); third term. Prerequisite: Familiarity with basic concepts of thermodynamics and mineralogy. See instructor.* This course deals with the application of high-pressure physics to geologic problems. Topics to be covered include: concepts of elastic and shock propagation in single and polycrystalline solids and in fluids, and their relation to various thermodynamic processes; phase changes, dynamic yielding, shock metamorphism, and high-pressure electrical properties of minerals and application of shock and ultrasonic equation-of-state data to earth and planetary interiors. The student is introduced to current laboratory methods used in measuring the properties of earth materials under static and dynamic high pressure. Instructor: Ahrens. Offered in alternate years (1973-74).

Ge 261 abc. Advanced Seismology. *9 units (3-0-6); Prerequisite: AMa 95 or 113.* Essential material in modern seismology; elastic wave propagation, ray theory, normal mode theory, free oscillations, applications to determination of earth structure and earthquake source mechanism, interpretation of seismograms, geophysical time series analysis and synthesis. Instructors: Harkrider, Helmberger.

Ge 264 abc. Theoretical Geophysics. *9 units (3-0-6); Prerequisite: Ph 129 abc or equivalent. Ge 264 c may be taken independently of Ge 264 ab.*

First term. A systematic presentation of basic continuum theory relevant to planetary geophysics. Topics from: hydrodynamics, electromagnetics, hydromagnetics, shock-wave theory, elasticity, thermodynamics and the basic solid state theory relating to mechanical properties of solids.

Second term. Applications to planetary dynamics and thermal properties. Topics include: convection and diffusion processes, heat transport processes, phase changes, discussion of the hydromagnetic dynamo problem, geophysical evidence and dynamical model calculations related to mass transport and planetary evolution. The final part of the term will be devoted to an introduction to stress wave propagation. Topics include: reflection, refraction and scattering of waves in fluid media, waves in random media, waves in multiphase media, statistical continuum methods.

Third term. Theory of wave propagation in elastic and anelastic media, structure of the earth. Topics include: representation theorems in elastic wave propagation, dislocation and relaxation sources, free and forced oscillations of a radially inhomogeneous planet, wave propagation in layered media, inversion theory, perturbations of the free oscillation spectra due to rotation and lateral variations in earth properties, physics of anelastic processes and absorption, asymptotic wave theory, elastic-anelastic structure of the earth. Instructor: Archambeau. Offered in alternate years (1974-75).

Ge 265 ab. Advanced General Geophysics. *9 units (3-0-6); first, second term. Prerequisite: Ph 129 abc.* A discussion of a range of problems of current geophysical importance selected from among the general categories of: planetary magnetic and gravity fields, thermal history and evolution, mass transport processes in the earth and tectonics, high temperature-pressure geophysics, anelastic processes, wave propagation theory and solid state geophysics. Instructors: Archambeau, in charge, and staff. Offered in alternate years (1975-76). Not offered in 1973-74.

Ge 268 ab. Selected Topics in Theoretical Geophysics. *4 units (2-0-2), first term; 8 units (3-0-5), second term. Prerequisite: Ph 129 abc or equivalent.* Discussion of seismic wave propagation, general thermodynamics and dynamics as applied to earth processes, gravitational and magnetic fields, and stress systems in the rotating earth. Course content is altered in emphasis from year to year depending mainly on student needs. Instructor: Dix.

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

Ge 297. Advanced Study. Students may register for up to 15 units 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 contributions to scientific knowledge. These may be carried on in the following fields:

Geology:
- (A) Economic Geology
- (B) Field Geology
- (C) Geomorphology
- (D) Glaciology
- (E) Invertebrate Paleontology
- (F) Mineralogy
- (G) Paleoecology
- (H) Petrology
- (I) Sedimentation
- (J) Stratigraphy
- (K) Structural Geology

Geochemistry:
- (L) General Geochemistry
- (M) Geochronology
- (N) Isotopic Geochemistry
- (O) Meteorites

Geophysics:
- (P) Applied Geophysics
- (Q) General Geophysics
- (R) Geophysical Instruments
- (S) Seismology
- (T) Theoretical Geophysics

Planetary Science:
- (U) Planetary Surfaces
- (V) Planetary Dynamics
- (W) Planetary Atmospheres
- (X) Radar Observations
- (Y) Radio Emissions

German

(See Languages)

History

UNDERGRADUATE COURSES

H 1 abc. Introduction to Europe. *9 units (3-0-6).* Europe, its background, development, and relations with other parts of the world. Topics will vary from instructor to instructor, but will usually include feudalism, the Renaissance and Reformation, 17th century England, the Enlightenment, the French Revolution and Napoleon, the Industrial Revolution, 19th century liberalism and nationalism, Marx, overseas expansion and contraction, the Russian Revolution and Stalin, fascism, the two World Wars, and the Cold War. Instructors: Staff.

H 2 abc. Revolution to Roosevelt. *9 units (3-0-6).* An examination of American history from 1765 through the New Deal. The first term will cover the period 1765 to 1800; the second, from 1830 to 1877; and the third from the end of the nineteenth century to World War II. The first two terms will focus on such questions as: Why do men revolt? How and why do they set up stable political structures? What motivates Radicals? Under what conditions do moderate reforms fail to prevent Civil War? The third term will ask: Why was Victorian America swept by tumultuous protests in the closing years of the nineteenth century? What motivated the reforms of the early twentieth century and of the New Deal? And who led the nation and why? Instructors: Staff.

H 6 abc. American Life and Thought. *9 units (3-0-6).* Topics in the development of American culture, explored through an examination of selected social, political and artistic materials, including essays, novels and films. Instructors: Staff.

H 8 bc. Introduction to Asia. *9 units (3-0-6); second, third terms.* Not a textbook survey. Rather, an examination of selected topics in the history of Asia from Mohammed to the Arab-Israeli conflict, Akbar to Gandhi, the Sung dynasty to Mao Tse-tung, using books marked by their narrative quality. Each term will end with a short reading period during which students will read one book of their own choosing. Not offered in 1973-74.

H 23. Cultural History of Early Medieval Europe. *9 units (3-0-6); first term.* From the end of the Roman Empire to the First Crusade. Shows how classical, Christian and barbarian cultures combined to form a new civilization. Instructor: Benton.

H 24. Cultural History of the High Middle Ages and Renaissance. *9 units (3-0-6); second term. H 23 precedes but is not a prerequisite for H 24.* Europe from the 12th through 15th centuries. Shows relationship of art, literature, music and social relations to political, economic and religious institutions. Instructor: Benton.

H 25. Europe in the 17th and 18th Centuries. *9 units (3-0-6). Not intended for students who took European history as freshmen.* A survey of Europe in this period, with special attention to the English revolutions, Louis XIV, the Enlightenment, and the French Revolution. Not offered 1973-74.

H 26. Europe in the 19th and 20th Centuries. *9 units (3-0-6). Not intended for students* *who took European history as freshmen.* A survey of Europe in this period, with special attention to the Industrial Revolution, liberal revolutions and reforms, the formation of Germany, the two world wars, the Russian Revolution, and Hitler. Not offered 1973-74.

H 40. Reading in History. *Units to be determined for the individual by the department. Elective, in any term.* Reading in history and related subjects, done either in connection with the regular courses or independently of any course, but under the direction of members of the department. A brief written report will usually be required. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

H 97 bc. Junior Tutorial. *9 units (2-0-7); second, third terms. Prerequisite: Instructor's permission.* Designed primarily for students majoring in history. The course will be taught on a tutorial basis with frequent meetings between the instructor and student. The course subject matter will vary according to individual needs. The course will normally be taken in the junior year. Instructors: Staff.

H 98 ab. Senior Tutorial. *9 units (2-0-7); first, second terms. Prerequisite: Instructor's permission.* Designed primarily for students majoring in history. The course will be taught on a tutorial basis with frequent meetings between the instructor and student. The course will normally be taken in the senior year. Instructors: Staff.

H 99 abc. Research Tutorial. *9 units (1-0-8). Prerequisite: Instructor's permission.* Students will work with the instructor in the preparation of a research paper which will form the basis of an oral examination. Instruction will be conducted on a tutorial basis. Instructors: Staff.

ADVANCED COURSES

H 106 ab. Topics in Medieval and Renaissance History. *9 units (3-0-6); first, second terms. Prerequisite: H 23 or H 24 or instructor's permission.* Seminar treatment of special topics, varying from term to term. Topics in the past have included history of autobiography, economic development, love and marriage, political theory, and childhood. For schedule of anticipated topics, see instructor or Registrar. Instructor: Benton.

H 107. Psychohistory. *See Psy 107.*

H 108. Europe and Asia. *9 units (3-0-6).* Topics in the interrelation of Europe and Asia since the fall of Rome. May include the Arab conquest of the Mediterranean, the Crusades, Turkey in Europe, Russia in Asia, the spice trade, Christ and opium in China, Lawrence and the Hashemites, and the birth of Israel. Not offered 1973-74.

H 109. Protestant, Catholic, and Jew. *9 units (3-0-6).* Topics in the political and social history of religion and religious communities in Europe since the fall of Rome. May include Becket and Henry II, the medieval ghetto, the Renaissance Papacy, Luther, the Revolt of the Netherlands, church and chapel in Victorian England, and the "final solution." Not offered 1973-74.

H 112. Contemporary Europe. *9 units (3-0-6); first term.* This course will deal with some of the public issues, social trends, and cultural developments which are of special interest in Europe today. While the setting will be historical, particular emphasis will be placed on what has been going on in the last twenty-five years. Instructor: Elliot.

H 116. Germany. *9 units (3-0-6).* Principal historical developments in Germany from the Reformation to the present day. Emphasis on the evolution of social and political institutions and attitudes. Instructor: Ellersieck.

H 117. Russia. *9 units (3-0-6).* An attempt to discover and interpret the major recurring characteristics of Russian history and society, with attention particularly to developments in the Soviet period. Instructor: Ellersieck.

H 118. Britain. *9 units (3-0-6).* Main elements in the political life of modern Britain. Attention will be concentrated primarily on events since 1832, and emphasis will be placed on economic and social trends, on political and constitutional development, and on the lives of important statesmen. Instructor: Elliot.

H 120. The British Empire and Commonwealth. *9 units (3-0-6).* The growth of the imperial idea and the institutional development of the Empire and the Commonwealth with particular reference to Africa and Asia. Instructor: Huttenback.

H 121. India and Pakistan. *9 units (3-0-6).* The growth of Indian nationalism in the years before independence, and developments in India and Pakistan since partition. Special emphasis will be placed on the philosophical conflict between British and indigenous Indian attitudes and the consequent effect on contemporary India and Pakistan. Instructor: Huttenback.

H 130. History of War. *9 units (3-0-6).* An examination of instructive episodes in the evolution of warfare. Emphasis upon the role of political, economic and social factors in influencing the choice of organization, armament, tactics and the timing of conflict. Instructor: Ellersieck.

H 147. The Far West and the Great Plains. *9 units (3-0-6).* The exploration and development of the great regions of western America. Especial attention will be paid to the influence of the natural environment, and the exploitation of it by such industries as the fur trade, mining, cattle ranching, farming, and oil. Instructor: Paul.

H 148. The Supreme Court in U.S. History. *9 units (3-0-6); first term.* An examination of the development of the Supreme Court, its doctrines, and its role in U.S. history through analyses of selected cases. Instructor: Kousser.

H 151. The Shaping of Modern America, 1890-1917. *9 units (3-0-6).* An examination of the consolidation and expansion of economic, political, and social control by regional and national power elites. Instructor: Kousser.

H 153 ab. America Since 1929. *9 units (3-0-6); second, third terms; a is not a prerequisite for b.* Topics in the recent social, cultural and political history of the United States. The first quarter will cover the period to the late 1940s, the second from then to the present. Instructors: Kevles, Rosenstone.

H 154. American Foreign Policy in the Twentieth Century. *9 units (3-0-6).* How American foreign policy has been formed and administered in recent times: the respective roles of the State Department, Congress, and the President, of public opinion and pressure groups, of national needs and local politics. Instructor: Paul.

H 157 a. Science in America, 1865-present. *9 units (3-0-6).* A study of the social and political history of American science, emphasizing the relationship of the research community to universities, industry, and government. Instructor: Kevles.

H 157 b. Science in America, 1865-present. *9 units (3-0-6). H 157 a is a prerequisite.* A seminar on selected topics, concentrating on the writing of an original research paper. Instructor: Kevles.

H 158. American Intellectual History. *9 units (3-0-6); first term.* A study of selected topics in the history of American thought and attitudes. Instructor: Rosenstone.

H 159 a. American Radicalism. *9 units (3-0-6); second term.* An examination of the nature of dissident American social and political movements in the nineteenth and twentieth centuries, with emphasis on their critiques of American life, their role in society, and their contributions. Instructor: Rosenstone.

H 159 b. American Radicalism. *9 units (3-0-6); third term. Prerequisite: H 159 a, or instructor's permission.* A seminar on selected topics, concentrating on a deep examination of some aspect of radicalism and the writing of an original research paper. Instructor: Rosenstone.

H 160. The History of Black People in America. *9 units (3-0-6).* This course will focus primarily on actions taken and ideas expressed by Negroes themselves rather than by whites. Themes will include accommodation and resistance before and after the Civil War; the development of racism and segregation; the migration from black belt to ghetto; and the roles of certain black leaders and ideologies. Instructor: Kousser.

H 161. Selected Topics in History. *9 units (3-0-6).* Instructors: Staff and visiting lecturers.

H 201. Reading and Research for Graduate Students. Units to be determined for the individual by the staff.

Humanities and Social Sciences

HSS 99. Humanities-Social Science Tutorial Program. Upon application and screening by the Tutorial Committee, which is composed of HSS faculty, a limited number of sophomores, juniors, and seniors will be admitted to a tutorial program. Once admitted, a student will work on a one-to-one basis with tutors drawn from the division's faculty, at the rate of 9 units per term, on subjects agreed upon between student, tutor, and the Tutorial Committee. Written work will be required, letter grades given, and a term's work and grade reported (through the Tutorial Committee) in the form shown by the following example:

HSS 99 Tutorial (World War I in fiction) 9 units.
Instructor: Tutorial Committee (D. C. Elliot).

The Tutorial Committee will review each student's work periodically, may require that a student take regular HSS courses along with or prior to a tutorial, and may ask a student to leave the program altogether.

The program is not designed for students in the four HSS options, and units earned in it do not take the place of course or tutorial instruction in those options, unless the options say they may. The program is nevertheless open to applicants from those options.

Hydraulics

ADVANCED COURSES

Hy 100. Hydraulics Problems. *Units to be based upon work done, any term.* Special problems or courses arranged to meet the needs of first-year graduate students or qualified undergraduate students. Graded pass/fail.

Hy 101 abc. Fluid Mechanics. *9 units; first, second, third terms. Prerequisites: ME 19 abc and Hy 111 or equivalent.* General equations of fluid motion; two- and three-dimensional steady and non-steady potential motion; cavity and wake flow; surface waves, linear and nonlinear shallow-water waves, layered media, stability; acoustic fields, sound radiation and scattering, acoustic energy transport; one-dimensional steady gasdynamics, expansion fans, shock waves; two- and three-dimensional flow fields; laminar flow, Stokes and Oseen problems, laminar boundary layer; laminar instability, turbulence shear flow; introduction to problems in heterogeneous flow, chemically reacting flow, sediment transport, flow through porous media. Instructor: Rannie or Marble.

Hy 103 ab. Advanced Hydraulics and Hydraulic Structures. *9 units (3-0-6); first, second terms. Prerequisites: ME 19 abc and Hy 111 or equivalent.* Steady and unsteady flow in open channels; high-velocity flow in open channels; theory and design of some hydraulic structures such as chutes, energy dissipators, manifolds, and canals; unsteady flow in closed systems, e.g., surge and waterhammer. Instructor: Raichlen.

Hy 105. Analysis and Design of Hydraulic Projects. *6 or more units as arranged; any term.* The detailed analysis or design of a complex hydraulic structure or water resources project emphasizing interrelationships of various components, with applications of fluid mechanics and/or hydrology. Students generally work on a single problem for the entire term, with frequent consultations with the instructor. Instructors: Staff.

Hy 111. Fluid Mechanics Laboratory. *6-9 units as arranged with instructor; second or third term. Prerequisite: ME 19 ab.* A laboratory course illustrating the basic mechanics of incompressible fluid flow, and complementing the lecture course ME 19 abc. Students will usually select 4 or 5 regular experiments, but with the permission of the instructor they may propose special investigations of brief research projects of their own in place of some of the regular experiments. Objectives also include giving students experience in making engineering reports. Although the course is primarily for seniors, it is also open to first-year graduate students who have not had an equivalent course. Instructor: Raichlen.

Hy 113 ab. Coastal Engineering. *9 units (3-0-6); first, second terms. Prerequisites: ME 19 abc and Hy 111 or equivalent; AMa 95 abc.* Engineering applications of the theory of small and finite amplitude water waves; diffraction, reflection, refraction; wind-generated waves and wave prediction procedures; tides and their interaction with the coastline; effect of waves on coastal structures such as breakwaters and pile-supported structures; coastal processes. Instructor: Raichlen.

Hy 121. Advanced Hydraulics Laboratory. *6 or more units as arranged; any term. Prerequisite: instructor's permission.* A laboratory course primarily for first-year graduate students dealing with flow in open channels, sedimentation, waves, hydraulic structures, hydraulic machinery, or other phases of hydraulics of special interest. Students may perform one comprehensive experiment or several shorter ones, depending on their needs and interests. Instructor: Raichlen.

Hy 200. Advanced Work in Hydrodynamics or Hydraulic Engineering. *Units to be based upon work done; any term.* Special courses to meet the needs of advanced graduate students.

Hy 201 abc. Turbomachines. *(Same as JP 250 abc.) 6 units (2-0-4); first, second, third terms. Prerequisite: Hy 101 or instructor's permission.* A study of the characteristics of hydraulic and aerodynamic turbomachines including pumps, compressors, turbines, fans, propellers. Radial and axial cascade theory, axisymmetric flow and linearized perturbations of strong vorticity fields, transonic and supersonic blading; cavitation phenomena; propagating stall and effect of distorted inlet flow; secondary flows and blade tip clearance flows. Not offered every year. Instructor: Acosta or Rannie.

Hy 203. Cavitation Phenomena. *6 units (2-0-4); third term. Prerequisite: Graduate standing.* A study of the occurrence and effects of cavitation on the flow past bodies, lifting surfaces, and through machines; material damage and acoustic noise caused by cavitation will also be covered. Not offered every year. Instructor: Acosta.

Hy 204 abc. Hydrodynamics of Free Surface Flows. *9 units (3-0-6); first, second, third terms. Prerequisites: Hy 101 abc, AM 113 abc and AM 125 abc, or equivalent.* Theory of surface waves in a dispersive medium. Infinitesimal waves and wave resistance of floating or submerged bodies. Ship hydrodynamics. Theory of planing surface and hydrofoil. Scattering and diffraction of surface waves. Geometrical wave approximation. Hydrodynamic stability. Nonlinear waves and existence theorems. Shallow-water waves. Open-channel flows and river waves. Flows with shear and stratification of density and entropy. Free streamline theory for jets, wakes, and cavities. General theory for curved obstacles; existence and uniqueness. Unsteady flows with jets and cavities. Instructor: Wu. Not offered in 1973-74.

Hy 210 ab. Hydrodynamics of Sediment Transportation. *9 units (3-0-6); second, third terms. Prerequisites: AMa 95 abc, Env 112 abc, and Hy 101 abc.* A study of the mechanics of the entrainment, transportation, and deposition of solid particles by flowing fluids. This will include discussion and interpretation of results of laboratory and field studies of alluvial streams, and wind erosion. Instructor: Vanoni.

Hy 211. Advanced Hydraulics Seminar. *4 units (2-0-2); every term.* A seminar course for advanced graduate students to discuss and review the recent technical literature in hydraulics and fluid mechanics. Emphasis will be on topics related to civil and environmental engineering which are not already available in courses offered by the Division of Engineering and Applied Science. The subject matter will be variable depending upon the needs and interests of the students. It may be taken any number of times with permission of the instructor. Instructor: Brooks.

Hy 213. Advanced Coastal Engineering. *9 units (3-0-6); third term. Prerequisites: Hy 101 abc and Hy 113 ab.* Selected topics in coastal engineering such as: harbor resonance, mooring and berthing of ships, structural forces due to waves, tsunamis and other impulsive wave systems. Instructor: Raichlen.

Hy 300. Thesis Research.

Information/Computer Science*

UNDERGRADUATE COURSES

IS 10 a. Introduction to the Use of Computers. *6 units (1-2-3); one-term course offered second and third terms. Freshmen only or instructor's permission.* The purpose of this course is to introduce to the students the use of computers for solving mathematical problems arising in engineering and science. By solving a variety of sample problems, the student will learn basic techniques of computational mathematics. Algebraic computer languages will be employed in batch processing and in conversational time-sharing. Instructor: McCann.

IS 80 abc. Undergraduate Research in Information Science. *Units in accordance with work accomplished. Consent of both research adviser and course supervisor required before registering.* This course is intended to provide supervised research in information science by undergraduates. The topic of research must be approved by the supervisor and a formal final report must be presented at the completion of the research. Graded pass/fail. Instructors: Information science staff; Course Supervisor: Ingargiola.

ADVANCED COURSES

IS 110 abc. Principles of Digital Information Processing. *9 units (3-3-3); three terms.* This course presents the principles and concepts of digital information processing systems with emphasis on the stored program synchronous computer. This includes switching theory and its application to the design of systems. The organization of digital processors at the machine language level is covered together with the basic concepts of formal algebraic languages, their uses and the translation between them and machine languages. The laboratory permits direct experimentation with a variety of systems ranging from basic subsystems to complete computers. Instructor: Ray.

IS 121 abc. Biosystems Analysis. *6 units (2-0-4); three terms. Same as Bi 121 abc. Prerequisite: Bi 151 or concurrently.* This course presents a systematic consideration and application of the methods of systems analysis, information theory and computer logic to problems in neurobiology. The subjects to be considered include the mechanical properties of striated muscle, the analysis of neuronal integrative mechanisms and reflex behavior in terms of logical net theory. The course will seek to describe some aspects of human cortical activity in terms of information theory and conceptual modeling. The course will be conducted as a research seminar and the detailed subject matter will change from year to year. Instructor: Fender.

IS 130 abc. Language Systems. *9 units (3-0-6). Prerequisite: IS 129 or equivalent.* Issues involved in designing and using programming languages are considered in detail. Current languages (FORTRAN, ALGOL, LISP, PL/I, SIMUIA, etc.) together with languages now being developed (ALGOL/6 8, PPL, EII, PLANNER, etc.) are used to illustrate such issues. Selected topics in the theory of programming languages, such as formal models of syntax and semantics, program verification and automatic program synthesis will be examined. Instructor: Ingargiola. Not offered in 1973-74.

IS 137. Systematic Computer Programming. *12 units (3-3-6); first term.* An informal introduction to computer programming in a well-structured, efficient programming language. The main goal is to enable the student to write small programs with a clearly

*For linguistics, Lit 102, see page 361.

defined purpose and structure and to test and document them systematically. The influence of computer properties on program efficiency is discussed and an overview of a simple compiler is given. Instructor: Brinch-Hansen.

IS 138. Data Structures and Algorithms. *12 units (3-3-6); second term. Prerequisite: IS 137 or equivalent.* An introduction to the abstract properties and implementation techniques of computer programming languages. The main topic is the axioms and representation of data structures and algorithms. Exercises in language implementation are solved by small student teams. Instructor: Brinch-Hansen.

IS 139. Multiprogramming and Resource Sharing. *12 units (3-3-6); third term. Prerequisites: IS 137, IS 138 or equivalent.* An introduction to the common principles of computer operating systems. The main topics are the abstract properties of concurrent processes and their implementation in terms of processor and store management, scheduling algorithms and resource protection techniques. The students will solve exercises in multiprogramming and study selected advanced topics. Instructor: Brinch-Hansen.

IS 140 ab. Programming Laboratory. *12 units (3-9-0); second and third term. Prerequisites: IS 137, IS 138 or equivalent.* The aim of this course is to allow students to gain experience in the design, documentation, implementation and testing of medium size programming projects. Projects will be carried out by teams of two to four students. They will be realistic problems in the sense that they are loosely defined by the instructor. The students are expected to refine the problem definition, to define the internal structure of the program, to select an appropriate implementation language and to build the system. Each team is expected to distribute a written description of its work weekly. Classes will be dedicated to the critical evaluation of such reports by the instructor and the students. Instructor: Ingargiola.

IS 141. Formal Models of Computation. *9 units (3-0-6); first term.* The aim of this course is to make students familiar with the main theoretical results of computer science, to point out to which extent these results are relevant to computer applications, and to facilitate further study of the literature. Models of effective computations: Turing machines, combinatorial systems, lambda calculi, recursive functions, decidable and undecidable problems. Formal languages: their specification by phrase structure grammars, their generation and recognition by automata. Instructor: Ingargiola.

IS 142 abc. Computer Modeling and Data Analysis. *9 units (3-3-3).* The building of conceptual models as an expression of the patterns perceived in the analysis of data. Analysis of data through model fitting and the study of residuals. Mathematical, statistical, and simulation models will be studied. Real life data bases from a variety of subject areas will be analyzed. The computer will be used extensively. Instructor: Thompson.

IS 203 ab. Analysis and Modeling of Nervous Systems. *9 units (3-3-3); second, third terms. Prerequisite: IS 121 or concurrently.* The development of adequate theories for complex living systems requires the extensive integration of computer-aided strategies for data acquisition, analysis and modeling. Since the proper development of such theories requires a rich data base, supplementary material is presented on the physiology of systems used as examples. A laboratory is provided to test and extend the integrated use of computer concepts in such research. Instructor: McCann.

IS 220. Theories of Visual Nervous Systems. *9 units (3-0-6); third term. Prerequisites: IS*

121 abc and IS 203 ab. Strategies for the correlation of experimental techniques for studying nervous systems with computer instrumented methods of examining experimental results by data analysis and modeling. Comparisons will be made between models based upon formal mathematics and new computer instrumented strategies that provide more complete and detailed correlations with experimental results. Instructor: McCann.

IS 240 ab. Digital Image Processing. *9 units (2-2-5); first, second terms.* The course presents an introduction to the techniques and uses of digital image processing, and the hardware required for sampling, digitizing, processing, and reconstructing images. Techniques for contrast manipulation, geometric manipulation and algebraic manipulation are covered along with 2-dimensional transformations and filtering. Algorithm development is included for the location, measurement and classification of "objects" in images and for binary image analysis. Processing techniques are presented for 3-dimensional images, multispectral analysis and texture analysis. The course describes the mathematical development of processing techniques, the implementation of these techniques as computer algorithms, and the application of these algorithms to imaging problems. Instructor: Castleman.

IS 250 abc. Mathematical Linguistics. *9 units (3-0-6); three terms. Prerequisite: Ma 116 abc.* This course presents a systematic development of the syntactic and semantic properties of languages. This includes the natural languages as well as the formal languages of symbolic logic and information processing. The philosophical aspects of languages will be stressed together with the formalization of language structures suitable for computer simulation. Instructor: Thompson. Taught in alternate years. Not offered in 1973-74.

IS 260 abc. Artificial Intelligence. *9 units (3-0-6). Prerequisite: instructor's permission.* Investigation of principal strategies and problems in achieving intelligent behavior on a computer; discreteness of the space of alternatives, search strategies and heuristics, hill climbing, pattern recognition and articulation of patterns; learning systems. Review of recent developments in selected areas of research; problem solving programs, computer understanding of natural and graphic languages and question answering. Simulation of cognitive processes. The student will be expected to develop and successfully run a computer program demonstrating understanding of advanced application of computers. Instructor: Weinstein.

IS 280. Research in Information Science. *Units in accordance with work accomplished. Approval of student's research adviser and his department adviser must be obtained before registering.*

IS 282. Reading in Computer Science. *6 units or more by arrangement; first, second, third terms. Prerequisites: IS 137, IS 138 or equivalent.* A seminar in which a small group of students and the instructor discuss and summarize the literature of a potential research area of computer science. Only qualified students will be admitted after consultation with the instructor. A written report will usually be required. Instructor: Brinch-Hansen.

The following courses cover related basic mathematics and applied mathematics:

AMa 104. Matrix Theory. See Applied Mathematics Section.

AMa 105 ab. Introduction to Numerical Analysis. See Applied Mathematics Section.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. See Mathematics Section.

Ma 121 abc. Combinatorial Analysis. See Mathematics Section.

Ma 125 abc. Analysis of Algorithms. See Mathematics Section.

Ma 205 abc. Advanced Numerical Analysis. See Mathematics Section.

Ma 216 abc. Advanced Mathematical Logic. See Mathematics Section.

Independent Studies Program

The course for ISP students is intended to accommodate individual programs of study or special research that fall outside ordinary course offerings. Students signing up for the ISP course will prepare, with the help of the advisory committee, a description of the course of study, a syllabus delineating the work to be accomplished, and a time schedule for reports both on progress and for work completed. The units of credit and form of grading of this course are decided by mutual agreement between the ISP committee, the student, and his three-member advisory committee.

Jet Propulsion

ADVANCED COURSES

JP 121 abc. Jet Propulsion Systems and Trajectories. *9 units (3-0-6); each term. Open to all graduate students and to seniors with permission of the instructor.* Modern aspects of rocket, turbine, electrical, and nuclear propulsion systems and the principles of their application to lifting, ballistic, and space flight trajectories. Combustion thermodynamics, equilibrium and nonequilibrium nozzle flow, propellant evaluation. Combustion and burning characteristics of solid and liquid propellants, liquid propellant fuel systems, combustion instability. Subsonic and supersonic compressor and turbines, basic gas turbine propulsion cycle and its variations, inlets and diffusers. Ion and colloidal engines, plasma thrustors, crossed field and wave MHD propulsion systems. Nuclear rockets, nuclear air breathing cycles, radio-isotope propulsion. Instructors: Marble, Zukoski.

JP 130 ab. Molecular Gas Lasers. *(Same as APh 195 ab.) 9 units (3-0-6); first, second terms.* An introduction to gas lasers based on transitions involving molecular degrees of freedom. Some acquaintance with fluid mechanics, and knowledge of electromagnetic theory and quantum mechanics at the advanced undergraduate level will be assumed. Background material on the interaction of radiation and matter, and optical resonators will be included, but the emphasis will be on processes particular to molecular lasers. Examples of electrical discharge, gas dynamic, and chemical lasers will be discussed. Instructor: Culick.

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: ME 17 abc or equivalent.* Introduction to quantum mechanical and statistical mechanical methods for calculating thermodynamic properties, in particular properties of materials at high temperatures; transport theory.

JP 213 abc. Gas Dynamics and Combustion in Propulsion Systems. *6 units (2-0-4); each term. Prerequisites: JP 120 abc, JP 121 abc, Ae 101 abc or Hy 101 abc, or equivalent.* Topics from theory of real gases; gas dynamics of reacting mixtures; theory of combustion of solid, liquid, and gaseous fuels. Inlet diffusers for supersonic and hypersonic air-breathing engines; effects of real gases, rarefied gas and low Reynolds number flow; diffuser stability. Review of laminar and turbulent flame theory; combustion of solid and liquid propellants; combustion in boundary layers, wakes, and mixing regions; flame stability. Nozzle for rockets and air-breathing engines; one-dimensional and axially symmetric nozzle flow with chemical reactions, characteristic theory, integral methods, two-phase flow. Instructor: Marble.

JP 250 abc. Turbomachines. *(Same as Hy 201 abc.) 6 units (2-0-4); first, second, third terms.* A study of the characteristics of hydraulic and aerodynamic turbomachines including pumps, compressors, turbines, fans, propellers. Radial and axial cascade theory, axisymmetric flow and linearized perturbations of strong vorticity fields, transonic and supersonic blading; cavitation phenomena; propagating stall and effect of distorted inlet flow; secondary flows and blade tip clearance flows. Not offered every year. Instructor: Acosta or Rannie.

JP 270. Special Topics in Propulsion. *6 units (2-0-4); each term.* The topics covered will vary from year to year. Instructors: Staff.

JP 280. Research in Jet Propulsion. *Units to be arranged.* Theoretical and experimental investigations of problems associated with propulsion and related fields. Instructors: Staff.

JP 290 abc. Advanced Seminar in Jet Propulsion. *1 unit (1-0-0); each term.* Seminar on current research problems in propulsion and related fields. Instructors: Staff.

Languages*

UNDERGRADUATE COURSES

L 39. Reading in French, German or Russian. *Units to be determined for the individual by the department.* Reading in scientific or literary French, German or Russian under the direction of the department. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

HSS 99. See page 351 for description.

ADVANCED COURSES

L 101. Selected Topics in Language. *Units to be determined by arrangement with the instructor.* Graded pass/fail. Instructors: Staff and visiting lecturers.

L 102 abc. Elementary French. *10 units (3-1-6); first, second, third terms.* A course taught by the conversational method, aimed at giving a student a superior reading knowledge of French and the ability to understand the contents of a lecture in his general field and to discuss the subject matter in French, as well as competence in general conversation. This is the first course of a two-year sequence, but enrollment is not re-

*For linguistics, Lit 102, see page 361.

stricted to students intending to complete the two-year program. Credit not given for high school courses repeated at Caltech; any student who has had two years of high school French should not register for first-year French without consulting the instructor. Instructor: A. Smith.

L 103 abc. Intermediate French. *9 units (3-0-6); first, second, third terms. Prerequisite: L 102 abc or equivalent.* Continuation of L 102 abc, includes a review of grammar, conversational practice, and introduction to French history, literature, and politics. Instructor: A. Smith.

L 105 abc. French Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 103 abc or equivalent. Courses need not be taken in sequence.* Open to undergraduates and graduates. Credit in this course may be applied towards a subject minor in French. Each term treats a body of French literature from the standpoint of a dominant theme: Alienation and Literature; The Search for Values in an Absurd Universe (after World War II); The Classical Age of the Sun King. Conducted in French. Instructor: A. Smith.

L 130 abc. Elementary German. *10 units (3-1-6); first, second, third terms.* The course provides the basis for developing a broad knowledge of the German language, covering aural comprehension, speaking, reading, and writing. Classroom work is supplemented by language laboratory drill. Open to graduate and undergraduate students. This course also constitutes the first year of the two-year intensive program in German for graduate students. Students who have had German in the secondary school or junior college should not register for this course without consulting the staff in languages. Instructor: Wayne.

L 132 abc. Intermediate German: Readings in German Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 130 abc, or equivalent.* The reading of selected short contemporary stories and plays of intermediate difficulty with emphasis on the development of communication skills. Open to undergraduate students, and to graduate students who are not taking the two-year intensive program in German. Students who wish to offer German study elsewhere as basis for admittance to the course should consult with the instructor. Instructors: Staff.

L 139. Independent Reading in French, German, or Russian Literature. For graduate students who have completed at least one year of literature in the foreign language. Credit in this course may be applied towards a subject minor in language. Units to be determined for the individual by the department. Graded pass/fail. Instructors: Staff.

L 140 abc. German Literature. *9 units (3-0-6); first, second, third terms. Courses need not be taken in sequence. Prerequisite: L 132 or equivalent.* The reading and discussion of work by selected twentieth-century authors. Conducted in German. Open to undergraduates and graduates. Credit in this course may be applied towards a subject minor in German. Instructor: Wayne.

L 150 abc. Literature in Translation. *9 units (3-0-6); first, second, third terms.* A coherent body of French, German, Russian, or other literature will be covered each term. The content of each course may vary from year to year, and will be announced by the Registrar and posted by the Humanities and Social Sciences Division before preregistration. The readings, lectures, discussions, papers, and examinations will be in English, although language students may request to do some or all their work in the original. The three terms may be taken independently of each other. Course may be taken more than once, if content varies. Instructors: Language and Literature Staff. *(See also Lit 150 abc.)*

L 152 abc. Elementary Russian. *10 units (3-1-6); first, second, third terms.* The course aims to give the student the vocabulary and knowledge of morphology and syntax to read, write about, discuss and comprehend basic materials (stories and articles) from the literary language. The first course of a two-year sequence; enrollment not restricted to students intending to complete the two-year program. Credit not given for high school or junior college courses repeated at Caltech; any student who has had two years of high school Russian or one year of junior college Russian should not register for this course without consulting the instructor. Instructor: Moller.

L 153 abc. Intermediate Russian. *9 units (3-0-6).* Continuation of L 152. Grammar review; readings, discussion and written and oral reports on material from Russian science, culture, and history. Instructor: Moller.

L 154 abc. Russian Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 153 or equivalent.* Students are advised to take these courses in sequence. Reading and discussion of representative works of selected nineteenth- and twentieth-century Russian authors. Conducted in Russian. Open to undergraduates and graduates. Credit in this course may be applied towards a subject minor in Russian. Not offered in 1973-74.

Literature

UNDERGRADUATE COURSES

Lit 1 abc. Literature Past and Present. *9 units (3-0-6); first, second, third terms.* An exploration of major literary texts — poetry, narrative fiction, essays and plays — from the Middle Ages or the Renaissance to our own day. Readings will be chosen from English, American and Continental literatures, with the English tradition at the center. Literature will be considered both as the art of giving pleasure to man and the art of interpreting man. Using the historical approach the course will trace the development of new idioms and forms in response to changing concepts of life. The student will be defining the characteristics of Renaissance, baroque, neo-classical, romantic, Victorian, and twentieth-century literary expression, while searching for the permanent aesthetic qualities that keep a portion of the literary output of every age alive. Frequent analytical and critical papers will be assigned. Instructors: Staff.

Lit 3 abc. The Modes of Literature. *9 units (3-0-6); first, second, third terms.* A sequence of courses dealing with Western man's attitudes towards his experience as expressed in drama, narrative, and poetry. The ways in which literature explores man's relationship to himself and his world are studied through the forms of comedy and tragedy, epic and novel, lyric, narrative, and dramatic poetry. The material is drawn from acknowledged literary classics of the Graeco-Roman world, the Middle Ages, the Renaissance, the Age of Enlightenment, the Romantic Age, and the contemporary world. Frequent critical papers are assigned. Instructors: Staff. *Cannot be taken for credit by students who have received credit for En 7 abc.*

Lit 8. The Bible as Literature: the Old Testament Tradition. *9 units (3-0-6); first term.* A study of ancient Hebrew epic, legend, fiction, drama and poetry as represented in the King James Version of the Old Testament and Apocrypha. Instructor: Cozart.

Lit 9. The Classical Tradition: Homer and Virgil. *9 units (3-0-6); second term.* An introduction to the literature of the civilizations of ancient Greece and Rome. Concentrating upon the major figures of Homer and Virgil (in English translations), this course will explore the ways in which classical mythology, literature, and art have shaped the foundations of Western culture. Not offered 1973-74.

Lit 10. The Christian Tradition: Dante and Milton. *9 units (3-0-6); third term.* An introduction to the literature of the Middle Ages and the Renaissance and Reformation. Concentrating upon the major figures of Dante and Milton, this course will explore the ways in which poets attempted to integrate Western man's heritage of the Bible, ancient mythology, and classical literature and art. Instructor: Cozart.

Lit 13. Reading in English. *Units to be determined for the individual by the department.* Collateral reading in literature and related subjects, done in connection with regular courses in English or history, or independently of any course, but under the direction of members of the department. Graded pass/fail. Instructors: Staff. *Not available for credit toward humanities-social science requirement.*

Lit 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.

Lit 20. Summer Reading. *Units to be determined for the individual by the department. Maximum 9 units. Elective.* Reading in literature, history, and other fields during summer vacation, books to be selected from a recommended reading list, or in consultation with a member of the staff. Critical essays on reading will be required. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

HSS 99. See page 351 for description.

ADVANCED COURSES

Lit 100 abc. The Nineteenth and Twentieth Century Novel. *9 units (2-0-7); first, second, third terms.* A three-term exploration of the novels and novelists, European and English, of the late 19th and 20th centuries. No term is prerequisite to the other terms. A background to the modern novel will be provided, and such topics as symbolism and decadence, realism and experiment will be investigated. While surveying the development of the modern novel to the present time, the course will tend to concentrate on such major figures as Joyce, Conrad, Flaubert, Grass, Solzhenitsyn, Kafka, Mann, and Lawrence. Instructor: Mayhew.

Lit 101. Selected Topics in Literature. *Units to be determined by arrangement with the instructor.* Instructors: Staff and guest lecturers.

Lit 102 ab. Linguistics. *9 units (2-1-6); first, second terms. Open to sophomores, juniors, and seniors.* A two-term intensive introduction to the fundamental concepts and methods of current structural study of natural language (exemplified largely through English). Primary focus on three levels of linguistic analysis: (1) phonology, (2) morphology, and (3) syntax as descriptive and theoretical levels for the study, respectively, of (1) sound systems, (2) internal structure of words, (3) inter- and intraphrase and sentence structure and relations, including transformational grammar. Emphasis on current models of linguistic structure and implications of linguistic study for understanding human mental behavior, involving review of current work in semantics and psycholinguistics. Discussion of fields of application (linguistics and the computer, language in society, pedagogical linguistics). Instructor: Henisz-Dostert.

Lit 102 c. Topics in Linguistics. *9 units (1-2-6); third term. Prerequisite: En 102 ab or equivalent.* A seminar-type course focusing on major aspects of language structure, models of linguistic description and functions of language. Problems in syntax, semantics, psycholinguistics (including experiments) and sociological and biological aspects of language. Participants are expected to concentrate on individual or small-group research projects. Instructor: Henisz-Dostert.

Lit 105. The Colonial Background and the Beginnings of American Nationalism. *9 units (3-0-6); first term.* A study of the ideas, traditions and literary figures that led to the creation of a distinctively American literature. Among the authors studied will be Mather, Edwards, Franklin, Jefferson, Paine, Brown, Irving and Cooper. Instructor: Penn.

Lit 106. The American Renaissance. *9 units (3-0-6); second term.* A study of the principal authors and intellectual movements in the emerging American tradition. Authors studied will include Emerson, Poe, Thoreau, Melville, Hawthorne and Whitman. Instructor: D. Smith.

Lit 107. The Gilded Age. *9 units (3-0-6); third term.* A survey of American literature from the post-Civil War period to World War I. It will explore the conflict between the "genteel tradition" and the new social and intellectual forces. Emphasis will be placed on the writings of Mark Twain, Henry James, W. H. Howells, Henry Adams, Stephen Crane, and Theodore Dreiser. Instructor: D. Smith.

Lit 108 abc. Twentieth Century American Literature. *9 units (3-0-6); first, second, third terms.* An exploration of the literary forms, influences and works that have shaped American writing from World War I period until the present. The first term will deal with writers whose principal works were written before World War II. The second term will cover the postwar period. The third term will be devoted to the works of writers from outside the mainstream of the American tradition, including black authors, distinctively Jewish writers, and foreign-born authors. The first two terms cannot be taken for credit by students who have taken En 5 bc. Instructors: Langston, Penn, D. Smith.

Lit 110 abc. From Mysteries to Absurdism: A Survey of Drama. *9 units (3-0-6); first, second, third terms.* A three-term course which will trace the development of English and Continental drama from its medieval and Renaissance origin through French Classical Drama. Lit 110 b will include the 18th century "Age of Elegance," the Romantic Age and the 19th century to Ibsen. Lit 110 c will deal with leading British, American and Continental dramatists from Ibsen to the present. Special attention will be given to dramatic technique and to philosophical content. The three terms may be taken as a sequence or independently of each other. Instructor: Mandel.

Lit 118 ab. Twentieth Century Poetry. *9 units (3-0-6); first, second, third terms.* A two-term seminar on major poets, and poetic theories, of the twentieth century. The first term will concentrate on Frost, Eliot, Yeats, Auden, Thomas and other poets whose principal work was done before 1950. The second term will concentrate upon Lowell, Ginsberg, Wilbur, and other poets of the post-war and contemporary scene. Instructor: Clark.

Lit 119. Classical Literature in Translation: The Greek Tradition. *9 units (3-0-6); first term.* Readings in English of outstanding Greek authors. The course will include a study of the major classical genres, emphasizing the development of comedy, tragedy, lyric poetry, and history, philosophy, and religion. Not offered 1973-74.

Lit 120. Classical Literature in Translation: The Latin Tradition. *9 units (3-0-6); second term.* Outstanding works by Virgil, Ovid, Lucretius, Petronius, Terence, and Plautus in English translation will be considered in the light of the humane and religious traditions of Europe. Not offered 1973-74.

Lit 121. The Medieval Imagination in English. *9 units (3-0-6); third term.* A course designed to examine the major literary and cultural developments in England before and after the Norman Conquest, with special attention to Chaucer and the fourteenth century. The major forms — epic, romance, lyric, and drama — will be studied against their backgrounds in history, philosophy, painting and architecture. Instructor: Cozart.

Lit 123 abc. Shakespeare. *9 units (3-0-6); first, second, third terms. Prerequisite: 27 units of English.* A three-term study of a selection of comedies, histories and tragedies. The selection will differ each term, so all three terms may be taken for credit. No term of this course is prerequisite to other terms. Instructor: H. Smith. *Not available for credit to students who have credit for En 50 abc.*

Lit 125 ab. Sixteenth and Seventeeth Centuries. *9 units (3-0-6); first, second terms. Prerequisite: 27 units of English.* A course designed to acquaint the student with the principal figures and genres of the period from the Reformation to the Restoration. It includes the Humanists, Elizabethan poetry, non-Shakespearian drama, seventeenth century prose writers, metaphysical and cavalier poets, Dryden, and Milton. Instructor: LaBelle.

Lit 126. Eighteenth Century. *9 units (3-0-6). Prerequisite: 27 units of English.* A study of the most important authors, genres, and critical theories of the Augustan and later eighteenth-century period. Authors include Dryden, Swift, Pope, Johnson and the Restoration and eighteenth-century dramatists. (Strongly recommended for English majors.) Instructor: Clark.

Lit 127. Earlier English Novel. *9 units (3-0-6); third term.* The novel from Richardson and Fielding to Scott and Jane Austen. Instructors: Staff.

Lit 128. The Nineteenth Century British Novel. *9 units (3-0-6); second term.* A study of the emergence of modern prose and perspectives, with particular attention to the latter part of the century, the great age of the novel. Among various foci: the evolving sensibility of the hero; the relations of hero to landscape and to society; the difficult exclusiveness of morality and esthetics. Novelists include Scott, Austen, the Brontes, Dickens, Thackeray, George Eliot, Hardy. Instructor: Ende.

Lit 129 ab. British and European Romantic Literature. *9 units (3-0-6); second, third terms. Prerequisite: 27 units of English.* An approach to the literary expression of the profound shift in sensibility and values that we call romanticism. Topics include revolutionary desires and individual creativity; vision, imagination, and the natural world; apocalypse or salvation without transcendence; and the ambiguous relation of writers to their predecessors. Readings in Milton, Blake, Wordsworth, Goethe, Holderlin, Byron, Shelley, Keats, Stendhal, Baudelaire, Dostoevsky, Wallace Stevens. (Strongly recommended for English majors.) Instructor: Ende.

Lit 132. The Fiction of William Faulkner. *9 units (3-0-6); third term. Prerequisite: 27 units of English or instructor's permission.* An investigation of the ideas, forms, and development of the novels and short stories of William Faulkner. Emphasis will be divided between reading and research. Instructor: Langston.

Lit 135. Modern Literary Criticism. *9 units (2-0-7); third term.* Modern literary critics and critical theories. Selected works of the traditional, aesthetic, historical, psychoanalytic and archetypal or genre schools of critical theory, as represented by such recent critics as T. S. Eliot, F. R. Leavis, George Lukacs, Northrop Frye, Wayne C. Booth, and others. (Strongly recommended for English majors.) Instructor: Mayhew.

Lit 150 abc. Literature in Translation. *9 units (3-0-6); first, second, third terms. Open to sophomores, juniors, and seniors.* A coherent body of French, German, Russian, or other literature will be covered each term. The content of each course may vary from year to year, and will be announced by the Registrar and posted by the Humanities and Social Sciences Division before preregistration. The readings, lectures, discussions, papers, and examinations will be in English, although language students may request to do some or all their work in the original. The three terms may be taken independently of each other. Instructors: Language and Literature Staff. *(See also L 150 abc.)* Course may be taken more than once, if content varies.

Lit 151. Science Writing, Communications, and Language. *9 units (3-0-6); second term.* This course deals with the development of brevity and clarity in the communication of scientific and engineering subjects to non-scientists and engineers. It requires a 700-word essay written each week. Subjects for the essays will be guest lectures that deal with the various languages of science and the techniques and methods involved in the flow, processing, and dissemination of information. Instructor: Bengelsdorf.

Materials Science

UNDERGRADUATE COURSES

MS 4. Introduction to Materials Science. *(Same as APh 4.) 6 units (2-0-4); third term.* Selected engineering systems, such as jet engines, superconducting transmission lines and nuclear reactors, are discussed in terms of the critical role played by materials in their construction and performance. Those material properties of greatest significance are explored to show how they are governed by the structure and basic physics and chemistry of the material. Graded pass/fail. Instructor: Wood.

MS 5 abc. Structure and Properties of Solids. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 abc, Ph 2 abc, AM 97 a.* The purpose of this course is to acquaint the student with the principles underlying the properties of solid materials. The electronic structure of atoms, the types of bonds between atoms in molecules and crystals, crystal structure and its determination by X-ray diffraction, and the band theory of crystalline solids are discussed. Topics in the physical properties of solids include: electrical and thermal conductivity; the dielectric properties of insulators; diamagnetism, paramagnetism, ferromagnetism, and antiferromagnetism; specific heat; thermoelectric effects. An introduction to statistical thermodynamics is given. Rate processes such as diffusion and phase transformations in solids are discussed briefly. Elastic and plastic deformation of crystals, the concept of dislocations, properties, and interactions of dislocations are studied and applied to discussions of mechanical properties of polycrystalline aggregates, influence of grain size, alloying and phase dispersion, and high-temperature creep and fracture. Texts: *The Physics of Engineering Solids,* Hutchison and Baird (first and third terms); *Solid State Physics,* Dekker (second term). Instructors: Buffington (MS 5 b), Wood (MS 5 a, c).

MS 10. Engineering Physical Metallurgy. *9 units (3-0-6); first term.* 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. Text: *Physical Metallurgy for Engineers.* Clark and Varney. Instructors: Clark, Buffington.

MS 11. Metallography Laboratory. *9 units (0-6-3); second term. Prerequisite: MS 10.* The technique of metallographic laboratory practice including microscopy, preparation of specimens, etching reagents and their use, photomicrography. The study of the microstructure of ferrous and non-ferrous metals and alloys for different conditions of treatment. Text: *Principles of Metallographic Laboratory Practice,* Kehl. Instructor: Clark.

ADVANCED COURSES

MS 100. Advanced Work in Materials Science. The staff in materials science will arrange special courses or problems to meet the needs of students working toward the M.S. degree or of qualified undergraduate students. Graded pass/fail for research and reading.

MS 101 abc. Introduction to Crystal Kinetics. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 97 a or equivalent.* First term: treatment of crystal imperfections, their interactions, and their influence on some physical and mechanical properties. Text: Hull, *Introduction to Dislocations.* Second term: fundamentals of diffusion in the solid state; taught at the level of Manning, *Diffusion Kinetics for Atoms in Crystals,* and Shewmon, *Diffusion in Solids.* Third term: discussion of nucleation and growth and phase transformation in one and two component systems; taught at the level of Christian, *The Theory of Transformations in Metals and Alloys.* Instructors: Lau, Vreeland.

MS 102 abc. Introduction to Crystal Structure and Diffraction Techniques. *9 units (3-0-6); first, second, third terms. First term:* structure of crystals, symmetry operations, symmetry classes and space groups; reciprocal lattice and its use in interpreting the x-ray diffraction patterns obtained by the Laue, the rotating crystal, and the powder methods of crystal structure analysis; structure of the elements in relation to their electronic configuration; various types of alloys and phase diagrams; factors governing the formation of solid solutions and intermediate phases (Hume-Rothery rules); nature of amorphous alloys and their unusual properties. Text: Barrett and Massalski, *Structure of Metals. Second term:* theory and application of image-forming systems used to study defects and phases in crystalline solids; transmission electron microscopy, x-ray topography, scanning electron microscopy, and field ion microscopy; wave mechanical descriptions of these systems will be developed as an aid to fully understanding the associated image contrast; taught at the level of Amelinckx, *et al.* Ed., *Modern Diffraction and Imaging Techniques in Material Science. Third term:* various diffraction techniques used to study defects and phases in crystalline solids; Kirchhoff theory of diffraction, transmission electron diffraction, low-energy electron diffraction, neutron diffraction, X-ray and electron small angle scattering; taught at the level of Born and Wolf, *Principles of Optics.* Instructors: *first term,* Duwez; *second term,* Villagrana; *third term,* Villagrana.

MS 104 abc. Materials Science Laboratory. *9 units (0-6-3); first, second, third terms.* The purpose of this course is to familiarize students with the relationship between materials properties and structure, and with the equipment and techniques used in materials science laboratories to study these relationships. Any one term may be taken independently of the others. First term: metallurgical studies of materials of current technological interest utilizing optical metallography and photomicrography, temperature measurements and cooling curves to study phase transformations. Second term: techniques used in the study of crystal defects and their influence on physical and mechanical properties; relationship between crystal structure and properties studied in experiments which utilize optical microscopy, electron microscopy, and X-ray topography. Third term: X-ray metallography involving the determination of crystal structures, use of the X-ray spectrometer, and the application of X-ray diffraction methods to the study of phase diagrams. Instructors: *first term,* Clark, Wood; *second term,* Villagrana, Vreeland; *third term,* Duwez.

MS 105. Mechanical Behavior of Metals. *9 units (3-0-6); second term. Prerequisites: AM 97 abc, MS 5 abc.* A study of the mechanical behavior of metals for engineering applications. Elastic behavior of anisotropic materials and polycrystalline aggregates. Yielding, plastic flow, and strengthening mechanisms, the influence of temperature and rate of loading on plastic deformation. Fracture of metals by ductile flow, brittle cracking, fatigue, and creep. Behavior under impact loading. Instructor: Wood.

MS 110. Special Topics in Physical Metallurgy. *9 units (3-0-6); third term. Prerequisite: MS 10 or MS 101 abc.* The emphasis is on recent developments, so topics will vary from year to year. Both metals and nonmetals are considered. Areas of interest include: the influence of special environments, such as nuclear reactors and high temperatures; the development of specific physical properties, such as magnetic and electrical properties; the study of special systems and procedures, such as transformations in titanium-base alloys, ultra-high strength steels, and fiber reinforcement of metals. Instructor: Buffington.

MS 200. Advanced Work in Materials Science. The staff in materials science will arrange special courses or problems to meet the needs of advanced graduate students.

MS 202. Advanced Electron Diffraction Theory. *9 units (3-0-6); first term. Prerequisites: MS 102 bc, APh 50 abc, or equivalent.* Advanced topics in transmission electron microscopy and diffraction: noncolumn approximation dynamical theory, inelastic scattering, computer enhancement of electron micrographs, and advanced image and diffraction analysis techniques. Instructor: Villagrana.

MS 205 ab. Dislocation Mechanics. *9 units (3-0-6); second, third terms. Prerequisites: MS 101 abc, MS 102 abc.* The theory of crystal dislocations in isotropic and anisotropic crystals. Applications of dislocation theory to physical and mechanical properties of crystals taught at the level of Hirth and Lothe, *Theory of Dislocations.* Instructors: Vreeland, Wood.

MS 250 abc. Advanced Topics in Materials Science. *6 units (2-0-4); first, second, third terms.* The content of this course will vary from year to year. Topics of current interest will be chosen according to the interests of students and staff. Visiting professors may present portions of this course from time to time. Instructors: Staff.

MS 300. Thesis Research.

Other courses related to Materials Science include:

Ae 210 abc	Advanced Solid Mechanics (See Aeronautics Section)
Ae 213	Fracture Mechanics (See Aeronautics Section)
Ae 221	Theory of Viscoelasticity (See Aeronautics Section)
AM 135 abc	Mathematical Elasticity Theory (See Applied Mechanics Section)
AM 140 abc	Plasticity (See Applied Mechanics Section)
AM 141 abc	Wave Propagation in Solids (See Applied Mechanics Section)
APh 102 abc	Applied Modern Physics (See Applied Physics Section)
APh 105 abc	States of Matter (See Applied Physics Section)
APh 114 abc	Solid-State Physics (See Applied Physics Section)
APh 181 abc	Physics of Semiconductors and Semiconductor Devices (See Applied Physics Section)
APh 185 abc	Ferromagnetism (See Applied Physics Section)
APh 214 abc	Solid-State Physics (See Applied Physics Section)
ChE 107 abc	Polymer Science (See Chemical Engineering Section)
ChE 207 abc	Mechanical Behavior and Ultimate Properties of Polymers (See Chemical Engineering Section)
Ch 21 abc	The Physical Description of Chemical Systems (See Chemistry Section)
Ch 24 abc	Elements of Physical Chemistry (See Chemistry Section)
Ch 122 ab	The Structure of Molecules (See Chemistry Section)
Ch 124 abc	Elements of Physical Chemistry (See Chemistry Section)
Ch 129 abc	The Structure of Crystals (See Chemistry Section)
Ch 223 ab	Statistical Mechanics (See Chemistry Section)
Ph 125 abc	Quantum Mechanics (See Physics Section)
Ph 221	Topics in Solid-State Physics (See Physics Section)

Mathematics

UNDERGRADUATE COURSES

Ma 1 abc. Freshman Mathematics. *9 units (4-0-5); first, second, third terms. Prerequisites: High school algebra and trigonometry.* Topics covered: the calculus of functions of one variable and an introduction to differential equations; vector algebra; analytic geometry in two and three dimensions; infinite series. The course work consists of two general lectures each week in which the mathematical notions of the calculus and the other topics listed above are presented and two class recitations which provide active practice in applications of the corresponding mathematical techniques. Instructors in charge: Bohnenblust, Dean, Fuller.

Ma 1.5 abc. Advanced Placement Freshman Mathematics. *9 units (4-0-5); first term. 12 units (5-0-7); second and third terms.* This course is intended for entering freshmen who are given advanced placement in mathematics but who do not qualify for Ma 2. The course covers the material for Ma 2 together with certain topics from Ma 1. Students who complete this course will have satisfied the Institute requirement for Ma 1 abc and Ma 2 abc. Instructors: Carroll, Lautzenheiser, Moore.

Ma 2 abc. Sophomore Mathematics. *9 units (4-0-5); three terms.* A continuation of the freshman mathematics course extending the calculus to functions of several variables. Topics are selected from linear algebra, multiple integrals, vector analysis, ordinary and partial differential equations, probability, and numerical analysis.

Ma 5 abc. Introduction to Abstract Algebra. *9 units (3-0-6); three terms.* Groups, rings, fields, and vector spaces are presented as axiomatic systems. The structure of these systems is studied, making use of the techniques of automorphisms, homomorphisms, linear transformations, subsystems, direct products, and representation theory. Many examples are treated in detail. Instructors: Hall, Kisilevsky, Smith.

Ma 31. Introduction to the Constructive Theory of Functions. *9 units (3-0-6). Prerequisite: Ma 1 abc.* Polynomial approximation. The Weierstrass theorem and the Bernstein polynomials. Extremal properties of the Chebyshev polynomials. Markov's theorems. Classical orthogonal polynomials. Applications to interpolation and approximation integration. Not offered in 1973-74.

Ma 91. Special Course. In 1973-74 a special course will be given.

Ma 91 c. Basic Numerical Mathematics-Numerical Algebra. *11 units (3-2-6); third term.* Instructor: J. Todd.

Ma 92 abc. Senior Thesis. *9 units (0-0-9); three terms. Prerequisite: Approval of adviser.* Open only to seniors who are qualified to pursue independent reading and research. The work must begin in the first term and will be supervised by a member of the staff. Students will consult periodically with their supervisor, and will submit a thesis at the end of the year. Graded pass/fail.

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. Graded pass/fail.

ADVANCED COURSES

[A] The following courses are open to undergraduate and graduate students.

Ma 102 ab. Differential Geometry. *9 units (3-0-6).* Selected topics in metrical differential geometry. Not offered in 1973-74.

Ma 103. Algebraic Geometry. *9 units (3-0-6); third term. Prerequisite: Ma 5 abc.* A study of the relations between geometric objects (varieties) and the algebraic structures attached to them. Instructor: Wales.

Ma 104 ab. Projective Geometry. *9 units (3-0-6); first, second terms. Prerequisite: Ma 5 abc.* Foundations of projective geometry. Theorems of Desargues and Pappus. Introduction of coordinates. Finite projective planes. Instructor: Dean.

Ma 108 abc. Advanced Calculus. *12 units (4-0-8); three terms.* In this course, advanced techniques and applications of the theory of real and complex analysis are treated. An introduction to metric spaces is the point of departure for the theory of convergence, and applications are made to infinite series and infinite products of real and complex numbers. The theory of the Lebesgue integral of functions of one or more variables is considered. Other topics include: functions defined by integrals; Fourier series and integrals; Poisson summation formula. Instructors: Apostol, Bennett.

Ma 109. Delta Functions and Generalized Functions. *9 units (3-0-6). Prerequisite: Ma 108 or equivalent.* Introduction to operational calculus and to delta functions. Applications to ordinary and partial differential equations. Not offered in 1973-74.

Ma 112 abc. Statistics. *9 units (3-0-6); three terms.* The first term is an introductory course covering the standard techniques most frequently applied in science and engineering, including elementary probability theory, hypothesis testing, least squares, and analysis of variance. The second and third terms include estimation theory, nonparametric inference, sequential analysis and statistical decision theory. Instructor: Lorden.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 5 abc or equivalent.* The predicate calculus and functional calculi of first order are presented and problems in the foundations of mathematics are studied. Included are Boolean algebra, theorems of Gödel, axiomatic set theory, and theory of cardinal and ordinal numbers. Instructor: Nadel.

Ma 118 abc. Functions of a Complex Variable. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Review of the basic concepts of the theory of analytic functions (Cauchy's theorem, singularities, residues, contour integration, analytic continuation). Further topics selected from: entire functions, conformal mapping, differential equations, special functions, applications of complex variable analysis. Instructor: Bohnenblust.

Ma 120 abc. Abstract Algebra. *9 units (3-0-6); three terms. Prerequisite: Ma 5.* Abstract development of the basic structure theorems of groups, commutative and noncommutative rings, lattices, and fields. Instructor: Dilworth.

Ma 121 abc. Combinatorial Analysis. *9 units (3-0-6); three terms. Prerequisite: Ma 5.* Elementary and advanced theory of permutations and combinations. Theory of partitions. Theorems on choice including Ramsey's theorem and the Hall-König theorem. Existence and construction of block designs with reference to statistical design of experiments, linear programming, and finite geometries. Instructor: Ryser.

Ma 125 abc. Analysis of Algorithms. *11 units (3-2-6); three terms.* Mathematical theory associated with algorithms for information processing; expected time and space requirements of algorithms, comparison of algorithms, construction of optimal algorithms, theory underlying particular algorithms. Instructor: J. Todd.

Ma 128 ab. Lie Algebras. *9 units (3-0-6); first, second terms.* Topics in the first term will include solvable and nilpotent Lie Algebras and the classification theorem for simple Lie Algebras in terms of the Dynkin Diagram. In the second term applications will be given including a discussion of Chevalley Groups. Instructor: Wales.

Ma 137 a. Real Variable Theory. *9 units (3-0-6); first term. Prerequisite: Ma 108 or equivalent.* Point set topology, measure theory and integration theory. The theory of the Lebesgue L^p-spaces of measurable functions. Functions of bounded variation and the theory of differentiation of functions of a real variable. Introduction to Fourier analysis, ergodic theory and the theory of integral equations. Instructor: Anderson.

Ma 141 abc. Ordinary Differential Equations. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Existence, uniqueness, continuous dependence on parameters of solutions of differential equations. Singular points, periodic solutions, stability, boundary value problems, eigenvalues. Not offered in 1973-74.

Ma 142 abc. Introduction to Partial Differential Equations. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Topics will include the following: Equations of the first order. Linear equations of the second order. Boundary value and eigenvalue problems for elliptic equations. Initial value and initial boundary value problems for parabolic and hyperbolic equations. Applications to problems of mathematical physics. Not offered in 1973-74.

Ma 143 ab. Introduction to Functional Analysis. *9 units (3-0-6); second, third terms. Prerequisite: Ma 108 or equivalent.* General theory of Hilbert and Banach spaces. Hahn-Banach extension principle, Banach-Steinhaus uniform boundedness principle, closed graph theorem, Krein-Milman theorem. Weak topologies. Separable and reflexive Banach spaces. Spectral analysis in Hilbert space. Operational calculus of operators on Banach spaces. Riesz-Schauder theory of compact operators. Instructor: Anderson.

Ma 144 ab. Probability. *9 units (3-0-6); second, third terms.* The course covers the basic concepts and techniques of modern probability theory, including conditional expectation, characteristic functions, laws of large numbers, and the central limit theorem. Also included is an introduction to stochastic processes such as Brownian motion, Poisson processes, and Markov chains, with applications. Not offered in 1973-74.

Ma 150 abc. Combinatorial Topology. *9 units (3-0-6); three terms.* Introduction to combinatorial topology. The course covers homology and cohomology theory with applications to fixed point theorems and homotopy theory. Selected topics from the theory of fiber bundles. Not offered in 1973-74.

Ma 151 abc. Fixed Point Theory and Its Applications to Analysis. *9 units (2-0-7); three terms.* Derivation of the finite dimensional index via differential forms. The Schauder fixed point theorem. The contraction principle. Leray-Schauder fixed point theory for compact maps. Existence theorems for differential and integral equations. Current research on monotone and non-expansive maps and minimization problems for nonlinear functionals. Instructors: DePrima, 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. Not offered in 1973-74.

Ma 165. Diophantine Analysis. *9 units (3-0-6); third term. Prerequisite: Ma 5.* The study of rational or integral solutions of equations. Theory of rational approximations to irrational numbers, and theory of continued fractions. The theorems of Thue-Siegel and Roth will be included. Not offered in 1973-74.

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. Graded pass/fail. Instructors: Staff.

Ma 191. Special Course. *9 units (3-0-6).* In 1973-74 three special courses will be given:

Ma 191 a. Sums of Squares. *First term. Prerequisite: Ma 120 or equivalent.* Sums of squares in number theory. Formally real fields. Composition. Positive definite quadratic forms. Positive matrices and operators. Positive polynomials. Instructor: O. Todd.

Ma 191 b. Local Fields and p-adic Numbers. *Second term. Prerequisites: Ma 160 or Ma 120 recommended.* Topics to include: basic properties of p-adic numbers. Algebraic extensions of local fields. Ramification theory. Instructor: Kisilevsky.

Ma 191 c. Theory of Equimeasurable Rearrangements of Measurable Functions. *Prerequisites: Ma 137 a and Ma 143 ab or equivalent are recommended.* Rearranging the value of a measurable function in such a way as not to change the value of its integral has become a powerful tool in analysis. In this course we shall discuss the theory of equimeasurable rearrangements from the point of view of integration theory. The ideas will be applied to the so-called Hardy-Littlewood-Pólya inequalities for convex functions and to the theory of doubly stochastic transformations. Instructor: Luxemburg.

[B] The following courses are open primarily to graduate students.

Ma 205 abc. Advanced Numerical Analysis. *9 units (3-0-6); three terms. Prerequisite: AMa 105 or equivalent.* Discussion of areas of current interest in numerical analysis and related mathematics, such as: matrix inversion and decomposition, ordinary differential equations, partial differential equations, integral equations, conformal mapping, discrete problems, linear programming and game theory, approximation theory, applications of functional analysis, theory of machines, theory of programming, theory of context-free languages, estimates for characteristic values of matrices. Each quarter will be treated as a separate unit. Where appropriate, accompanying laboratory periods will be arranged as a separate reading course. Not offered in 1973-74.

Ma 216 abc. Advanced Mathematical Logic. *9 units (3-0-6); three terms.* The propositional and predicate calculus. Gödel's completeness theorem. Recursive function theory and applications: Gödel's incompleteness theorem, undecidability. A treatment of the von Neumann-Bernays-Gödel set theory. Discussion of the axiom of choice, continuum hypothesis and inaccessible sets. Not offered in 1973-74.

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. Instructor: Aschbacher.

Ma 223 ab. Matrix Theory. *9 units (3-0-6); second, third terms. Prerequisite: Ma 120 or equivalent.* Algebraic, arithmetic and analytic aspects of matrix theory. Instructor: O. Todd.

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. Not offered in 1973-74.

Ma 226 ab. Ring Theory. *9 units (3-0-6). Prerequisite: Ma 120 or equivalent.* Selected topics in the structure of rings leading from classical theorems to areas of current research. Topics covered will include the role of the radical, decomposition theory, representation theory, group rings, polynomial identity rings, algebras, and commutative ideal theory. Instructor: Tobin.

Ma 238 abc. Advanced Complex Variable Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 118 or equivalent.* In this course the knowledge of basic parts of the classical theory of analytic functions is assumed, and special topics are presented introducing topological and group-theoretical considerations, and relations to functional analysis. The topics will be selected from: linear spaces of analytic functions, conformal mapping, algebraic functions, Riemann surfaces, functions of several complex variables, singular integral equations. Not offered in 1973-74.

Ma 243 ab. Functional Analysis. *9 units (3-0-6); second, third terms. Prerequisite: Ma 143 or equivalent.* Discussion of the theory of normed linear spaces; the closed graph theorem; the Riesz-Schauder theory; topics in Hilbert space; Banach algebras. Instructor: Tzafriri.

Ma 244 ab. Advanced Probability. *9 units (3-0-6); first, second terms. Prerequisite: Ma 144 or equivalent.* An exposition of probability theory in general sample spaces. Topics will include the following: modes of convergence of random variables, sequences of independent random variables, the central limit theorem, infinitely divisible distributions, conditional expectation, ergodic theory and the role of entropy in ergodic theory (and information theory). Not offered in 1973-74.

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 324 abc. Seminar in Matrix Theory. *Units to be arranged. Three terms.*

Ma 325 abc. Seminar in Algebra. *6 units. Three terms.*

Ma 340 abc. Special topics in Analysis. *9 units. Three terms.*

Ma 345 abc. Seminar in Analysis. *6 units. Three terms.*

Ma 350 abc. Special topics in Geometry. *9 units. Three terms.*

Ma 355 abc. Seminar in Geometry. *6 units. Three terms.*

Ma 360 abc. Special topics in Number Theory. *9 units. Three terms.*

Ma 365 abc. Seminar in Number Theory. *6 units. Three terms.*

Ma 390. Research. *Units by arrangement.*

Ma 392. Research Conference. *2 units. Three terms.*

See also the list of courses in Applied Mathematics.

Mechanical Engineering

UNDERGRADUATE COURSES

ME 1 ab. Introduction to Design. *9 units (2-6-1); second, third terms. Prerequisite: Gr 1.* Through a coordinated series of seminars, laboratory problems, and field trips, the student is introduced to design in the broad sense. Essential graphical and analytical techniques are developed as effective tools for rapid engineering approximations useful in preliminary design. Elements of kinematics and dynamic analysis of machines are treated along with other design criteria such as materials selection, manufacturing methods, economic factors, functional and aesthetic considerations, etc. Emphasis is placed on the rational imaginative approach and basic simplicity in formulating design concepts. Instructor: Welch.

ME 3. Materials and Processes. *9 units (3-0-6); second term. Prerequisites: Ph 1 ab, Ch 1 abc.* A study of the materials of engineering and of the processes by which these materials are made and fabricated. The fields of usefulness and the limitations of alloys and other engineering materials are studied, and also the fields of usefulness and limitations of the various methods of fabrication and of processing machines. The student is not only made acquainted with the technique of processes but with their relative importance industrially and with the competition for survival which these materials and processes continually undergo. Text: *Engineering Materials and Processes,* Clark. Instructors: Buffington, Clark.

ME 5 abc. Design. *9 units (2-6-1); first, second, third terms. Prerequisite: AMa 95 ab or concurrently.* The purpose of this course is to develop creative ability and engineering judgment through work in design and engineering analysis. Existing devices are analyzed to determine their characteristics and the possibilities for improving their performance or economy and to evaluate them in comparison with competitive devices. Practice in the creation or synthesis of new devices is given by problems in the design of machines to perform specified functions. The fundamental principles of scientific and engineering knowledge and appropriate mathematical techniques are employed to accomplish the analysis and designs. Text: *Design and Production,* Kent. Instructor: Welch.

ME 17 abc. Thermodynamics. *(Same as APh 17 abc.) 9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* An introduction to the laws governing the properties of matter in equilibrium and some aspects of non-equilibrium behavior. Definition and scales of temperature. The laws of classical thermodynamics. Thermodynamic potentials, Maxwell's relations, calculation of thermal properties, and applications to various homogeneous systems. First-order changes of phase and the Clausius-Clapeyron equation. Analyses of energy conversion cycles. General conditions for thermodynamic equilibrium, extremum properties of the thermodynamic potentials, and the thermodynamic inequalities. Chemical potential, mixtures of gases and vapors, solutions, basic chemical thermodynamics. Elementary statistical mechanics, ensembles, and statistical thermodynamics. Introduction to non-equilibrium thermodynamics, thermoelectric effects, and problems of heat conduction in solids. Thermodynamics of fluid flow. Some aspects of the kinetic theory of gases, calculation of transport properties by mean-free path methods and simplified forms of the Boltzmann equation. Instructor: Culick.

ME 19 ab. Fluid Mechanics and Gasdynamics. *9 units (3-0-6); first, second terms. Prerequi-*

sites: Ma 2 abc, Ph 1 abc. Basic equations of fluid mechanics, theorems of energy, linear and angular momentum, potential flow, elements of airfoil theory. Flow of real fluids, similarity parameters, flow in closed ducts. Boundary layer theory in laminar and turbulent flow. Introduction to compressible flow. Flow and wave phenomena in open channels. Instructors: Acosta, Sabersky.

ME 19 c. Heat and Energy Transfer. *9 units (3-0-6); third term. Prerequisites: ME 19 ab desirable or with instructor's permission.* An introductory course in energy and heat transfer. Energy conservation laws; introduction to flow machines. Basic differential equations of energy and mass transfer. Conduction of heat in solids, convection in moving fluids with application to heat exchange in thermal systems. Discussion of mechanical, chemical, nuclear and solar sources of energy and uses as time permits. Instructors: Sabersky, Acosta.

ADVANCED COURSES

ME 100. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses or problems to meet the needs of students working toward the M.S. degree or of qualified undergraduate students. Graded pass/fail for research and reading.

ME 101 abc. Advanced Design. *9 units (1-6-2); first, second, and third terms. Prerequisite: ME 5 abc or equivalent.* Creative design and analysis of machines and engineering systems are developed at an advanced level. Laboratory problems are given in terms of the need for accomplishing specified end results in the presence of broadly defined environments. Investigations are made of environmental conditions to develop quantitative specifications for the required designs. Searches are made for the possible alternate designs and these are compared and evaluated. Preferred designs are developed in sufficient detail to determine operational characteristics, material specifications, general manufacturing requirements and costs. Instructor: Welch.

ME 118 abc. Advanced Thermodynamics and Energy Transfer. *9 units (3-0-6); first, second, and third terms. Prerequisites: ME 17 abc, ME 19 abc, or equivalent.* Review of basic equations of fluid motion, energy, and mass transfer. Heat conduction in stationary and moving solids, with change of phase; numerical and approximate methods. Analysis of laminar flows with heat and mass transfer in free and forced convection. Turbulent flows and application of Reynolds analogy to heat and mass transfer. Introduction to thermal radiation, characteristics of solids and gases. Radiative transfer in enclosures. Topics in two-phase flow, boiling heat transfer, condensation and application to technological and environmental problems will be taken up as time permits. Instructors: Acosta, Sabersky.

ME 126. Fluid Mechanics and Heat Transfer Laboratory. *(Same as ChE 126.) 9 units (0-6-3); third term. Prerequisites: ME 17 abc, ME 19 ab, or equivalent.* Students with other background shall obtain instructor's permission prior to registration. Introduction to some of the basic measurement techniques and phenomena in the fields of heat transfer, fluid mechanics, chemical kinetics, and unit operations. The student may select several short projects from a rather wide list of possible experiments. The selection will be based on the individual needs and interests of the student. The course is generally taken by first-year graduate students and seniors. Specific areas from which experiments may be selected include free and forced convection, boiling heat transfer, combustion, solid-state energy conversion, free surface flows, supersonic flows, homogeneous gas-phase kinetics, homogeneous gas-solid interaction, homogeneous liquid-phase kinetics and control. Instructors: Acosta, Shair, Welch, Zukoski.

ME 200. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses on problems to meet the needs of advanced graduate students.

ME 300. Thesis Research.

Many advanced courses in the field of Mechanical Engineering may be found listed in other engineering options such as:

Applied Mechanics
Applied Physics
Hydraulics
Jet Propulsion
Materials Science

Music

Mu 11. Fundamentals of Music. *5 units (2-0-3); first term.* Course content: notation, music reading, chord structures, keys, elementary ear training, basic keyboard harmony. For students with little or no previous music study. Offered the first term of each year. Instructor: Ochse.

Mu 12. Music History and Music Theory. *9 units (3-0-6); second term. Prerequisite: Mu 11, or successful completion of the Music Fundamentals Test.* Course content, alternate years, beginning in January, 1972: history of music during the Renaissance and Baroque periods; analysis of forms and styles. Course content, alternate years, beginning in January, 1973: music theory, including diatonic chord progressions, common chord modulations, non-harmonic tones, composition in 2, 3, and 4 parts, harmonic analysis. Instructor: Ochse.

Mu 13. Music History and Music Theory. *9 units (3-0-6); third term. Prerequisite: Mu 12.* Course content, alternate years, beginning in March, 1972: history of music from 1750 to the present; analysis of forms and styles. Course content, third term of alternate years, beginning in March, 1973: music theory, including chromatic progressions and modulations, altered chords, composition in more advanced forms, introduction to counterpoint. Instructor: Ochse.

Mu 101. Selected Topics in Music. *Units to be determined by arrangement with the instructor.* Instructors: Staff and visiting lecturers.

Philosophy

UNDERGRADUATE COURSES

Pl 10. Introduction to Theory of Value. *9 units (3-0-6); first term.* An exploration of some of the important normative questions facing modern man. Topics to be discussed will include the validation of value-judgments, the search for goals and principles to guide personal decision-making, and the just society. Instructor: Hertz.

Pl 11. Classical and Modern Approaches to Self. *9 units (3-0-6); third term.* An examination of philosophical views, both occidental and oriental, classical and contemporary, on the problem of self-identity. Included will be representative views from idealism, rationalism, pragmatism, existentialism, mysticism, esotericism, and modern psychology. Instructor: Bures.

Pl 12. Induction. *9 units (3-0-6).* Inductive logic and the foundations of probability. Investigation of the inductive basis of scientific theories. The course will be built around readings in the contemporary literature. Instructor: Thompson.

Pl 13. Reading in Philosophy. Elective in any term or for summer reading with consent of specific instructor. Units to be determined by consultation with the instructor. Reading in philosophy, supplementary to, but not substituted for, courses listed; supervised by members of the department. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

Pl 16. Life Cycles. *9 units (3-0-6); second term.* A study of life patterns, world cultures, and conceptions of human life. Instructor: Bures.

Pl 17. Introduction to Philosophy. *9 units (2-0-7); first term.* A study of a selected number of major philosophical systems by way of readings in the sources. Priority is given to philosophical traditions which are still existent and influential in the contemporary world. Instructor: Jones.

Pl 18. Existentialism and Modern Man. *9 units (3-0-6); third term.* A critical study of the development of Existentialism in France and Germany. The course will explore literary manifestations of the movement. Alienation in Existentialism and alienation in contemporary counter cultures will be compared. Instructor: Hertz.

Pl 19. Human Nature and Ethics. *9 units (3-0-6); first term.* A study of ethical values in relation to human nature and culture. Conceptions of human nature provide bases for study of human value systems. All phases of human inquiry which bear on human nature are considered. Instructor: Bures.

Pl 20. Theory of Knowledge. *9 units (3-0-6); second term.* The theory of knowledge both classical and modern, with emphasis on contemporary views. Topics to be discussed will include: the problem of perception and the status of our knowledge concerning the external world, other minds, the past and the future; theories of truth; the concept of rationality; the concept of a person. Instructor: Hertz.

HSS 99. See page 351 for description.

ADVANCED COURSES

Pl 100 abc. Philosophy of Science. *9 units (2-0-7); first, second, third terms. A full-year sequence.* A study of the relationships between science and philosophy. The three terms respectively concentrate on: language and logic, logical analysis of some basic problems in the philosophy of science such as measurement, causality, probability, induction, space, time, reality; human nature, science and society. Not open to new registrants second and third terms. Instructor: Bures.

Pl 101 abc. History of Thought. *9 units (2-0-7); first, second, third terms. A full-year sequence.* A study of the basic ideas of Western Civilization in their historical development. The making of the modern mind as revealed in the development of philosophy and in the relations between philosophy and science, art and religion. The history of ideas in relation to the social and political backgrounds from which they came. Instructor: Hertz.

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

Pl 103. World Views. *9 units (2-0-7); first term.* A study of world views and of the ways in which they are reflected in the literature, art, philosophy and science of different cultures. Several contrasting views will be selected for detailed study. Instructor: Jones.

Pl 104. Educational Issues and Problems. *9 units (3-0-6); first, third terms.* A course in educational theories, issues, and problems. Special emphasis on basic changes necessary to facilitate growth and restructuring of the public schools. Topics to include: innovative curricula, integration and the minority group student, new directions in teacher certification, student-teacher relations, political and financial control of the public schools, school administration and student rights, and the learning process. Selected requirements for credit include: required reading, a documented paper, a journal, and several visitations to local educational institutions. Selected guest speakers prominent in the field of education and psychology. Instructor: Browne.

Pl 113. Reading in Philosophy. Same as Pl 13 but for graduate credit.

IS 250 abc. Mathematical Linguistics. *9 units (3-0-6).* (See page 356.)

Physics

UNDERGRADUATE COURSES

Ph 1 abc. Kinematics, Particle Mechanics, and Electric Forces. *9 units (4-0-5); first, second, third terms. Prerequisites: High school physics, algebra, and trigonometry.* The first year of a two-year course in introductory classical and modern physics. Topics to be covered include the kinematics and dynamics of particles, planetary and harmonic motion, geometrical and physical optics, kinetic theory, and thermodynamics. After the first term the course is offered in two tracks; track A emphasizes fundamentals, while track B is at a somewhat higher mathematical level and covers more topics. In both tracks, emphasis is placed upon the application of the fundamental principles through the solution of problems. Instructors: Stone, Walker, Werner, Zachariasen and assistants.

Ph 2 abc. Electromagnetism and Quantum Mechanics. *9 units (4-0-5); first, second, 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. Topics to be covered include electricity and magnetism, Maxwell's equations, electromagnetic waves and elementary quantum mechanics. The course is offered in two tracks, similarly to Ph 1. In track B there is greater use of mathematics, and more emphasis upon quantum mechanics. Instructors: Barish, Gomez, Lauritsen, Neugebauer, Sciulli and assistants.

Ph 3. Physics Laboratory. *6 units; first, second, third terms.* Normally not offered to freshmen the first term. The six units cover a three-hour laboratory session per week, and three hours per week in preparation, library work, and writing of reports. This introductory laboratory course emphasizes the treatment of errors entering into physical measurements, the nature of probability and graphical analysis. It also contains experiments in direct current circuits and in the application of Newton's laws of motion to the behavior of masses moving on nearly frictionless surfaces. Instructors: Kavanagh, Pine and assistants.

Ph 4. Physics Laboratory. *6 units; third term only. Prerequisite: Ph 3 or equivalent.* This course is an extension of Ph 3 laboratory. It involves experiments in classical physics such as the harmonic oscillator, which is studied in both the mechanical and electrical forms. Other experiments are concerned with the properties of wave motion in various media and with some of the fundamental properties of gases. Instructors: Kavanagh, Pine and assistants.

Ph 5. Physics Laboratory. *6 units; first term. Prerequisites: Ph 1 abc, Ph 2 a (or taken concurrently) and Ph 3 or equivalent.* This is a continuation of Ph 3 laboratory. Measurements of physical quantities, their analysis and assignment of errors are stressed. Most of the experiments are concerned with topics in the theoretical course, Ph 2 a. These include experiments in electrostatics and direct currents. Instructors: Kavanagh, Pine and assistants.

Ph 6. Physics Laboratory. *6 units; second term. Prerequisites: Ph 1 abc, Ph 2 b (or taken concurrently) and Ph 3 or equivalent.* This laboratory course involves experiments in electromagnetic phenomena such as electromagnetic induction, properties of magnetic materials and high-frequency circuits. The mobility of ions in gases is studied and a precise measurement of the value of e/m of the electron may be found. Instructors: Kavanagh, Pine and assistants.

Ph 7. Physics Laboratory. *6 units; third term. Prerequisite: Ph 5 or Ph 6.* In this laboratory course, experiments are performed in atomic and nuclear physics. These include studies of the Balmer series of hydrogen and deuterium, the decay of radioactive nuclei, absorption of X rays and gamma rays, ratios of abundances of isotopes and the Stern-Gerlach experiment. Instructors: Kavanagh, Pine and assistants.

Ph 10 ab. Special Topics in Introductory Physics. *6 units (2-0-4); second, third terms.* An elective course for first-year students, based upon material covered in Ph 1 abc. The purpose of the course is to provide interested students an opportunity to penetrate more deeply into some of the topics covered earlier in Ph 1. Emphasis will be given to the analysis of problems of broad scientific and technical interest. Topics to be covered will be selected partly on the basis of class preference. Not offered in 1973-74.

Ph 77 ab. Advanced Physics Laboratory. *6 units; first, second, or third terms.* A two-term laboratory course open to junior and senior physics majors. The purpose of the course is to familiarize the student with laboratory equipment and procedures that are used in the research laboratory. The experiments are designed to illustrate fundamental physical phenomena, such as Compton scattering, nuclear and paramagnetic resonance, the photoelectric effect, the interaction of charged particles with matter, etc. Instructor: Whaling.

Ph 78 abc. Senior Thesis Experimental. *9 units; first, second, and third terms. Prerequisite: instructor's permission.* This course is intended to provide supervised experimental research experience, and is open only to senior physics majors. Requirements will be set by individual faculty members, but will include a term paper based upon actual laboratory experience. The selection of topics and the final report must be approved by the Physics Undergraduate Committee. Not offered on pass/fail basis. Instructors: Physics Staff.

Ph 79 abc. Senior Thesis Theoretical. *9 units; first, second, third terms. Prerequisite: instructor's permission.* This course is intended to provide supervised theoretical research experience and is open only to senior physics majors. Requirements will be set by individual faculty members, but will include a term paper based on the work performed. The selection of topics and the final report must be approved by the Physics Undergraduate Committee. Not offered on pass/fail basis. Instructors: Physics Staff.

Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with Professor Cowan, chairman of the Physics Undergraduate Committee, or any other member of the committee.

Ph 92 abc. Modern Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc, Ma 2 abc, or equivalents; Ph 106 abc concurrently.* Applications of quantum mechanics to atomic and nuclear phenomena. The one-electron atom, the periodic table, atomic spectra, and quantum statistics will be studied. In addition there will be an introduction to the interactions of radiation with matter. Additional selected topics will be studied, depending upon the instructor and the interests of the students. These might, for example, be chosen from the fields of solid-state physics, low-temperature physics, cosmic rays, elementary particles, nuclear physics, quantum optics, or astrophysics. Instructors: Cowan, Vogt.

Ph 93 abc. Topics in Contemporary Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 92 abc or Ph 125 abc.* A series of introductory one-term courses on topics of contemporary physics. In general, students may register for any particular term or terms. In 1973-74, the topics will be (a) nuclear physics, (b) elementary particle physics, and (c) low-temperature physics. Instructors: Boehm, Mercereau, Pine.

ADVANCED COURSES

Ph 106 abc. Topics in Classical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc, Ma 2 abc.* An intermediate course in the application of the basic principles of classical physics to a wide variety of subjects. It is intended that roughly half of the year will be devoted to mechanics, and half to electromagnetism. Topics to be covered include the Lagrangian and Hamiltonian formulations of mechanics, small oscillations and normal modes, boundary value problems, multipole expansions, and various applications of electromagnetic theory. Graduate students majoring in physics or astronomy will be given only 6 units credit for this course. Instructors: Davis, Corngold, Peck, Tollestrup.

Ph 112 abc. Modern Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 106, Ph 125 abc, or equivalents. Not open to students who have taken Ph 92.* A lecture and problem course on the physics of atoms, nuclei, and elementary particles. Among the topics discussed are: quantum mechanics, atomic and molecular structure, electromagnetic interactions, quantum statistical mechanics, superfluidity and superconductivity, selected topics from solid-state physics, nuclear structure physics, and elementary particle physics. Instructor: Tombrello.

Ph 118 abc. Electronic Circuits and their Application to Physical Research. *(Same as EE 118 abc.) 9 units (3-3-3); first, second, third terms.* A course on the fundamentals of analog and digital electronics with emphasis on proven techniques of instrumentation for scientific research. The first two terms will deal with the physical principles and properties of electronic components and circuits and the last will discuss the logical design of digital systems. Topics considered in the first two terms will include the theory of transient signal response in linear networks, the properties of solid state devices, basic passive and active circuit combinations, linear amplifiers, feedback theory, and the properties of currently available integrated circuits. The third term topics will include techniques of systematic logic design, Boolean algebra reductions using Karnaugh maps, the design of both synchronous and asynchronous sequential circuits, and existing computer aids for digital design. Common electronic instruments, computer interfaces, and typical digital control logic in scientific research will be used as illustrative examples. The homework will consist mostly of laboratory problems. Instructors: Gomez, Peck, Tollestrup.

Ph 125 abc. Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 abc. Recommended: Ph 92 abc, and either AMa 95 abc or Ma 108 abc.* Avail*able to juniors only by permission of instructor.* A fundamental course in quantum mechanics aimed at understanding the mathematical structure of the theory and its application to physical phenomena at the atomic and nuclear levels. The subject matter will include the various formulations of quantum mechanics, properties of operators, one-dimensional and central potentials, angular momentum and spin, scattering theory, perturbation theory, identical particles, and introductory relativistic quantum theory. Instructors: Firestone, Mathews.

Ph 127 abc. Statistical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 92 abc, Ph 106 abc.* This course will present a thorough introduction to problems in physics which are fundamentally statistical. Topics to be covered will include: fundamental laws and concepts of thermodynamics, kinetic theory and transport phenomena, statistical mechanics and the connection between macroscopic and atomic laws. Instructors: Plesset, Wu.

Ph 129 abc. Methods of Mathematical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or the equivalent. Recommended: either AMa 95 abc or Ma 108 abc.* Aimed at developing familiarity with the mathematical tools useful in physics, the course discusses practical methods of summing series, integrating, and solving differential equations, including numerical methods. The special functions (Bessel, Elliptic, Gamma, etc.) arising in physics are described, as well as Fourier series and transforms, partial differential equations, orthogonal functions, eigenvalues, calculus of variations, integral equations, matrices and tensors, and group theory. The emphasis is toward applications, with special attention to approximate methods of solution. Instructors: Fox.

Ph 171. Reading and Independent Study. Occasionally, advanced work involving reading, special problems, or independent study is carried out under the supervision of an instructor. Units in accordance with work accomplished. Approval of the instructor and of the student's departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 172. Experimental Research in Physics. *Units in accordance with the work accomplished.* Approval of the student's research supervisor and of his department adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 173. Theoretical Research in Physics. *Units in accordance with the work accomplished.* Approval of the student's research supervisor and of his departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 203 ab. Nuclear Physics. *9 units (3-0-6); second, third terms. Prerequisites: Ph 92 abc or Ph 93a, plus Ph 125 abc or equivalents.* A problem and lecture course in nuclear physics concerning experimental and theoretical methods for the study of nuclear structure. Topics include: review of angular momentum coupling, nuclear sizes and moments, two-body interactions and the deuteron, nuclear models including liquid drop, shell and collective models, electromagnetic transitions, and relativistic systems involving beta decay and muonic atoms. Instructor: Boehm.

Ph 205 abc. Advanced Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125 abc, Ph 92 abc.* The course will cover advanced nonrelativistic quantum mechanics and relativistic quantum mechanics with an introduction to field theory. Topics covered include angular momentum, transition probabilities, scattering theory, Dirac equation, Feynman diagrams, quantum electrodynamics, and other applications of field theory. Instructor: Feynman.

Ph 209 abc. Electromagnetism and Electron Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc.* Electromagnetic fields in vacuum and in matter; classical electron theory, retarded potentials, radiation, dispersion, and absorption; theories of the electric and magnetic properties of materials; selected topics in wave propagation; special relativity. Instructor: Papas.

Ph 213 ab. Nuclear Physics and Nuclear Astrophysics. *9 units (3-0-6); first, second terms.* A lecture or reading course in the applications of nuclear physics to astronomy, geochronology, cosmochronology and other fields. The first term reviews the fundamental properties, interactions and structure of nuclei. The experimental evidence on nuclear cross sections is analyzed in terms of current theories of nuclear reactions and is applied to the rates of nuclear processes under astrophysical circumstances. The second term covers energy generation (nuclear, gravitational and rotational) and element synthesis in stars, supernovae, and massive condensations with applications to pulsars, quasars, and extended radio sources. Nuclear evidence on the origin of the solar system and on the chronology of the Galaxy is discussed. Not offered in 1973-74.

Ph 221. Topics in Solid-State Physics. *9 units (3-0-6); third term. Prerequisite: APh 114 abc or equivalent.* A course on selected topics in solid state physics, with different subjects being presented each year. Not offered in 1973-74.

Ph 224 abc. Space Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 92, Ph 106 or equivalent.* A thorough exposition of theoretical and observational space physics. The first two terms will be devoted to theoretical foundations and will consist of an introduction to plasma physics, with application to various astrophysical situations. There will be detailed discussion of the solar wind, radiation belts, cosmic rays, interstellar medium and related phenomena. The third term will concentrate on observations and experimental techniques, with emphasis on cosmic rays, plasmas, magnetic fields, and high-energy photons. Instructor: Jokipii.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205 abc (may be taken concurrently).* A course in advanced techniques of elementary particle theory, including field theory, renormalization, dispersion theory, groups and symmetries, and other approaches of current interest. Not offered in 1973-74.

Ph 231 abc. High Energy Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125 abc or equivalent.* An introductory course covering the properties of elementary particles and their interactions, especially at high energies. Emphasis will be on discussion of problems of current experimental interest. Topics discussed include the classification of particles and their symmetries, experimental detection of particle properties, strong interactions at low and high energies, weak decays of strange and non-strange particles, problems associated with very high energy interactions. Instructor: Frautschi.

Ph 234 abc. Topics in Theoretical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 205 abc and Ph 231 abc, or instructor's permission.* Current topics of research in high energy physics will be presented. Independent study and research will be encouraged. The detailed content of this course may vary from quarter to quarter. Not offered in 1973-74.

Ph 236 abc. Relativity. *9 units (3-0-6); first, second, third terms. Prerequisite: A mastery of special relativity at the level of* Goldstein, *Classical Mechanics, or of* Leighton, *Principles of Modern Physics.* A systematic exposition of Einstein's general theory of relativity, with particular emphasis on applications to astrophysical and cosmological problems. Topics covered include a review of special relativity; accelerated observers in special relativity; modern differential geometry; the foundations of general relativity and of other geometric theories of gravity; past and future experimental tests of general relativity; relativistic stars; gravitational collapse; black holes; gravitational radiation; cosmology; singularities and singularity theorems. Instructor: Press.

Ph 237. Theoretical Nuclear Physics. *9 units (3-0-6); first term. Prerequisite: Ph 205 or equivalent.* A lecture course on non-relativistic scattering and reaction theory. The emphasis will be on various approximation methods for inelastic scattering and rearrangement collisions, with applications in several areas of physics. Not offered in 1973-74.

Ph 240 abc. Current Theoretical Problems in Particle Physics. *6 units (2-0-4); first, second, third terms. Prerequisite: Ph 230 abc or equivalent.* Emphasis on symmetries and broken symmetries. Discussion and argument are encouraged. Instructor: Gell-Mann.

Ph 241. Research Conference in Physics. *No credit; first, second, third terms.* Meets once a week for a report and discussion of the work appearing in the literature and that in progress in the laboratory. Advanced students in physics and members of the physics staff take part.

Ph 300. Research in Physics. *Units in accordance with work accomplished.* Ph 300 is elected in place of Ph 172 when the student has progressed to the point where his research leads directly toward the thesis of the degree of Doctor of Philosophy. Approval of the student's research supervisor and of his department adviser or registration representative must be obtained before registering.

Political Science

UNDERGRADUATE COURSES

PS 1. Political Psychology. *9 units (3-0-6); first term.* This course will survey the application in political studies of theories of individual psychology, and especially of theories of psychoanalytic persuasion. Through an analysis of the most successful works in this tradition, students will acquire a critical appreciation of the power, the limits, and the method of this approach. Materials will include psychological biographies, noted essays in psychoanalysis, and studies of leadership behavior. Instructors: Staff.

PS 2. Group Processes and Political Behavior. *9 units (3-0-6); second term.* The course will focus on selected works in the literature on group dynamics; isolate the principal ideas and assertions contained therein; and apply these to materials on politics. We will be primarily concerned with the studies of attitude formation, decision-making, innovation and leadership; and with applications in the areas of presidential decision-making, electoral choice, and the operation of Congressional committees. A critical secondary concern will be with evaluating the relative merit of this group dynamics literature and the theories of groups and committees deriving from the social choice literature in economics. Instructors: Staff.

PS 3. Stratification and Community Power. *9 units (3-0-6); third term.* The course will study theories of social inequality deriving from the classical works of Marx and Weber. It will then assess the validity of extensions of these theories in politics through the analysis of community power structures. Applications to the area of political change will be made through the studies of community responses to disasters. Instructors: Staff.

PS 8. Introduction to American Politics. *9 units (3-0-6); first term.* The major emphasis of the course will be placed on substantive topics. Sections of the course will be devoted to the electoral process, the legislative process, the judicial process, the bureaucracy, and the presidency. The course will focus on the American system, but aspects of Western European and British Commonwealth democracies will receive some attention where reliable studies exist. The theoretical framework of contemporary political science will be introduced via several nontechnical works, but emphasis will be placed on real-world happenings rather than theoretical esoterics. Instructor: Fiorina.

HSS 99. See page 351 for description.

ADVANCED COURSES

PS 101. Selected Topics in Political Science. *Units to be determined by arrangement with the instructor.* Instructors: Staff and visiting lecturers.

PS 102. Black Africa 800 A.D. to the Present. *9 units (2-0-7).* Topics relating to the origins of Americans of African descent, including African empires such as Ghana and Songhai, the Slave Trade, and the emergence of independent nations. Emphasis will be given to West Africa and there will be African lecturers. Instructors: Munger, in collaboration with Scudder and Bates.

PS 110 ab. Political Modernization and Development. *9 units (3-0-6); second, third terms.* The first term is devoted to the general literature in the field; the second, to case studies of African nations; e.g., Nigeria and Zaire. Topics will include: the nature and origins of political change, the formation of new elites and pressure groups, the erosion of traditional sources of power, the integrative role of political symbols, and the role of parties and bureaucracies in managing the process of change. Instructor: Bates.

PS 115. Seminar on National Security. *9 units (2-0-7).* The object of this course is to afford an opportunity to study some of the problems faced by the U.S. Government in the world today. Consideration will be given to such matters as the process of policy formation within the government, the relationship of disarmament and arms control to defense policy, and the role of international organizations in the development of an orderly world society. Instructor: Elliot.

PS 118. Democratic Theory. *9 units (3-0-6); third term.* This course will raise several types of questions and answer none. Is it possible to have a democracy; how ought citizens to act in a democracy; how do democratic governments and citizens of democratic politics actually behave; and is a democratic government necessarily just? Instructor: Ferejohn.

PS 120 ab. American Electoral Behavior and Party Strategy. *9 units (3-0-6); first, second terms.* A consideration of existing literature on the voting behavior of the citizen, moving to an examination of theoretical and empirical views of the strategies followed by the parties. Instructors: Fiorina, Ferejohn.

PS 121. Congressional Policy Formation and Legislative Process. *9 units (3-0-6); second term.* An analysis of decision making in legislative bodies with major emphasis on the American Congress. Where appropriate, comparative materials from state legislatures and non-American systems will be introduced. The course also includes an investigation into the impact of Congressional structure and practices on the kinds of policies which are produced by the Federal Government. Instructors: Fiorina, Ferejohn.

PS 125. Peasant Politics. *9 units (3-0-6); third term.* The course will study the political role of the peasantry. Topics will include: the behavior of peasants in the French, Russian and Chinese revolutions; the origins of peasant movements and insurgencies in the developing world; the rise of ethnic associations in Africa; urban migration as an alternative to political action; and the determinants of peasant political apathy. Particular attention will be paid to rural political organization — feudal relationships, local administration, the incidence and methods of taxation and conscription, etc. — and the effect of market relationships, e.g., shifts in the prices for agricultural commodities, consumer goods, agricultural inputs, on the level of wellbeing of peasant societies. Instructor: Bates.

PS 131. Mathematical Models of Political-Economic Decision Processes. *9 units (3-0-6); third term. Same as Ec 131 and SS 131.* Selected models will be reviewed with special emphasis on behavioral interpretations. Special attention will be given to simple majority rule and spatial models of electoral processes. Instructor: Plott.

PS 132. Strategy in Politics. *9 units (3-0-6); first term. Prerequisite: PS 131.* Game theory examined on a non-technical level, considering experimental work and political applications, with a focus on applications. Instructors: Fiorina, Ferejohn.

PS 135 abc. Political Geography of Developing Countries. *9 units (2-0-7).* The swift transition from colonialism or an undeveloped state to the present includes the growth of one-party states; the role of the military; tribal, religious, and class pressures; the internal and external role of boundaries; and new foreign policies including such regional groupings as the OAU and OAS. Emphasis on Africa with outside lecturers, including AUFS associates, on Latin America and Southeast Asia. Instructor: Munger.

PS 140. Seminar in Foreign Area Problems. *9 units (3-0-6); second term.* The object of this course is to give students an opportunity to study in some detail problems current in certain selected foreign areas. Three or four areas will be considered each time the course is given, and the selection will normally vary from year to year. Instruction will be given mainly by area specialists of the American Universities Field Staff. Instructors: Staff and members of AUFS.

PS 141 abc. African Studies. *9 units (2-0-7); first, second, third terms.* Problems of transition from colonial status to independence in countries south of the Sahara. Racial and cultural tensions in the Republic of South Africa. Instructor: Munger.

PS 150. Political Stability. *9 units (3-0-6); third term.* The course delves into the theory and practice of extremism and extremist movements, domestic violence, and revolution. Instructors: Fiorina, Ferejohn.

PS 151. Justice and Obligation. *9 units (3-0-6); third term.* An analysis of the concepts of justice and obligation primarily within a social contract framework but with some comparative study of utilitarian, Kantian and other ethical schemes. Other normative concepts such as that of "the public interest," "rights," and "duty," will be examined as well. Instructors: Fiorina, Ferejohn.

Psychology

UNDERGRADUATE COURSES

Psy 11. Introduction to Psychology. *9 units (3-0-6); first term.* Class discussion, readings, papers and occasional lectures designed to permit a relatively free exploration of the variety of topics that comprise psychology. Topics can include, but are not limited to: historical background, development of personality and intellect, biological-evolutionary factors, issues in motivation, learning, social and abnormal psychology. Suggested, but not required, as background for later courses in psychology. Instructor: Breger.

Psy 12. Introduction to Abnormal Psychology. *9 units (3-0-6); second term.* An introduction to the development of mental and emotional disturbances. Basic theory will be reviewed in relation to selected case material and relevant research. Instructor: Hunter.

Psy 13. Introduction to Social Psychology. *9 units (3-0-6); third term.* A survey of background and current areas in social psychology including, but not limited to: structure and functioning of small groups, leadership and communication, the use and abuse of social power, attitude structure and change, and interpersonal attraction and affiliation. Instructor: Beakel.

Psy 25. Reading and Research in Psychology. *Units to be determined by the instructor.*

Reading and research in psychology and related subjects, either in connection with a regular course or independently of any course, but under the direction of members of the department. A written report or field research will usually be required. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

ADVANCED COURSES

Psy 100. Psychological Development. *9 units (3-0-6); second term.* A study of the psychological development of the individual within a context of biological, cultural, and social evolution. Instructor: Breger.

Psy 101. Selected Topics in Psychology. *Units to be determined by arrangement with the instructor.* Instructors: Staff and visiting lecturers.

Psy 105. Conscience and Moral Development. *9 units (3-0-6); third term.* A study of the internalization of social values and standards and the relationships between motivational factors, moral reasoning and moral action. The course will draw on theory and evidence from psychoanalytic, neo-analytic, and Piagetian sources, and recent empirical studies of moral development. Instructor: Breger.

Psy 107/H 107. Psychohistory. *9 units (3-0-6); third term.* An examination of the interaction of psychological factors on the course of history; and of historical forces in the shaping of individual psychology. The course will focus on the intensive psychological study of important historical figures. Instructors: Breger, Rosenstone.

Psy 110. Advanced Seminar in Psychology. *9 units (3-0-6). Offered in selected terms only.* Topics to be determined on a quarter-by-quarter basis. Instructors: Staff and visitors.

Psy 125. Reading and Research in Psychology. Same as Psy 25, but for graduate credit. *Not available for credit toward humanities-social science requirement.*

Russian

(See Languages)

Social Science

UNDERGRADUATE COURSES

SS 11 a. Social Science Principles and Problems. *(Same as Ec 11.) 9 units (3-0-6); first term.* An introduction to the methodology of social science and the applications of that methodology to current social problems. This course emphasizes the role of wages, prices, and profits in a free enterprise economy and develops a theory of individual and firm decision making that can be used to analyze the behavior of business and public institutions. Subjects covered may also include financial markets, international trade, development, and alternative economic systems. Instructors: Staff.

SS 11 b. Social Science Principles and Problems. *9 units (3-0-6); second term. Prerequisite: SS 11a/Ec 11.* This course concentrates on non-market decisions. It focuses on committee and legislative decision making as well as providing an introduction to recent work in the theory of voting and the political process. Instructors: Staff.

SS 11 c. Social Science Principles and Problems. *9 units (3-0-6); third term. Prerequisite: SS 11 b.* This course is devoted to current social problems and is designed to show the student that the theoretical tools developed in the first two terms can be used as the basis for rational solutions to pressing social problems. Although the particular problems studied may vary from term to term, they might include housing, health delivery systems, the environment, public expenditures, and poverty. Instructors: Staff.

ADVANCED COURSES

SS 131. Mathematical Models of Political-Economic Decision Processes. *9 units (3-0-6); third term. Same as Ec 131 and PS 131.* Selected models will be reviewed with special emphasis on behavioral interpretations. Special attention will be given to simple majority rule and spatial models of electoral processes. Instructor: Plott.

SS 140. Laboratory Experiments in the Social Sciences. *9 units (3-0-6).* An examination of recent work in laboratory testing in the social sciences with particular reference to work done in social psychology, economics, and political science. Included will be a discussion of simulation, gaming, and the use of the computer as a source of the laboratory environment. In addition, the student will be introduced to problems of experimental design and will be expected to use the laboratory techniques in problems of his own design. Instructors: Breger, Ferejohn, Thompson.

SS 141. Field Research in the Social Sciences. *9 units (3-0-6).* An examination of the uses for census and social statistics, an introduction to survey techniques and an evaluation of recent work in the area, and a careful look at field studies with particular reference to the work of social and cultural anthropology; the application of these techniques to present problems in the social sciences. Instructors: Bates, Scudder.

SS 142 abc. Computer Modeling and Data Analysis. *9 units (3-3-3).* The building of conceptual models as an expression of the patterns perceived in the analysis of data. Analysis of data through model fitting and the study of residuals. Mathematical, statistical, and simulation models will be analyzed. The computer will be used extensively. Instructor: Thompson. (Also listed under IS 142 abc.)

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

SS 201 ab. Microeconomics. *9 units (3-0-6).* The first quarter covers classical consumption, including the psychological foundation of value theory, the theory of production and markets, externalities and the question of public goods. The second quarter deals with modern economic theory, including decision theory, game theory, the role of uncertainty, and investment theory. Instructors: Quirk, Plott, Montgomery.

SS 210 ab. Foundations of Political Economy. *9 units (3-0-6). SS 210 a is a prerequisite for SS 210 b.* Mathematical theories of individual and social choice applied to problems of welfare economics and political decision making will be the focus of the first quarter, which will also include the design and construction of political economic processes consistent with stipulated ethical postulates. The second quarter will cover political platform formulation, the theory of political coalitions and decision-making in large political (bureaucratic) organizations. Instructors: Plott, Ferejohn.

SS 222 ab. Econometrics. *9 units (3-0-6). Prerequisites: Mathematical Statistics, Ec 122 a.* Advanced topics in econometrics with special emphasis on the formulation, estimation, and evaluation of multi-equation systems. Students will be required to complete a major project in measurement. Instructor: Grether.

SS 230. Psychology and Organizational Behavior. *9 units (3-0-6).* Psychological theories of decision making, small-group and organizational behavior, uncertainty and the tolerance for ambiguity and stress and change. Instructors: Staff.

SS 231 abc. American Politics. *9 units (3-0-6).* A three term course in American politics and political behavior. Topics will include Congress and the legislative process; the presidency and the role of the federal executive; the Supreme Court and judicial behavior; political parties, pressure groups, and electoral behavior. The course will be run on a seminar basis. While drawing from contemporary materials, the course will emphasize the historical background of American political institutions. Instructors: Staff.

SS 240. Techniques of Policy Research. *9 units (3-0-6); first term. Prerequisites: Advanced courses in social science theory and data analysis.* The application of social science theory and methods to the formulation and evaluation of public policy. Case studies are used to illustrate various techniques employed by social scientists for estimating the effects of government institutions and programs. Among the topics covered are benefit-cost analysis and other methods of program evaluation, social experiments for testing new policies and policy instruments, and social choice theory as a guide to designing government agencies. Instructor: Noll.

SS 241 ab. Workshop in Policy Research. *9 units (3-0-6); second, third terms. Prerequisite: SS 240.* (Note: SS 241 b is offered only if the participants is SS 241 a agree that continuation of the workshop for an additional term is worthwhile.) A working seminar in which the students and participating faculty apply the techniques examined in SS 240 to a policy problem of mutual interest. After exploring the relevant research done by others, the participants assist each other in designing and executing individual research projects that are relevant to formulating policy in the selected problem area. Students intending to enroll in the course should contact the instructor by November 15 so that they may participate in choosing the policy issue to be studied. Instructor: Noll.

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