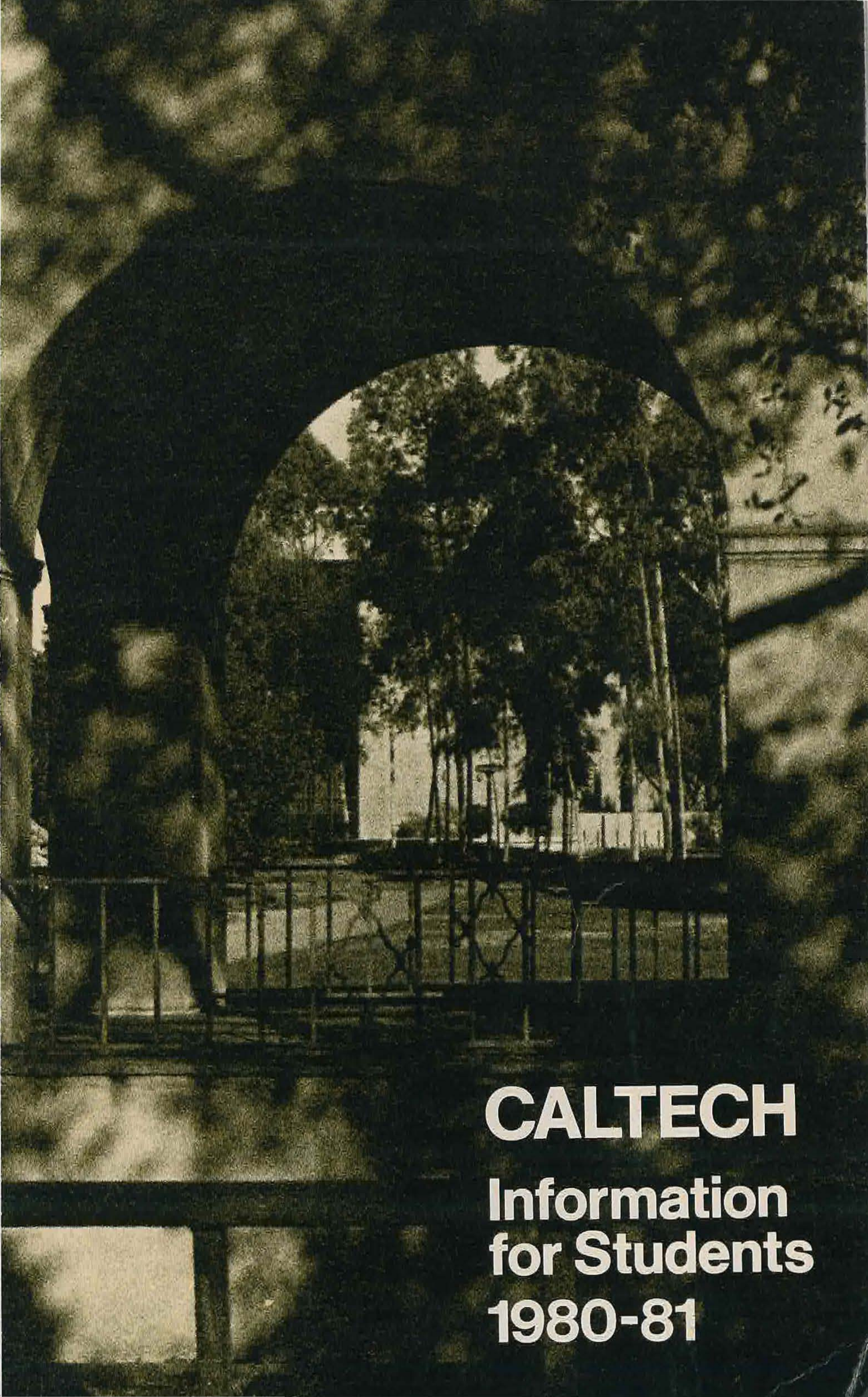

CALTECH

Information for Students 1980-81

INFORMATION FOR STUDENTS
1980–81

CALIFORNIA INSTITUTE OF TECHNOLOGY
1201 East California Boulevard
Pasadena, California 91125
Telephone: (213) 795-6811

September 1980

CONTENTS

Key to Abbreviations

Aeronautics .... Ae
Anthropology .... An
Applied Mathematics .... AMa
Applied Mechanics .... AM
Applied Physics .... APh
Art .... Art
Astronomy .... Ay
Bioinformation Systems .... BIS
Biology .... Bi
Business Economics and Management .... BEM
Chemical Engineering .... ChE
Chemistry .... Ch
Civil Engineering .... CE
Computer Science .... CS
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
Jet Propulsion .... JP
Languages L
Linguistics .... Lin
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
1980–81

1980	**First Term**
September 24	Registration of entering freshmen—1:00 p.m.–4:30 p.m.
September 25–27	New Student Orientation
September 29	General Registration—8:30 a.m.–3:30 p.m.
September 29	Undergraduate Academic Standards and Honors Committee —9:00 a.m.
September 30	Beginning of instruction—8:00 a.m.
October 17	Last day for adding courses and for removing conditions and incompletes
November 3–7	Mid-Term week
November 7	Last day for admission to candidacy for Master's and Engineer's degrees
November 10	Mid-Term deficiency notices due—9:00 a.m.
November 17–21	Pre-registration for second term, 1980–81
November 27–30	Thanksgiving recess
November 27–28	Thanksgiving holidays
December 5	Last day for dropping courses, changing sections, and track changes
December 13–19	Final examinations, first term, 1980–81
December 20	End of first term, 1980–81
December 21-January 4	Christmas recess
December 22	Instructors' final grade reports due—9:00 a.m.
December 24–26	Christmas holidays

1981	**Second Term**
January 1–2	New Year's Day holidays
January 5	General Registration—8:30 a.m.–3:30 p.m.
January 5	Undergraduate Academic Standards and Honors Committee —9:00 a.m.
January 6	Beginning of instruction—8:00 a.m.
January 23	Last day for adding courses and for removing conditions and incompletes
February 9–13	Mid-Term week
February 16	Mid-Term deficiency notices due—9:00 a.m.
February 23–27	Pre-registration for third term, 1980–81
March 6	Last day for dropping courses, changing sections, and track changes
March 14–20	Final examinations, second term, 1980–81
March 20	Last day for obtaining admission to candidacy for the degree of Doctor of Philosophy
March 21	End of second term, 1980–81
March 22–29	Spring recess
March 23	Instructors' final grade reports due—9:00 a.m.

1981	**Third Term**
March 30	General Registration—8:30 a.m.–3:30 p.m.
March 30	Undergraduate Academic Standards and Honors Committee —9:00 a.m.
March 31	Beginning of instruction—8:00 a.m.
April 17	Last day for adding courses and for removing conditions and incompletes
April 27–May 1	Mid-Term week
May 1–2	Examinations for admission to upper classes, September 1981
May 4	Mid-Term deficiency notices due—9:00 a.m.
May 18–22	Pre-registration for first term, 1981–82, and registration for summer research (graduate and undergraduate)
May 22	Last day for dropping courses, changing sections, and track changes
May 25	Memorial Day holiday
May 29	Last day for presenting theses for the degrees of Doctor of Philosophy and of Engineer
May 30-June 5	Final examinations for senior and graduate students, third term, 1980–81
June 6–12	Final examinations for undergraduate students, third term, 1980–81
June 8	Instructors' final grade reports due for senior and graduate students—9:00 a.m.
June 10	Undergraduate Academic Standards and Honors Committee —9:00 a.m.
June 10	Curriculum Committee meeting—10:00 a.m.
June 10	Faculty meeting—2:00 p.m.
June 12	Commencement
June 13	End of third term, 1980–81
June 15	Instructors' final grade reports due for undergraduate students —9:00 a.m.
June 24	Undergraduate Academic Standards and Honors Committee —9:00 a.m.
July 3	Independence Day holiday
September 7	Labor Day holiday

	First Term 1981–82
September 23	Registration of entering freshmen, 1:00 p.m.–4:30 p.m.
September 24–26	New Student Orientation
September 28	General Registration—8:30 a.m.–3:30 p.m.
September 29	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
Palomar Mountain
San Diego County

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97. Alumni House
3. Alumni Swimming Pool
25. Arms Laboratory (Geological and Planetary Sciences)
77. Art Gallery
61. Athenaeum (Faculty Club)
77. Baxter Lecture Hall
77. Baxter, Donald E., M.D., Hall (Humanities and Social Sciences)
91. Beckman Auditorium
76. Beckman Laboratories (Behavioral Biology)
60. Blacker House (Undergraduate Residence)
51. Bookstore (Student Center)
79. Booth Computing Center
88. Braun House (Graduate Residence)
75. Braun Laboratories (Cell Biology and Chemistry) (Site of)
34. Bridge Annex
33. Bridge Laboratory (Physics)
1. Brown Gymnasium
74. Campbell Laboratory (Plant Research)
85. Central Engineering Services
5. Central Plant
52. Chandler Dining Hall
43. Chemical Engineering Laboratory
73. Chemistry Laboratory, Undergraduate
29. Church Laboratory (Chemical Biology)
93. Coffeehouse, Student
4. Cooling Tower Buildings
34. Cosmic Ray Laboratory
30. Crellin Laboratory (Chemistry)
40. Dabney Hall (Administration, EQL, and Humanities)
58. Dabney House (Undergraduate Residence)
36. Development Offices
47. Downs Laboratory (Physics)
40, 96. EQL
50. Firestone Laboratory (Flight Sciences and Applied Mathematics)
57. Fleming House (Undergraduate Residence)
31. Gates Building
31A. Gates Annex (Chemistry)
82. Grounds Operations Office
45. Guggenheim Laboratory (Aeronautics and Applied Physics)
56. Housing Office
90. Industrial Relations Center
35. Isotope Handling Laboratory
80. Jorgensen Laboratory (Computer Science and Bioinformation Systems)
46. Karman Laboratory (Fluid Mechanics and Jet Propulsion)
86. Keck House (Graduate Residence)
78. Keck Laboratories (Environmental Engineering and Materials Science)
38. Kellogg Radiation Laboratory
27. Kerckhoff Laboratory (Biological Sciences)
48. Lauritsen Laboratory (High Energy Physics)
54. Lloyd House (Undergraduate Residence)
89. Marks House (Graduate Residence)
32. Millikan (Library and Administration)
87. Mosher-Jorgensen House (Graduate Residence)
23. Mudd, North (Geology and Geochemistry)
21. Mudd, South (Geophysics and Planetary Sciences)
72. Noyes Laboratory (Chemical Physics)
53. Page House (Undergraduate Residence)
4, 5, 82, 83, 84. Physical Plant
92. Public Events Office
71. Public Relations and Publications
77. Ramo Auditorium
59. Ricketts House (Undergraduate Residence)
24. Robinson Laboratory (Astrophysics)
55. Ruddock House (Undergraduate Residence)
37. Sloan Laboratory (Mathematics and Physics)
6. Spalding Building (Business Services)
41. Spalding Laboratory (Chemical Engineering)
94. Steele House (Residence, Master of Student Houses)
81. Steele Laboratory (Applied Physics and Electrical Engineering)
44. Thomas Laboratory (Civil and Mechanical Engineering)
92. Ticket Office
82. Transportation and Grounds Operations
95. Watson Laboratories of Applied Physics (Site of)
51. Winnett Student Center
51. Caltech Y
8. Young Health Center

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1980–81

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*Ex officio

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A. James Hudspeth, *Executive Officer*

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George E. MacGinitie, M.A. .... *Biology*
Antonie Van Harreveld, Ph.D., M.D. .... *Physiology*

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William J. Dreyer, Ph.D. .... *Biology*
Derek H. Fender, Ph.D. .... *Biology and Applied Science*
Leroy E. Hood, M.D., Ph.D. .... *Bowles Professor of Biology*
John J. Hopfield, Ph.D. .... *Roscoe G. Dickinson Professor of Chemistry and Biology*
Norman H. Horowitz, Ph.D. .... *Biology*
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Thomas P. Maniatis, Ph.D. .... *Biology*
Herschel K. Mitchell, Ph.D. .... *Biology*
Ray D. Owen, Ph.D., Sc.D. .... *Biology*
Jean-Paul Revel, Ph.D. .... *Albert Billings Ruddock Professor of Biology*
Roger W. Sperry, Ph.D., Sc.D. .... *Hixon Professor of Psychobiology*
Felix Strumwasser, Ph.D. .... *Biology*

Sherman Fairchild Distinguished Scholars

William Hayes, Sc.D.[2] .... *Biology*
Donald M. MacKay, Ph.D.[2] .... *Biology*

Senior Research Associate

Roy J. Britten, Ph.D.[3] .... *Biology*

[1]Option Representative
[2]In residence 1979–80
[3]Joint appointment with Carnegie Institution of Washington

Associate Professors

John M. Allman, Ph.D. .... *Biology*
A. James Hudspeth, M.D., Ph.D.[1] .... *Biology*
Henry A. Lester, Ph.D. .... *Biology*
John D. Pettigrew, M.D. .... *Biology*
James H. Strauss, Ph.D. .... *Biology*
David C. Van Essen, Ph.D. .... *Biology*

Research Associates

Barbara Hough Evans, Ph.D. .... *Biology*
Charles R. Hamilton, Ph.D. .... *Biology*
Peter H. Lowy, Doctorandum .... *Biology*
Marianne E. Olds, Ph.D. .... *Biology*

Gosney Visiting Associates

San-Chiun Shen, Ph.D. .... *Biology*
Obaid Siddiqi, Ph.D. .... *Biology*

Del Webb Visiting Associates

Sudarshan K. Malhotra, Ph.D. .... *Biology*
Evelyn Teng, Ph.D. .... *Biology*

Visiting Associates

James F. Baker, Ph.D. .... *Biology*
Welcome Bender, Ph.D. .... *Biology*
Raymond P. Briggs, Ph.D. .... *Biology and Applied Science*
Hermes Bravo, D.D.S. .... *Biology*
Joel Buxbaum, M.D.[2] .... *Biology*
Kathryn L. Calame, Ph.D. .... *Biology*
Thomas A. Cole, Ph.D. .... *Biology*
Patrice L. French, Ph.D. .... *Biology*
Theodore A. Goodman, M.D.[2] .... *Biology*
Rodney M. Hewick, Ph.D. .... *Biology*
Dennis J. Hocevar, Ph.D. .... *Biology and Applied Science*
Stanley Klein, Ph.D. .... *Biology and Applied Science*
I. Richard Lapidus, Ph.D. .... *Biology*
Keh-Chi Ling, Ph.D. .... *Biology*
EveLynn McGuinness, Ph.D. .... *Biology*
Ronald L. Meyer, Ph.D. .... *Biology*
Josette M. Michelot, M.D.[2] .... *Biology*
Oscar L. Miller, Ph.D.[2] .... *Biology*
Julio Montoya, Ph.D. .... *Biology*
Carlo Morandi, Ph.D. .... *Biology*
Joel Myerson, Ph.D. .... *Biology*
Kunio Nakai, M.D. .... *Biology*
Joel Nargeot, Ph.D.[2] .... *Biology*
Edward F. Pate, Ph.D. .... *Biology*

[1]Pre-Medical Adviser
[2]In residence 1979-80

Ruggero Pierantoni, Ph.D.[1] .... *Biology and Applied Science*
Lajos Piko, D.V.M. .... *Biology*
Theo B. Sonderegger, Ph.D. .... *Biology*
Mamoru Umemoto, Ph.D.[1] .... *Biology*
R. Bruce Wallace, Ph.D. .... *Biology*
Ji-hou Xin, B.S. .... *Biology*
Eran Zaidel, Ph.D. .... *Biology*

Assistant Professors

Jeremy P. Brockes, Ph.D. .... *Biology*
Mary B. Kennedy, Ph.D. .... *Biology*
Ronald J. Konopka, Ph.D.[2] .... *Biology*
Elias Lazarides, Ph.D. .... *Biology*
Elliot M. Meyerowitz, Ph.D. .... *Biology*

Senior Research Fellows

David M. Anderson, Ph.D. .... *Biology*
Dorwin L. Birt, Ph.D. .... *Biology*
Michael W. Hunkapiller, Ph.D. .... *Biology*
Leonard K. Kaczmarek, Ph.D. .... *Biology*
Takuji Kasamatsu, M.D. .... *Biology*
Peter F. R. Little, Ph.D. .... *Biology*
Michael D. Manson, Ph.D. .... *Biology*
Minnie McMillan, Ph.D. .... *Biology*
Makoto Okuno, Ph.D. .... *Biology*
Nancy S. Petersen, Ph.D. .... *Biology*
Nicholas J. Proudfoot, Ph.D. .... *Biology*
M. Viswanath Reddy, D.Sc. .... *Biology*
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Janet M. Roman, Ph.D. .... *Biology*
Ellen G. Strauss, Ph.D. .... *Biology*
Terry L. Thomas, Ph.D. .... *Biology*
S. Barbara Yancey, Ph.D. .... *Biology*

Lecturer

Kathleen M. Crandall, Ph.D. .... *Physiology*

[1]In residence 1979-80
[2]Undergraduate Student Adviser

Research Fellows

David J. Asai, Ph.D.[1]
Alan H. Barr, Ph.D.
Martha Bond, Ph.D.[1]
Jennifer L. Breckler, Ph.D.
Carlos V. Cabrera, Ph.D.[2]
Ricardo Castro-Gonzalez, Ph.D.
Lee D. Chabala, Ph.D.[3]
Anne Chomyn, Ph.D.
Toni Claudio, Ph.D.[4]
Richard H. Douglas, Ph.D.[5]
Ian W. Duncan, Ph.D.[6]
Philip Early, Ph.D.[1]
Alberto Ferrus, Ph.D.[2]
Konstantinos Flytzanis, Dr.rer.nat.[7]
John Frelinger, Ph.D.[8]
Lawrence C. Fritz, Ph.D.[3]
Shinobu C. Fujita, Ph.D.[4]
Paul A. Galland, Ph.D.[9]

Spyros D. Georgatos, Ph.D.[3]
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Mark E. Gurney, Ph.D.[3]
Eliot Herman, Ph.D.
Karen Herman, Ph.D.[3]
Henry Huang, Ph.D.
Howard T. Jacobs, Ph.D.
Linda L. Jagodzinski, Ph.D.
Lawrence M. Kauvar, Ph.D.[1]
Laurence A. Lasky, Ph.D.[8]
Leslie S. Leutwiler, Ph.D.
Maria-Luisa Maccecchini, Ph.D.[11]
Gordon C. Machray, Ph.D.
Pamela L. Mellon, Ph.D.[1]
David J. Meyer, Ph.D.[1]
Andrew Moiseff, Ph.D.[6]
Kevin W. Moore, Ph.D.[12]
Monica Mottes, Ph.D.[13]
Jeanne Nerbonne, Ph.D.[1]
Clare M. O'Connor, Ph.D.[14]
Manfred K. Otto, Ph.D.[9]
Janine Perlman, Ph.D.[3]
R. Gilles Plourde, M.D.
David E. Presti, Ph.D.[15]
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Elizabeth A. Repasky, Ph.D.[17]
Winfield S. Sale, Ph.D.[6]
Richard H. Scheller, Ph.D.
Monica H. M. Shander, Ph.D.
Che-Kun James Shen, Ph.D.[8]
Robert E. Sheridan, Jr., Ph.D.
Michael Steinmetz, Ph.D.[9]
Katherine A. Stygall, Ph.D.[16]
Mark Tanouye, Ph.D.[14]
Murray F. Teitell, Ph.D.[10]
Martin M. Weinstock, Ph.D.[1]
Kendrick N. Williams, Ph.D.

[1]U.S. Public Health Service Fellow
[2]Gosney Fellow
[3]Del Webb Fellow
[4]National Science Foundation Fellow
[5]Arthritis Foundation Fellow
[6]Helen Hay Whitney Foundation Fellow
[7]Deutsches Krebsforschungszentrum Fellow
[8]U.S. Public Health Service Postdoctoral Trainee
[9]Deutsche Forschungsgemeinschaft Fellow
[10]American Cancer Society Fellow
[11]Swiss National Fellow
[12]Damon Runyon–Walter Winchell Cancer Fund Fellow
[13]European Molecular Biology Organization Fellow
[14]Muscular Dystrophy Association of America Fellow
[15]Chaim Weizmann Research Fellow
[16]National Multiple Sclerosis Society Fellow
[17]Cooley's Anemia Foundation Fellow

Graduate Students 1980–81

John Richard Bell
Steven M. Block
Beverley Jean Bond
Arlene Y. C. Chiu
Stephen Thomas Crews
Alice M. Cronin
Madeline Anne Crosby
Thomas Edward Crowley
Mark Morris Davis
Ruth Anne Eatock
Jay William Ellison
Douglas Arthur Fisher
Karl Joseph Fryxell
George Loweree Gaines III
Boning Gao
David Lynn Gard
Mark David Garfinkel
David Alan Goldberg
Richard Hans Gomer
Herman John Gordon
Bruce Leslie Granger
Steven Haym Green
Tim Hunkapiller
Kent Richard Jennings
Deanna K. Ojala Johnson
Nelson Daniell Johnson

Gary Stephen Jones
Chris Alan Kaiser
Lawrence Charles Katz
Stuart Kilsu Kim
Mitchell Edwin Kronenberg
Mauri Eugene Krouse
Baruch Kuppermann
James Joseph Lee
Greg Erwin Lemke
David Eliot Levy
Richard Sheridan Lewis
Donna Lucy Livant
Jeffrey Nelson Masters
William Wayne Mattox
John Henry Richard Maunsell
Jeffrey Terrell Mayne
James Stacy McCasland
Paul Wells Meyer
Katharine Stevens Mixter
David Alan Myers
Jay Jasper Myers
Bruce John Nicholson
Dominic Ping-Yim Orr
Jing-hsiung James Ou
Vann Phillips Parker
Steven Elery Petersen
James W. Posakony
Robert Edwin Pruitt
Antonio Arevalo Reyes
Charles Moen Rice III
Arthur Henry Roach
Thomas Dean Sargent
Loveriza A. Sarmiento
Michael John Savage
Jeffrey Edward Segall
Beverly Taylor Sher
Sandra Lee Shotwell
Dave William Sivertsen
Randall Forrest Smith
Michael Paul Snyder
Yi Henry Sun
Chung Wang
Wilson Wu
Joanne Mulligan Yeakley
Sachie Yoshida

Division of Chemistry and Chemical Engineering

Harry B. Gray, *Chairman*
John H. Seinfeld, *Executive Officer for Chemical Engineering*

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Linus Pauling, Ph.D., Sc.D., L.H.D., U.J.D., Dr.h.c., D.F.A., LL.D., Nobel Laureate .... *Chemistry*
Bruce H. Sage, Ph.D., Eng.D. .... *Chemical Engineering*
Ernest H. Swift, Ph.D., LL.D. .... *Analytical Chemistry*

Senior Research Associates Emeriti

Edward W. Hughes, Ph.D. .... *Chemistry*
Joseph B. Koepfli, D. Phil. .... *Chemistry*
Oliver R. Wulf, Ph.D. .... *Physical Chemistry*

Professors

Fred C. Anson, Ph.D. .... *Chemistry*
James E. Bailey, Ph.D. .... *Chemical Engineering*
John D. Baldeschwieler, Ph.D. .... *Chemistry*
Jesse L. Beauchamp, Ph.D. .... *Chemistry*
John E. Bercaw, Ph.D. .... *Chemistry*
Sunney I. Chan, Ph.D. .... *Chemical Physics and Biophysical Chemistry*
William H. Corcoran, Ph.D. .... *Institute Professor of Chemical Engineering*
Norman Davidson, Ph.D. .... *Chemistry*
Richard E. Dickerson, Ph.D. .... *Physical Chemistry*
David A. Evans, Ph.D. .... *Chemistry*

George R. Gavalas, Ph.D. .... *Chemical Engineering*
William A. Goddard III, Ph.D. .... *Chemistry and Applied Physics*
Harry B. Gray, Ph.D. .... *William R. Kenan, Jr. Professor and Professor of Chemistry*
Robert H. Grubbs, Ph.D. .... *Chemistry*
John J. Hopfield, Ph.D. .... *Roscoe G. Dickinson Professor of Chemistry and Biology*
Robert E. Ireland, Ph.D. .... *Organic Chemistry*
Aron Kuppermann, Ph.D. .... *Chemical Physics*
L. Gary Leal, Ph.D. .... *Chemical Engineering*
Rudolph A. Marcus, Ph.D. .... *Arthur Amos Noyes Professor of Chemistry*
Vincent McKoy, Ph.D. .... *Theoretical Chemistry*
Cornelius J. Pings, Ph.D. .... *Chemical Engineering and Chemical Physics*
Michael A. Raftery, Ph.D., D.Sc. .... *Chemical Biology*
John H. Richards, Ph.D. .... *Organic Chemistry*
John D. Roberts, Ph.D., Dr.rer.nat. h.c., Sc.D. .... *Institute Professor of Chemistry*
John H. Seinfeld, Ph.D. .... *Chemical Engineering*
Fredrick H. Shair, Ph.D. .... *Chemical Engineering*
Nicholas W. Tschoegl, Ph.D. .... *Chemical Engineering*
W. Henry Weinberg, Ph.D. .... *Chemical Engineering and Chemical Physics*

Sherman Fairchild Distinguished Scholars

Rutherford Aris, Ph.D., D.Sc. .... *Chemical Engineering*
Mostafa A. El-Sayed, Ph.D. .... *Chemistry*
Malcolm L. H. Green, Ph.D. .... *Inorganic Chemistry*
Bo G. Malmström, Fil.dr. .... *Biochemistry*

Associate Professors

Peter B. Dervan, Ph.D. .... *Chemistry*
Ahmed H. Zewail, Ph.D. .... *Chemical Physics*

Research Associates

Terry Cole, Ph.D. .... *Chemistry and Chemical Engineering*
Richard E. Marsh, Ph.D. .... *Chemistry*
Sten O. Samson, Fil. Dr. .... *Chemistry*
William P. Schaefer, Ph.D. .... *Chemistry*
Walter A. Schroeder, Ph.D. .... *Chemistry*

Visiting Associates

Richard J. Bing, M.D. .... *Chemistry and Chemical Engineering*
Gerhard Binsch, Ph.D. .... *Chemistry*
John P. Chesick, Ph.D. .... *Chemistry*
Bianca Conti-Tronconi, M.D. .... *Chemistry*
Gyorgy Csanak, Ph.D. .... *Chemistry*
Fred Gelbard, Ph.D. .... *Chemical Engineering*
M. Michael Glovsky, M.D. .... *Chemistry*
Sergio G. Gonzalez, Ph.D. .... *Chemistry*
Daniel Grosjean, Ph.D. .... *Chemical Engineering*
Earl C. Harrison, M.D. .... *Chemical Engineering*
Karin Hoffman, Vordiplom .... *Chemical Engineering*
Raymond M. Houriet, Dr. es Science .... *Chemistry*

Keiichi Itakura, Ph.D. .... *Chemistry*
Sol Kimel, Ph.D. .... *Chemistry*
Masato Koda, Ph.D. .... *Chemical Engineering*
Boguslaw Kuszta, Ph.D. .... *Chemistry*
Ting-Fong Lai, Ph.D. .... *Chemistry*
Rachmiel Levine, M.D. .... *Chemical Engineering*
Alan P. Marchand, Ph.D. .... *Chemistry*
Marco A. C. Nascimento, Ph.D. .... *Chemistry*
Mitsuo Oka, Ph.D. .... *Chemical Engineering*
Shigeru Omatu, Ph.D. .... *Chemical Engineering*
Charles A. Root, Ph.D. .... *Chemistry*
Hector Rubalcava, Ph.D. .... *Chemistry*
Eugene A. Ryabov, Ph.D. .... *Chemistry*
B. D. Sharma, Ph.D. .... *Chemistry*
Stephen H. Smallcombe, Ph.D. .... *Chemistry*
R. Shankar Subramanian, Ph.D. .... *Chemical Engineering*
Hung Tan .... *Chemistry*
Henrique E. Toma, Ph.D. .... *Chemistry*
Sister Mary Woods, Ph.D. .... *Chemistry*
Yu Chun .... *Chemistry*

Associate

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

Assistant Professors

Judith L. Campbell, Ph.D. .... *Chemistry*
Terrence J. Collins, Ph.D. .... *Chemistry*
Dennis A. Dougherty, Ph.D. .... *Chemistry*
Robert R. Gagné, Ph.D. .... *Chemistry*
Eric Herbolzheimer, Ph.D. .... *Chemical Engineering*
Gregory N. Stephanopoulos, Ph.D. .... *Chemical Engineering*

Senior Research Fellow

H. Hollis Reamer, M.S. .... *Chemical Engineering*

Noyes Research Instructors

Kenneth C. Janda, Ph.D. .... *Chemistry*
Randal K. Sparks, Ph.D. .... *Chemistry*

Research Fellows

Alex P. Alder, Ph.D.
Vasil K. Babamov, Ph.D.
Raphael Badoud, Ph.D.
John J. Bisaha, Ph.D.
Kathy B. Burck, Ph.D.
Chi-Ming Chan, Ph.D.
Moon H. Chang, Ph.D.
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Stephen E. Crane, Ph.D.
Michael T. Crimmins, Ph.D.
Ronald L. Davis, Ph.D.
Eric J. M. deBoer, Ph.D.
Piotr Dembek, Ph.D.
Duong D. Do, Ph.D.
Susan M. J. Dunn, Ph.D.
Karl Eberl, Ph.D.
David A. Edmonson, Ph.D.
Janet R. Elliott, Ph.D.

Ann M. English, Ph.D.
Beat Ernst, Ph.D.
Rolf Etter, Ph.D.
Scott V. Falkenthal, Ph.D.
Eric A. Fyrberg, Ph.D.
Thomas Geiger, Ph.D.
Thierry Godel, Ph.D.
Michel I. Goldberg, Ph.D.
Nina C. Gonella, Ph.D.
P. Dieter Häbich, Ph.D.
Nancy Ann Harvey, Ph.D.
Gregory L. Hillhouse, Ph.D.
Friedrich M. Hoffman, Ph.D.
Virginia H. Houlding, Ph.D.
Takao Ikariya, Ph.D.
Seong H. Lee, Ph.D.
Albert M. H. Lin, Ph.D.
Vanessa R. Lum, Ph.D.
Patrick Martigny, Ph.D.
Yoshiki Matsuura, Ph.D.
Steven J. Milder, Ph.D.
Galina Moller, Ph.D.
Roger G. Mortimer, Ph.D.
James I. Mullins, Ph.D.
Hitoshi Nakayama, Ph.D.
Ronald J. Pace, Ph.D.
Michael A. Reuben, Ph.D.
John G. Reynolds, Ph.D.
Raymond J. Robbins, Ph.D.
Charles E. Rozek, Ph.D.
Joseph R. Schuh, Ph.D.
Kiyotaka Shigehara, Ph.D.
Charles J. Simmons, Ph.D.
Karl M. Sirotkin, Ph.D.
Roy K. Smith, Ph.D.
Ulrich Strauss, Ph.D.
Kazuo Takatsuka, Ph.D.
Vernon Taniguchi, Ph.D.
Steven P. Tanis, Ph.D.
Suvit Thaisrivongs, Ph.D.
Lawrence R. Thorne, Ph.D.
Richard S. Threlkel, Ph.D.
George W. Tin, Ph.D.
Joseph A. Uliana, Ph.D.
Jean-Paul Vevert, Ph.D.
Lorenz J. Walder, Ph.D.
Raymond M. Withy, Ph.D.
Joseph Wong, Ph.D.
Piotr K. Wrona, Ph.D.
Po-Shun Wu, Ph.D.

Graduate Students 1980–81

Applied Physics
John Samuel Batchelder
Stuart Thomas Hopkins
Michael Steven Muha
Dean Paul Neikirk

Chemical Engineering
David Thomas Allen
Alan Brad Anton
Samir Ilyas Barudi
Mark Elliott Bassett
Barry Jerome Bentley
Clarke Berdan II
Russell Leslie Bone
Willie Ann Brown
Douglas Glenn Carson
Karl Kho-Chung Chang
Bo Kyung Chi
Christopher Chow
Douglas Snyder Clark
Thomas William Cochran
Mark Daniel Cohen
James Gleason Crump
Brian Henry Davison
Pauline Mavis Doran
Paul Nathan Dunlap
Kurt Dale Fickie
Lynn Forester
Anthony Sigmund Geller
Panagiotis Georgopoulos
Murray Ross Gray
Cigdem Gurer
Daniel Dale Hanle
Martin Aksel Hjortso
Philip Alan Hookham
Dale Edward Ibbotson
Nicholas Alexandrou Kaffes
William Samson Kalema
Rohit Khanna
James Gregory Kralik
Constantine Kravaris
Ronald Robert Lagnado
Joseph Anthony Leone

Gerasimos Lyberatos
Edward Douglas Lynch
Michael Aaron Mendelson
William Kevin Moonan
Byron Lance O'Steen
William O'Such
Young Hoon Park
Steven Peretti
Andrew John Pesthy
Charunya Phichitkul
Puvin Pichaichanarong
Danny David Reible
Donald F. Rogers
Gregory Ryskin
Ka-Yiu San
John Robert Schlup
Mark Alan Siddoway
Conrad B. Smith
Aquiles Carlos Sobrero
Tonny Soesanto
Arthur Wesley Stelson
David Michael Strand
David Walter Suobank
Michael Karpovich Templeton
Koji Toyoda
Nick Vasilakos
Nam Sun Wang
Dale R. Warren
Theresa Ann Weston
Gary Eugene Whatley
Thomas Stephen Wittrig
Seung-Man Yang

Chemistry

Janet Noel Allison
William George Antypas, Jr.
Jay Douglas Audett
Roger Bennett Baar
Raymond Alan Bair
Utpal Banerjee
Paul Theron Barger
Javier Francisco Bartroli
Michael McClellan Becker
Nancy Newton Becker
Tadhg Pulcarius Begley
David Beratan
Daniel Wayne Berman
Donald Harry Berry
Scott Adams Biller
David Francis Blair
John James Boland
David Scott Bomse
Robert Clark Bowman, Jr.
David Edward Brinza
William Joseph Brittain
Katherine Ann Brown-Wensley
Gary Wayne Brudvig
Daniel Alan Buttry
Gary Wayne Campbell
Steven Carroll
Michael Paul Casassa
Carla Jutta Casewit
Robert John Cave
Francis Gabriel Celii
Susan Elizabeth Celniker
Yie-Hwa Chang
Chi-Ming Che
Huey-jenn Chiang
Jocelyn Terese Chupka
Steven Alan Cohen
Benjamin Norman Conner
Thomas Smith Coolbaugh
John Powell Daub
John Austin Dodge
Robert Lee Dow
William Clinton Dow
Kenneth Martin Doxsee
Horace Rainsford Drew III
Daniel Charles Duan
Richard Raymond Durand, Jr.
Kenneth Eugene Eigenberg
Walther Robert Ellis
Michael Dalton Ennis
Joseph John Falke
Peter Mark Felker
Brian Joseph Fitzsimmons
Dorothy Jean Flanagan
Jane Elizabeth Frommer
Gregory J. Gajda
James Francis Garvey
Jeff Daniel Gelles
Patricia Margaret George
Laura Rhea Gilliom
James William Gleeson
Aaron Henry Goldberg
Marvin Mark Goodgame
Linda Fay Halle
Neal Bruce Handly
Maureen Alice Hanratty
Richard Randolph Hardy

Debra Heckendorn
James Hedges
Lawrence Michael Henling
Brian Garnet Herndier
Robert Philip Hertzberg
Albert John Highe
Suzzy Chen Hsi Ho
Diane Marie Hood
Michael David Hopkins
Thomas Robert Howard
Richard Alan Ikeda
Carl R. Illig
Melvin Owen Jones
Alvin David Joran
Robert James Kaiser, Jr.
Santosh Pandurang Kamath
Keiko Kanamori
Heon Kang
Robert McNamara Kanne
Jack Alan Kaye
Peter Martin Koelsch
Charles Frederick Koerting
Terry Krafft
Eric Martin Krauss
Robert Paul Kreh
Chia-lam Kuo
William Roger Lambert
Chi-Woo Lee
JohnBosco Chi-Bun Lee
Thomas P. Lockhart
John James Low
Robert Ross Lucchese
David Neil Marks
William Alan Marritt
Craig Timothy Martin
David John Mathre
Barry James Maurer
Andrew William Maverick
James Moers Mayer
Mark H. McAdon
Christine McDade
Lisa Ann McElwee-White
Gloria McFarland
Dennis Emmett McGee
Lawrence Ray McGee
Nancy M. Doherty McGrady
Daniel Keith McIntyre
David S. Middlemas
David Philip Millar
James Arthur Miller
Charles H. Mitch
Mark Allen Mitchell
David Jerry Moll
Eric Jan Moore
Randall Heywood Morse
David Randall Moser
Jan Stanley Najdzionek
Michael Wei-Kuo Nee
James Joseph Neitzel
John Victor Nelson
Daniel George Nocera
Daniel Word Norbeck
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Kevin Curtis Ott
Mark Thomas Paffett
Laurence Timothy Pearson
Thomas Gardner Perkins
Joseph Walter Perry
Philip Edward Pjura
Anthony Kay Rappe
Jeffrey Allan Reimer
Ronald Rianda
Steven Frederick Rice
Randy Richard Robinson
Dean Michael Roddick
John H. Runnels
Irving Daniel Sand
Steven Alan Schichman
Peter George Schultz
Thomas L. Shih
Paul David Siders
Gerald Jen Ming Siu
Eric Brian Sjogren
Penny Slusser
Duane Donald Smith
Maile Elizabeth Smith
Terrance Patrick Smith
Jorge Soto-Gonzalez
George Spies
Michael Louis Steigerwald
Amy Elizabeth Stevens
Tom Hall Stevens
David John Strader
Daniel Albert Straus
Barry Allen Swartz
Alan Paul Sylwester
Phillip Szuromi
Terry Ray Taber
James Michael Takacs
Patricia Ann Thiel
Mark Edward Thompson
Brian H. Toby

Florence Lucy Trentacosti
Yu-Min Tsou
John James Vajo
Michael Wayne Van Dyke
Michael Varney
Arthur Ford Voter
Kerry Walzl
Hsin Wang
Charles Albert Wight
Brian Christopher Willett
Ellen D. Williams
Jay Richmond Winkler
Jaroslaw Walery Winniczek
Peter Thomas Wolczanski
Kathryn Mary Yocom
Ellen Yuan-Chu Ho-Yu
Thomas Zietlow
Jennifer Joanne Zinck

Division of Engineering and Applied Science

Roy W. Gould, *Chairman*
William B. Bridges, *Executive Officer for Electrical Engineering*
Wilfred D. Iwan, *Executive Officer for Civil Engineering and Applied Mechanics*
Hans W. Liepmann, *Director of the Graduate Aeronautical Laboratories and Executive Officer for Aeronautics*
E. John List, *Executive Officer for Environmental Engineering Science*
Herbert B. Keller, *Executive Officer for Applied Mathematics*

Professors Emeriti

Francis H. Clauser, Ph.D. .... *Clark Blanchard Millikan Professor of Engineering*
Frederick J. Converse, B.S. .... *Soil Mechanics*
Pol E. Duwez, D.Sc. .... *Applied Physics and Materials Science*
Arthur L. Klein, Ph.D. .... *Aeronautics*
Robert V. Langmuir, Ph.D. .... *Electrical Engineering*
Frederick C. Lindvall, Ph.D., D.Sc., D.Eng. .... *Engineering*
Gilbert D. McCann, Ph.D. .... *Applied Science*
William H. Pickering, Ph.D., D.Sc., D.Eng. .... *Electrical Engineering*
John R. Pierce, Ph.D., D.Sc., D.Eng., E.D., LL.D. .... *Engineering*
Milton S. Plesset, Ph.D. .... *Engineering Science*
Homer J. Stewart, Ph.D. .... *Aeronautics*
Vito A. Vanoni, Ph.D. .... *Hydraulics*
J. Harold Wayland, Ph.D., D.Sc. .... *Engineering Science*

Professors

Allan J. Acosta, Ph.D. .... *Mechanical Engineering*
Charles D. Babcock, Jr., Ph.D.[1] .... *Aeronautics*
William B. Bridges, Ph.D. .... *Electrical Engineering and Applied Physics*
Norman H. Brooks, Ph.D. .... *James Irvine Professor of Environmental and Civil Engineering; Director, Environmental Quality Laboratory*
Garry L. Brown, D.Phil. .... *Aeronautics*
Thomas K. Caughey, Ph.D. .... *Applied Mechanics*
Donald S. Cohen, Ph.D. .... *Applied Mathematics*
Donald E. Coles, Ph.D. .... *Aeronautics*
Noel R. Corngold, Ph.D. .... *Applied Physics*
Fred E. C. Culick, Ph.D. .... *Applied Physics and Jet Propulsion*
Derek H. Fender, Ph.D. .... *Biology and Applied Science*
Joel N. Franklin, Ph.D. .... *Applied Mathematics*
Roy W. Gould, Ph.D. .... *Simon Ramo Professor of Engineering*

[1]On leave of absence

George W. Housner, Ph.D.[1] .... *Carl F Braun Professor of Engineering*
Donald E. Hudson, Ph.D. .... *Mechanical Engineering and Applied Mechanics*
Wilfred D. Iwan, Ph.D. .... *Applied Mechanics*
Paul C. Jennings, Ph.D. .... *Civil Engineering and Applied Mechanics*
Herbert B. Keller, Ph.D. .... *Applied Mathematics*
Wolfgang G. Knauss, Ph.D. .... *Aeronautics*
James K. Knowles, Ph.D. .... *Applied Mechanics*
Heinz-Otto Kreiss, Dr.Tech. .... *Applied Mathematics*
Toshi Kubota, Ph.D. .... *Aeronautics*
Paco A. Lagerstrom, Ph.D. .... *Applied Mathematics*
Lester Lees, M.S. .... *Environmental Engineering and Aeronautics*
Hans W. Liepmann, Ph.D. .... *Charles Lee Powell Professor of Fluid Mechanics and Thermodynamics*
E. John List, Ph.D. .... *Environmental Engineering Science*
Frank E. Marble, Ph.D. .... *Jet Propulsion and Mechanical Engineering*
James O. McCaldin, Ph.D. .... *Applied Physics and Electrical Engineering*
Thomas C. McGill, Ph.D. .... *Applied Physics*
Carver A. Mead, Ph.D. .... *Gordon and Betty Moore Professor of Computer Science*
Robert D. Middlebrook, Ph.D. .... *Electrical Engineering*
Julius Miklowitz, Ph.D. .... *Applied Mechanics*
James J. Morgan, Ph.D. .... *Environmental Engineering Science*
Marc-Aurele Nicolet, Ph.D. .... *Electrical Engineering*
Wheeler J. North, Ph.D. .... *Environmental Science*
Charles H. Papas, Ph.D. .... *Electrical Engineering*
Fredric Raichlen, Sc.D. .... *Civil Engineering*
W. Duncan Rannie, Ph.D. .... *Robert H. Goddard Professor of Jet Propulsion and Professor of Mechanical Engineering*
Anatol Roshko, Ph.D. .... *Aeronautics*
Rolf H. Sabersky, Ph.D. .... *Mechanical Engineering*
Philip G. Saffman, Ph.D. .... *Applied Mathematics*
Ronald F. Scott, Sc.D.[2] .... *Civil Engineering*
Eli Sternberg, Ph.D., D.Sc. .... *Mechanics*
Bradford Sturtevant, Ph.D. .... *Aeronautics*
Frederick B. Thompson, Ph.D. .... *Applied Philosophy and Computer Science*
Thad Vreeland, Jr., Ph.D. .... *Materials Science*
Gerald B. Whitham, Ph.D.[3] .... *Applied Mathematics*
Charles H. Wilts, Ph.D. .... *Electrical Engineering and Applied Physics*
David S. Wood, Ph.D. .... *Materials Science*
Theodore Y. Wu, Ph.D. .... *Engineering Science*
Amnon Yariv, Ph.D. .... *Thomas G. Myers Professor of Electrical Engineering and Professor of Applied Physics*
Edward E. Zukoski, Ph.D. .... *Jet Propulsion and Mechanical Engineering*

Sherman Fairchild Distinguished Scholars

George F. Carrier, Ph.D. .... *Applied Mathematics*
John J. Lambe, Ph.D. .... *Applied Physics*
W. Gilbert Strang, Ph.D. .... *Applied Mechanics*

[1]Half time
[2]Leave of absence second and third terms
[3]Leave of absence first and third terms

Visiting Professors

Edward N. Adams, Ph.D. .... *Computer Science*
Charles E. Molnar, Sc.D.[1] .... *Computer Science*
Edward C. Posner, Ph.D. .... *Electrical Engineering*
Lawrence L. Rauch, Ph.D. .... *Electrical Engineering*
Martin Rem, Ph.D. .... *Computer Science*
Marvin K. Simon, Ph.D.[1] .... *Electrical Engineering*

Associate Professors

Christopher E. Brennen, Ph.D. .... *Mechanical Engineering*
Francis S. Buffington, Sc.D. .... *Materials Science*
Bengt Fornberg, Ph.D. .... *Applied Mathematics*
Michael R. Hoffmann, Ph.D. .... *Environmental Engineering Science*
William L. Johnson, Ph.D. .... *Materials Science*
Hardy C. Martel, Ph.D. .... *Electrical Engineering*
Charles L. Seitz, Ph.D.[2] .... *Computer Science*
Darryl L. Smith, Ph.D. .... *Applied Physics*
David F. Welch, I.D. .... *Engineering Design*

Visiting Associate Professor

Lincoln J. Wood, Ph.D. .... *Systems Engineering*

Research Associates

James E. Broadwell, Ph.D. .... *Aeronautics*
S. Lennart Johnsson, Ph.D. .... *Computer Science*
Robert C. Y. Koh, Ph.D. .... *Environmental Engineering Science*
Paulett C. Liewer, Ph.D. .... *Applied Physics*

Visiting Associates

Igor T. Alexanian, Cand.Sci.[1] .... *Electrical Engineering*
Ronald F. Ayres, Ph.D. .... *Computer Science*
Peter W. Bearman, Ph.D.[1] .... *Aeronautics*
William V. Brewer, Ph.D.[1] .... *Aeronautics*
Rolf D. Buhler, Ph.D. .... *Aeronautics*
Stephen H. Caine .... *Computer Science*
Ahmet S. Cakmak, Ph.D. .... *Civil Engineering*
Yi-Shung Chen, Ph.D. .... *Engineering Science*
Anthony T. W. Cheung, Ph.D. .... *Engineering Science*
Bruno Crosignani, Lib.Doc.[1] .... *Electrical Engineering*
Dwight W. Decker, Ph.D.[1] .... *Applied Mathematics*
Giorgio Franceschetti, Ph.D.[1] .... *Electrical Engineering*
Jean-Pierre Gailliard, Ph.D.[1] .... *Applied Physics*
Ilan Golecki, Ph.D. .... *Applied Physics*
Gerhard H. Gotz, Dr.sc.nat.[1] .... *Applied Physics*
Bertil Gustafsson, Ph.D.[1] .... *Applied Mathematics*
Jozsef Gyulai, Ph.D.[1] .... *Applied Physics*
Andrew V. Haeff, Ph.D. .... *Electrical Engineering*
Cornelius O. Horgan, Ph.D.[1] .... *Applied Mechanics*

[1]In residence 1979–80
[2]Also part-time Visiting Associate Professor of Computer Science second and third terms 1979–80

Liang-Sun Hung, Ph.D. .... *Applied Physics*
Chong-Oh Kim, M.Ed.[1] .... *Materials Science*
Doyle D. Knight, Ph.D.[1] .... *Applied Mathematics*
Anton Kuhelj, Dr.Tech.Sci.[1] .... *Aeronautics*
Silvanus S. Lau, Ph.D. .... *Applied Physics*
Jiin-Jen Lee, Ph.D. .... *Civil Engineering*
Philip L-F. Liu, Sc.D. .... *Civil Engineering*
Sami F. Masri, Ph.D. .... *Applied Mechanics*
Edward J. McGrath, M.S.E.C.E.[1] .... *Computer Science*
Charles R. Minter, Ph.D.[1] .... *Computer Science*
Antonmaria A. Minzoni, Ph.D.[1] .... *Applied Mathematics*
Derek W. Moore, Ph.D. .... *Applied Mathematics*
Richard C. Mosteller, B.S.[1] .... *Computer Science*
J. Craig Mudge, Ph.D. .... *Computer Science*
Donald R. Oestreicher, Ph.D.[1] .... *Computer Science*
Daniel M. Oldenziel, Ph.D. .... *Mechanical Engineering*
Victor L. Pereyra, Ph.D.[1] .... *Applied Mathematics*
Simon Ramo, Ph.D. .... *Engineering*
Chen Ti Rong, Ph.D. .... *Applied Physics*
C. Hunter Shelden, M.D. .... *Biomedical Engineering*
Helmut Siekmann, Dipl.Ing. .... *Mechanical Engineering*
Wee-King Soh, Ph.D.[1] .... *Engineering Science*
Salvatore Solimeno, Lib.Doc.[1] .... *Electrical Engineering*
Jeffrey W. Sondeen, M.S. .... *Computer Science*
Alastair Spence, Ph.D. .... *Applied Mathematics*
Yao-Xi Su, Ph.D. .... *Engineering Science*
Ivan E. Sutherland, Ph.D. .... *Computer Science*
David A. Thompson, Ph.D.[1] .... *Applied Physics*
James R. Tobias, Ph.D. .... *Computer Science*
Paul E. M. Vandenplas, D.Sc.[1] .... *Applied Physics*
Alan A. Vetter, Ph.D. .... *Applied Physics*
Gene W. Wester, Ph.D.[1] .... *Electrical Engineering*
Leszek Wielunski, Ph.D. .... *Applied Physics*
John D. Williams, M.S.[1] .... *Computer Science*
Howard Winet, Ph.D. .... *Engineering Science*
Dean E. Wooldridge, Ph.D. .... *Engineering*
De-Ming Wu, Ph.D. .... *Engineering Science*
Si-Jun Zhang, Ph.D. .... *Applied Physics*

Assistant Professors

Paul M. Bellan, Ph.D. .... *Applied Physics*
Glen R. Cass, Ph.D. .... *Environmental Engineering*
Slobodan M. Cuk, Ph.D. .... *Electrical Engineering*
Paul E. Dimotakis, Ph.D. .... *Aeronautics and Applied Physics*
Richard C. Flagan, Ph.D. .... *Environmental Engineering Science*
James T. Kajiya, Ph.D. .... *Computer Science*
George J. Milne, Ph.D. .... *Computer Science*
Demetri Psaltis, Ph.D. .... *Electrical Engineering*
David B. Rutledge, Ph.D. .... *Electrical Engineering*

[1]In residence 1979–80

Senior Research Fellows

James P. Ary, Ph.D. .... *Biomedical Engineering*
Mark C. Citron, Ph.D.[1] .... *Biomedical Engineering*
Lambertus Hesselink, Ph.D.[2] .... *Fluid Mechanics*
George T. Yates, Ph.D.[3] .... *Engineering Science*

Instructors

George Majda, Ph.D.[4] .... *Applied Mathematics*
Eitan Tadmor, Ph.D.[5] .... *Applied Mathematics*

Lecturers

Stanley H. Bacon .... *Electrical Engineering*
Gerald J. Bierman, Ph.D. .... *Systems Engineering*
James Boyk, M.F.A. .... *Music*
John Choma, Jr., Ph.D. .... *Electrical Engineering*
Erik P. DeBenedictis, M.S.[1] .... *Computer Science*
Douglas Fairbairn, M.S.[1] .... *Computer Science*
James R. Lesh, Ph.D. .... *Electrical Engineering*
Thomas R. McDonough, Ph.D. .... *Engineering*
Charles B. Ray, M.S. .... *Computer Science*
David Sonnabend, Ph.D. .... *Systems Engineering*
Michael K. Ullner, B.S.[1] .... *Computer Science*
Joseph H. Yuen, Ph.D. .... *Electrical Engineering*

Research Fellows

Nadav Bar-Chaim, Ph.D. .... *Applied Physics*
Jean M. M. Bletry, Ph.D. .... *Materials Science*
Miles G. V. Bogle, Ph.D. .... *Environmental Engineering Science*
Sally A. Browning, Ph.D.[6] .... *Computer Science*
Pandipati R. Chetty, Ph.D. .... *Electrical Engineering*
W. Nathan Cheung, Ph.D. .... *Applied Physics*
G. Wesley Davis, Jr., Ph.D.[1] .... *Biomedical Engineering*
Gregory Gartrell, Jr., Ph.D.[7] .... *Environmental Engineering Science*
Valrie Ann Gerard, Ph.D. .... *Environmental Engineering Science*
Maria G. Grimaldi, Laurea .... *Applied Physics*
John F. Hall, Ph.D. .... *Civil Engineering*
Medhat A. Haroun, Ph.D. .... *Civil Engineering*
Henry V. Huang, Ph.D. .... *Biology and Biomedical Engineering*
James R. Hunt, Ph.D.[1] .... *Environmental Engineering Science*
John P. Kroeker, Ph.D.[8] .... *Bioinformation Systems*
Yukio Kubota, M.Sc.[1] .... *Applied Physics*
Stelios Kyriakides, Ph.D. .... *Aeronautics*

[1]In residence 1979–80
[2]Also part-time Instructor in Applied Physics; in residence 1979–80
[3]Also part-time Lecturer in Applied Mechanics
[4]Bateman Research Instructor; in residence 1979–80
[5]Bateman Research Instructor
[6]Also part-time Lecturer in Computer Science; in residence 1979–80
[7]Chaim Weizmann Research Fellow
[8]James G. Boswell Research Fellow; also part-time Lecturer in Systems Engineering 1979–80

Ross M. Larkin, Ph.D. .... *Biomedical Engineering*
Marianela Lentini, Ph.D.[1] .... *Applied Mathematics*
Martti O. T. Maenpaa, Lic. Tech. .... *Applied Physics*
Kiran R. Magiawala, Ph.D. .... *Jet Propulsion*
Steven L. Manley, Ph.D. .... *Environmental Engineering Science*
Seifollah Nikdel, Ph.D.[1] .... *Environmental Engineering Science*
Bruce M. Paine, Ph.D. .... *Applied Physics*
Henry J. Pearson, Ph.D. .... *Environmental Fluid Mechanics*
Shiva Prasad, Ph.D.[2] .... *Applied Physics*
Peter S. Robertson, Ph.D.[1] .... *Computer Science*
James A. Rowson, Ph.D. .... *Computer Science*
Malladi V. Subbaiah, Ph.D. .... *Jet Propulsion*
Ilkka O. Suni, Lic. .... *Applied Physics*
Coenraad A. Swarts, Ph.D. .... *Applied Physics*
John M-M. Ting, Sc.D.[3] .... *Civil Engineering*
Timothy N. Turner, Ph.D.[1] .... *Aeronautics*
Thomas H. Upton, Ph.D.[4] .... *Applied Physics*
Israel Ury, Ph.D.[1] .... *Applied Physics*

[1]In residence 1979–80
[2]IBM Research Fellow; in residence 1979–80
[3]Also part-time Lecturer in Civil Engineering third term
[4]IBM Research Fellow

Member of the Professional Staff

William H. Bettes, *Manager, GALCIT*

Graduate Students 1980–81

Aeronautics

Kim Maynard Aaron
Thomas Patrick Bauer
Luis Paulino Bernal
Bernd Steffen Bernstorff
Sandra Lynne Buben
Christopher Jeyaparan Catherasoo
Herzl Chai
Samuel Kwang Yeh Chang
John Michael Cimbala
James Elmon Corning
Phuc The Doan
Dov Elyada
Igor Joze Emri
Morteza Gharib
Ari Glezer
Jean-Francois Luc Haas
Shigeyoshi Hata
James Carl Hermanson
Luc Jozef Heymans
Russell Duane Howard
Karyn Theresa Knoll
David Matthew Kuzo
Mark Robert Laessig
Charles Antoine Lamah
Louis Lamarche
Jane Ming-Chin Lin
Hiroshi Maekawa
Anthony Magaldi
Gad Meir
Manoochehr Mohseni-Koochesfahani
Mark Godfrey Mungal
Afshin Nassiri
Daniel Mark Nosenchuck
Tor Endre Ostbo
Dimitris A. Papantoniou
Jerome Perigne
Richard David Pfaff
Krishnaswamy Ravi Chandar
Fredrick Allan Roberts
Harry Francis Robey
Thomas Roesgen
Edward Kenneth Ruth

Alejandro Sergio Salamonovitz
Bhavani V. Sankar
William Stapf Sargent
Paul Russell Schatzle
Kevin John Sene
Choon-foo Shih
Lorenz Willard Sigurdson
Ming Han Tang
Stephen Taylor
Vincente Tortoriello
Bernd Otto Trebitz
Luigi Vigevano
Andreas Hubertus von Flotow
Chiun Wang
Joseph Kam-Leung Wat
Jeffrey Alan Zelt
Keith Peter Zondervan
Kevin Louis Zondervan

Applied Mathematics

John Wilson Barker
Gregory Allan Blaisdell
Jeffrey Michael Fier
Tomas Paul Girnius
Allan Douglas Jepson
William Lawrence Kath
Gregory William Medlin
James Robert Mueller
Allen Conrad Robinson
Louis Anthony Romero
James Carl Schatzman
Robert Elmer Scheid
Jeffrey Alan Simmen
Noel Frederick Smyth
James Lawrence Snyder
Zareh S. Tatoian

Applied Mechanics

Mark Carter Anderson
Constantine Chazapis
Kasivisvanathan Chelvakumar
Carl Leei Chen
Jeremiah Finbarr Connolly
Philippe Michel Costes
Graham Christopher Fleming
Graeme Francis Fowler
Garrett Duane Jeong
Charles Morton Krousgrill, Jr.
Timothy Christopher O'Sullivan
Thomas James Pence
Gustaf Per Reinhall
Kenneth Scott Smith
Peter Hans Stahlecker
James Michael Winget
Paul Jerome Yoder
Layne Zee
Carl Kirk Ziegler

Applied Physics

Rayhaneh Akhavan-Alizadeh
Pierre Asselin
Michael Atzmon
Thomas Clyde Banwell
Randall Kieth Bartman
David Verge Baxter
Thomas Michael Bemis
Henry Abram Blauvelt
Pei Chuang Chen
Arthur Er-terg Chiou
Liew-Chuang Chiu
Bruce Montgomery Clemens
Reuben Theodore Collins
William Sherwood Crane
Benjamin Paul Dolgopolsky
Randall Meindert Feenstra
Eric Donald Fredrickson
Andrew Keith Gabriel
Patrick William Goalwin
Glenn Joel Greene
Paul Baxter Harwood
Lowell Eugene Hazelton
Mark Allen Hedemann
Ralph Boyd James
Prakash Kasiraj
David Clark Keezer
Thomas Lawson Koch
Evelyn Ann Kramer
David Alan Krider
Thomas Francis Kuech
Daniel Bernard Lang
Christopher Paul Lindsey
Christian Mailhiot
Gordon Stuart Mitchard
Douglas Marion Moody, Jr.
Arati Prabhakar

Dale Austen Prouty
Tuviah Ehud Schlesinger
Robert Schulz
David Martin Scott
Joseph Emmett Shepherd
John Stephen Smith
Virgil Simon Speriosu
Lawrence Henry Sverdrup, Jr.
Michael Alan Tenhover
John Robert Torczynski
Russell Edward Walker
Jeffrey Owen White
Douglas Lee Whiting
Arthur Ray Williams
Daniel Paul Wilt
Kit-Lai Yu
Amikam Zur

Civil Engineering
Rajapillai Veluppillai Ahilan
Jean-Pierre Bardet
Dirceu Luiz Rodrigues Botelho
Alexander N. Brooks
William Robert Brownlie
Tsai Shing Chau
Glen John Cherepon
John Eric Christenson
Arturo Ovalle Cifuentes
Martin Francis Cohen
Yves Jacques Doucet
Charles William Engelhardt
Moh-jiann Huang
Behnam Hushmand
Sudhir Kumar Jain
Nicholas Patrick Jones
Thierry Lepelletier
Albert Niu Lin
Anne Lin
Wing Kam Liu
Emmanuel Antony Maragakis
Xavier Marie Mottet
Louis Alexander Ortiz
Ronald Yu Sang Pak
Panayiotis Nikolas Papanicolaou
Ioannis Psycharis
Ahmed Atef Rashed
James Eric Skjelbreia
Costas Emmanuel Synolakis
Catharine L. van Ingen
John Charles Wilson

Computer Science
Christopher Ralph Carroll
Sheue-Ling Chang
Marina Chien-Mei Chen
Young-Il Choo
Erik Penn DeBenedictis
Gregory H. Efland
Moshe Gray
Tai-Ping Ho
David Lawrence Johannsen
Charles Richard Lang, Jr.
Pey-yun Li
Tzu-mu Lin
Barry Bruce Megdal
Richard Craig Mosteller
Philip Malcolm Neches
Alexandros C. Papachristidis
Leonid Rudin
Richard Lawrence Segal
John Edward Tanner
Gary Mario Tarolli
David James Trawick
Stephen Mathias Trimberger
Michael Karl Ullner
Daniel Steven Whelan
Telle Elizabeth Whitney
Kwang-I Yu

Electrical Engineering
Mustafa Abushagur Gyth Abushagur
Frank Joseph Androski
Amin Khaled Chafik Badr-El-Din
Meir Bartur
Farhad Barzegar
David Bither
Alan Breight
Arthur Raymond Brown
Thomas D. Burton
Shepperd Chao
Joanna Maria Chiarito
Ilan Cohen
Antonio Decandia
Allen Mark Dewey
Russall G. DeWitt
Mark Barry Dolson

Nader Engheta
Robert Warren Erickson, Jr.
Dewey Alcott Frech
Michael Robert Gabrielli
Celestino John Gaeta
Michele Andree Grivillers
Ronald Steven Gyurcsik
Michael Lee Harmon
Steven Robert Hetzler
Timothy Daniel Hopmann
Kuan-Hsiung Hsieh
Joseph D. Jensen
Lawrence David Kamenetsky
Joseph Katz
Michael Joseph Kavaya
Luen-Hin Kwok
Didier Lacroix
Ian George Anthony Laing
Christopher Lamendola
Kam-Yin Lau
Stephen Koon-Yee Lau
Tuan-Anh Lee
Ricky Kayfaye Leo
Kathryn Lloyd Leonard
Chuen-Der Lien
Kevin Mark McNab
Theodore James Moody
Didier Rene Moretti
Phyllis Roberta Nelson
Khai Dt Ngo
William Joseph Nix
Richard Joseph O'Sullivan
David Bruce Parlour
Susan Jean Patch
William Michael Polivka
Robert Americo Rango
Leslie Ann Rusch
David Eugene Schwartz
Edgard Roger Schweig
David Bruce Squires
Guaning Su
Larry Keith Temple
Steve Joseph Tillman
Michael Tippner
Thomas E. Tkacik
Peter Ping Tak Tong
Paul William Tuinega
Kerry John Vahala
Timothy Edwin Van Eck
Gregory Vorback
Vatche Vorperian
Thang Q. Vu
Ann Pernall Waldhauer
Stephen Wilkowski
David Daniel Wolfe
Hon-Chi Yu
Barton Zwiebach

Engineering Science

Rob Bonney
Michael Jiu-Wei Chen
Jean-Luc Cornet
K. Jeffrey Eriksen
Michael Yih-Hwa Jin
Alan Stewart Katz
Richard Morris Katz
Harri Kaarlo Kytomaa
Harrison Mon Fook Leong
Daniel Margoliash
Ronald Benjamin Melton
Helene R. Schember
Michael Vincent Smith
Jack Strigberger

Environmental Engineering Science

Lisa Anderson
Roger Curtis Bales
David Atwood Bliss
Martha Harriet Conklin
Simon Henry Richard Davies
Donald Eugene Dunning, Jr.
Bruce Charles Faust
Harry Andrew Gray
James Evan Houseworth
Daniel James Jacob
Gregory John McRae
Marianna Plastourgou
Michel Rogge
Connie Lynn Senior
Alan Thomas Stone
Windsor Sung
Iraklis Valioulis
Eddy Hubert Paula Van Bouwel
Jed Michael Waldman
James Robert Young

Materials Science
Singaravelu Elangovan
Madhav Mehra

Mechanical Engineering
MD Khairul Alam
Francisco Eduardo Avila-Seguro
Elias Awad
Robert Bernier
Philippe Guy Boita
Rolf Brandt
Charles Soutter Campbell
Antonio Carpio-Carreon
Baki Mehmet Cetegen
Joel Gary Chaiken
Dimitri S. Chamieh
Albert Lee Charles
Javier Gutierrez Chavez
Francis Claude Couillard
Rodolphe Guy Cristiana
Luca d'Agostino
Susan Elizabeth Fuhs
Shawn Anthony Hall
Belgacem Jery
Ann Renee Karagozian
Michael P. Karyeaclis
Joseph Katz
Elizabeth Ann Kendall
Patrick Laurieux
Itzhak Levit
Edmond Yatman Lo
Eric Francois Matthys
Christian Michael Nielsen
Michael Allen Niman
Olin Perry Norton
Kean Khoon Ooi
Salvador Parisi
James Scott Patton
James Potechin
Yvon Resplandy
Julio A. Rodriguez Polanco
Taylor Johnson Rosenfeld
Armistead Goode Russell
Duane Andre Smith
Jan K. Spelt
John Cary Stevenson
Dean Dalton Taylor
Tayfun Ersin Tezduyar
Tak-Yiu Wong
Vigor Yang
David Nicholas Zichichi

Division of Geological and Planetary Sciences

Barclay Kamb, *Chairman*
Donald S. Burnett, *Academic Officer*
Don L. Anderson, *Director, Seismological Laboratory*

Professors Emeriti

C. Hewitt Dix, Ph.D. .... *Geophysics*
Charles F. Richter, Ph.D. .... *Seismology*
Robert P. Sharp, Ph.D. .... *Robert P. Sharp Professor of Geology*

Professors

Thomas J. Ahrens, Ph.D. .... *Geophysics*
Arden L. Albee, Ph.D. .... *Geology*
Clarence R. Allen, Ph.D. .... *Geology and Geophysics*
Don L. Anderson, Ph.D. .... *Geophysics*
Donald S. Burnett, Ph.D. .... *Nuclear Geochemistry*
Samuel Epstein, Ph.D. .... *Geochemistry*
Peter Goldreich, Ph.D. .... *Planetary Science and Astronomy*
David G. Harkrider, Ph.D. .... *Geophysics*
Donald V. Helmberger, Ph.D. .... *Geophysics*

Andrew P. Ingersoll, Ph.D. .... *Planetary Science*
Barclay Kamb, Ph.D. .... *Geology and Geophysics*
Hiroo Kanamori, Ph.D. .... *Geophysics*
Heinz A. Lowenstam, Ph.D. .... *Paleoecology*
Duane O. Muhleman, Ph.D. .... *Planetary Science*
Bruce C. Murray, Ph.D. .... *Planetary Science*
Eugene M. Shoemaker, Ph.D., Sc.D. .... *Geology and Planetary Science*
Leon T. Silver, Ph.D. .... *Geology*
Hugh P. Taylor, Jr., Ph.D. .... *Geology*
Gerald J. Wasserburg, Ph.D. .... *Geology and Geophysics*
James A. Westphal, B.S. .... *Planetary Science*

Sherman Fairchild Distinguished Scholar

Robert G. Coleman, Ph.D. .... *Geology*

Visiting Professor

C. Bernard Farmer, Ph.D. .... *Planetary Science*

Senior Research Associate

Clair C. Patterson, Ph.D. .... *Geochemistry*

Associate Professors

Jean-Bernard H. Minster, Ph.D. .... *Geophysics*
George R. Rossman, Ph.D. .... *Mineralogy*
Jason B. Saleeby, Ph.D. .... *Geology*
David J. Stevenson, Ph.D. .... *Planetary Science*

Research Associates

Richard M. Goldstein, Ph.D. .... *Planetary Science*
John C. Huneke, M.S. .... *Geochemistry*
Dimitri A. Papanastassiou, Ph.D. .... *Geochemistry*

Visiting Associates

Donald E. Brownlee, Ph.D. .... *Geochemistry*
Giuseppe Colombo, Ph.D. .... *Planetary Science*
Michael J. DeNiro, Ph.D. .... *Geochemistry*
A. Russell Flegal, Ph.D. .... *Geochemistry*
Carl A. Johnson, Ph.D. .... *Geophysics*
John Kelleher, Ph.D. .... *Geophysics*
George R. Mellman, Ph.D. .... *Geophysics*
John D. O'Keefe, Ph.D. .... *Planetary Science*
James F. Scheimer, Ph.D. .... *Geophysics*
Douglas A. Smith, Ph.D. .... *Geology*
Maureen B. Steiner, Ph.D. .... *Geology*
Dorothy S. Woolum, Ph.D. .... *Geochemistry*

Assistant Professors

Bradford H. Hager, Ph.D. .... *Geophysics*
Kerry E. Sieh, Ph.D. .... *Geology*
Edward M. Stolper, Ph.D. .... *Geology*
Yuk L. Yung, Ph.D. .... *Planetary Science*

Senior Research Fellows

Richard H. Becker, Ph.D. .... *Geochemistry*
Karen C. McNally, Ph.D. .... *Geophysics*
John T. Trauger, Ph.D. .... *Planetary Science*

Research Fellows

Mark Allen, Ph.D. .... *Planetary Science*
Nicole Borderies, Ph.D. .... *Planetary Science*
David M. Cole, Ph.D. .... *Geophysics*
Pham-Giem Cuong, Ph.D. .... *Planetary Science*
Stephen H. Hartzell, Ph.D. .... *Geophysics*
Stein B. Jacobsen, Ph.D. .... *Geology*
Thomas Kaiser, Ph.D. .... *Geochemistry*
Masayuki Kikuchi, Ph.D. .... *Geophysics*
Louise Levien, Ph.D. .... *Geology*
Kon-Kee Liu, Ph.D. .... *Geochemistry*
Gregory A. Lyzenga, Ph.D. .... *Geophysics*
Malcolm T. McCulloch, Ph.D. .... *Geochemistry*
Michael T. Murrell, Ph.D. .... *Geochemistry*
Bernhard K. Schaule, Ph.D. .... *Geochemistry*
Debra S. Stakes, Ph.D. .... *Geochemistry*
Robert K. Suchecki, Ph.D. .... *Geochemistry*
Ute R. Vetter, Ph.D. .... *Geophysics*
Igor M. Villa, Ph.D. .... *Geochemistry*
Volkar G. von Drach, Ph.D. .... *Geochemistry*
J. Peter Watt, Ph.D. .... *Geophysics*
Ian S. Williams, Ph.D. .... *Geology*
John L. Zyskind, Ph.D. .... *Physics and Planetary Science*

Members of the Professional Staff

Glenn L. Berge, Ph.D., *Senior Scientist*
Arthur A. Chodos, M.S., *Senior Research Spectroscopist*
Eleanor F. Helin, *Senior Scientist*
Wayne F. Miller, B.S., *Senior Electronic Engineer and Group Supervisor*
Dorothy M. Settle, M.S., *Senior Scientist*

Graduate Students, 1980–81

Applied Physics
Mark Bruce Boslough

Geochemistry
Robert Everett Criss
John Hume Jones

Geology

Roger Deane Aines
Cathryn Clement Allen
Melinda Mary Brugman
Josephine Beatrice Cimino
James Louis Conca
Rosemarie Cubba
Charles Brown Douthitt
Keith Alan Echelmeyer
Gerald Jonathan Fine
Lucien Froidevaux
George Ellery Gehrels
Alan Reed Gillespie
George Randall Gladstone
Robert Theodore Gregory
Thomas Martin Hearn
Robert Ian Hill
Sally Miranda Rigden Hill
Anne Marie Hofmeister
Astrid H. Howard
Eugene Drake Humphreys
Caroline Ann Lambert
Peter Brennan Larson
Thorne Lay
Ronan Le Bras
Richard Edwin Lewis, Jr.
Stephanie Margaret Mattson
Amy Chihang Ng
Donald Wallace Northfelt
Julie Marie Paque
Donald John Piepgras
Robert Edward Powell
David Bruce Sams
Christopher O'Neill Sanders
Henry Francis Shaw
George Cleve Solomon
Robert Frederik Svendsen, Jr.
Marios Simon Vassiliou
Joana Marija Vizgirda
Marianne Carol Walck
Terry Charles Wallace, Jr.
Ray James Weldon II

Geophysics

Luciana Astiz
Eric Paul Chael
John Joseph Cipar
Stephen Norfleet Cohn
Edward J. Corbett
Christopher Thomas Creaven
John Edward Ebel
Holly K. Eissler
Jeffrey Wayne Given
Jaime Rogelio Gonzalez Ruiz
Stephen Pierre Grand
Richard Paul Keller
Louise Victoria LeFevre
Craig Robert Lindberg
Hsui-Lin Liu
Kristian Erik Meisling
James Christopher Pechmann
Janice Regan
Mark Alan Richards
Larry John Ruff
Patricia Frances Scott
Gordon Selbie Stewart
Frank Lee Vernon III

Planetary Science

David Hugh Alexander
Robert Todd S. Clancy
Andrew James Friedson
Bruce Martin Jakosky
David Clifford Jewitt
Michael Alan Kroupa
Jonathan Irving Lunine
William Beall McKinnon
David Abbey Paige, Jr.
Quinn R. Passey
Judith Ann Pechmann
Carolyn C. Porco
Maritza Irene Stapanian
Michael Earl Summers
Daniel Wenkert

Division of the Humanities and Social Sciences

Roger G. Noll, *Chairman*
David M. Grether, *Executive Officer*
Daniel J. Kevles, *Executive Officer*

Professors Emeriti

Paul Bowerman, A.M. .... *Modern Languages*
Horace N. Gilbert, M.B.A., D.B.A. .... *Business Economics*
Hallett D. Smith, Ph.D., L.H.D. .... *English*
Alan R. Sweezy, Ph.D. .... *Economics*
Ray E. Untereiner, Ph.D., J.D. .... *Economics*

Lecturer Emeritus

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

Professors

Robert H. Bates, Ph.D. .... *Political Science*
John F. Benton, Ph.D. .... *History*
J. Kent Clark, Ph.D. .... *Literature*
Lance E. Davis, Ph.D. .... *Economics*
David C. Elliot, Ph.D. .... *History*
Peter W. Fay, Ph.D. .... *History*
John A. Ferejohn, Ph.D. .... *Political Science*
Morris P. Fiorina, Ph.D. .... *Political Science*
Michael J. Graetz, LL.B. .... *Law and Social Science*
David M. Grether, Ph.D. .... *Economics*
William T. Jones, Ph.D.[1] .... *Philosophy*
Daniel J. Kevles, Ph.D. .... *History*
Burton H. Klein, Ph.D. .... *Economics*
J. Morgan Kousser, Ph.D. .... *History and Social Science*
Michael E. Levine, J.D. .... *Luce Professor of Law and Social Change*
Oscar Mandel, Ph.D. .... *Literature*
George P. Mayhew, Ph.D.[2] .... *English*
Richard D. McKelvey, Ph.D. .... *Political Science*
Edwin S. Munger, Ph.D. .... *Geography*
Roger G. Noll, Ph.D. .... *Economics*
Robert W. Oliver, Ph.D. .... *Economics*
Rodman W. Paul, Ph.D. .... *Edward S. Harkness Professor of History*
Charles R. Plott, Ph.D. .... *Economics*
James P. Quirk, Ph.D. .... *Economics*
Robert A. Rosenstone, Ph.D. .... *History*
Thayer Scudder, Ph.D. .... *Anthropology*
Eleanor M. Searle, Ph.D. .... *History*
Frederick B. Thompson, Ph.D. .... *Applied Philosophy and Computer Science*
Martin Ridge, Ph.D.[1] .... *History*

[1]Part-time
[2]Leave of absence

Sherman Fairchild Distinguished Scholars

Richard A. Easterlin, Ph.D. .... *Economics*
Gerald Kramer, Ph.D. .... *Political Science*
Allan J. Lichtman, Ph.D. .... *History*

Visiting Professor

Alan Schwartz, LL.B. .... *Law and Social Science*

Associate Professors

Louis Breger, Ph.D. .... *Psychology and the Humanities*
Heinz E. Ellersieck, Ph.D. .... *History*
Stuart A. Ende, Ph.D. .... *Literature*
Jenijoy La Belle, Ph.D. .... *Literature*
David R. Smith, Ph.D. .... *Literature*
Louis L. Wilde, Ph.D. .... *Economics*

Visiting Associate Professor

Shyam Sunder, Ph.D. .... *Business Economics*

Research Associates

R. Talbot Page, Ph.D. .... *Economics*
Bozena Henisz-Dostert Thompson, Ph.D. .... *Linguistics*

Visiting Associates

Eileen M. Crimmins, Ph.D. .... *Sociology*
Manjula Shyam, Ph.D. .... *Political Science*

Assistant Professors

Kim Border, Ph.D. .... *Economics*
Bruce E. Cain, Ph.D. .... *Political Science*
Nicholas B. Dirks, Ph.D. .... *History*
Robert Forsythe, Ph.D. .... *Economics*
David W. Galenson, Ph.D.[1] .... *Social Science and History*
D. Roderick Kiewiet, Ph.D. .... *Political Science*
George W. Pigman III, Ph.D. .... *Literature*
Jennifer F. Reinganum, Ph.D. .... *Economics*
Randolph N. Splitter, Ph.D. .... *Literature*

Visiting Assistant Professors

David W. Burchmore, Ph.D. .... *Literature*
Edward J. Green, Ph.D. .... *Economics*
Ross M. Miller, Ph.D. .... *Economics*
Mary M. O'Keeffe, Ph.D. .... *Economics*
Asad Zaman, Ph.D. .... *Economics*

[1]Part-time

Mellon Postdoctoral Instructors

Barbara S. Freedman, Ph.D. .... *Literature*
David Sundelson, Ph.D. .... *Literature*

Instructor

Anne C. Rose, Ph.D. .... *History*

Lecturers

Andreas Aebi, Ph.D. .... *German*
Irving S. Bengelsdorf, Ph.D.[1] .... *Science Communication*
Mary G. Berg, Ph.D. .... *Literature*
James Boyk, M.F.A. .... *Music*
David J. Britton, D.M.A. .... *Music*
Lee F. Browne, M.S.[1] .... *Education*
Klara Carmely, Ph.D. .... *German*
Clayton Eshleman, M.A.T. .... *Lecturer in Creative Writing*
Sonia Ghattas, Ph.D. .... *French*
Philip T. Hoffman, Ph.D. .... *History*
Stirling L. Huntley, Ph.D. .... *Drama*
Edward Hutchings, Jr., B.A. .... *Journalism*
Richard Kirkham, B.A. .... *Debate*
David W. Morrisroe, M.B.A.[1] .... *Business Economics*
Jon R. Pariser, M.A. .... *Russian*
Aimée Brown Price, Ph.D. .... *Art History*
Harihar Rao .... *Music*
Elma Schonbach, B.M. .... *Music*
Annette J. Smith, Ph.D. .... *French*
Victor V. Veysey, M.B.A.[1] .... *Business Economics and Industrial Relations*
Robert R. Wark, Ph.D.[1] .... *Art*
Valentina Zaydman, M.A. .... *Russian*

Research Fellow

Euisoon Shin, Ph.D. .... *Economics*

Graduate Students 1980–81

Social Science
Joel Abe Balbien
Jose Edgardo Lopez Campos
Gary Walter Cox
Joshua Bennett Foreman
Rodney Douglas Fort
James Michael Gerard
Robert William Hahn
Bruce Gordon Herring
David Douglas Herring
James Takfay Hong
Jeffrey Bowman Johnson
Kap Yun Lee
Carl J. Lydick
Mathew Daniel McCubbins
Kenneth Frank McCue
Asha Bhalachandra Paranjape
Del Owen Powell
Venkatraman Sadanand
John Patrick Schmitz
Stephen Richard Selinger
Howard Alan Tarre
William Dale Turner
John Marshall Williamson

[1]Part-time

Division of Physics, Mathematics and Astronomy

Rochus E. Vogt, *Chairman*
Robert L. Walker, *Executive Officer for Physics*
W. A. J. Luxemburg, *Executive Officer for Mathematics*
W. L. W. Sargent, *Executive Officer for Astronomy*
Gerry Neugebauer, *Acting Director, Palomar Observatory*
Rochus E. Vogt, *Acting Director, Owens Valley Radio Observatory*
Harold Zirin, *Director, Big Bear Solar Observatory*

Board of Trustees Professor Emeritus

Carl D. Anderson, Ph.D., Sc.D., LL.D., Nobel Laureate .... *Physics*

Professors Emeriti

Robert F. Bacher, Ph.D., Sc.D., LL.D. .... *Physics*
H. F. Bohnenblust, Ph.D. .... *Mathematics*
Jesse L. Greenstein, Ph.D. .... *Lee A. DuBridge Professor of Astrophysics*
H. Victor Neher, Ph.D., Sc.D. .... *Physics*
William R. Smythe, Ph.D. .... *Physics*
Olga Taussky Todd, Ph.D. .... *Mathematics*

Professors

Tom M. Apostol, Ph.D. .... *Mathematics*
Michael Aschbacher, Ph.D. .... *Mathematics*
Barry C. Barish, Ph.D. .... *Physics*
Roger G. Blandford, Ph.D. .... *Theoretical Astrophysics*
Felix H. Boehm, Ph.D.[1] .... *Physics*
Robert F. Christy, Ph.D. .... *Theoretical Physics*
Donald S. Cohen, Ph.D. .... *Applied Mathematics*
Marshall H. Cohen, Ph.D.[2] .... *Radio Astronomy*
Eugene W. Cowan, Ph.D. .... *Physics*
Leverett Davis, Jr., Ph.D. .... *Theoretical Physics*
Richard A. Dean, Ph.D. .... *Mathematics*
Charles R. De Prima, Ph.D. .... *Mathematics*
Robert P. Dilworth, Ph.D. .... *Mathematics*
Ronald W. P. Drever, Ph.D. .... *Physics*
Richard P. Feynman, Ph.D., Nobel Laureate .... *Richard Chace Tolman Professor of Theoretical Physics*
William A. Fowler, Ph.D., D.Sc. .... *Institute Professor of Physics*
Geoffrey Fox, Ph.D. .... *Theoretical Physics*
Steven C. Frautschi, Ph.D. .... *Theoretical Physics*
F. Brock Fuller, Ph.D. .... *Mathematics*
Gordon P. Garmire, Ph.D. .... *Physics*
Murray Gell-Mann, Ph.D., Sc.D., Nobel Laureate .... *Robert Andrews Millikan Professor of Theoretical Physics*
Marvin L. Goldberger, Ph.D. .... *Theoretical Physics*
Peter Goldreich, Ph.D. .... *Planetary Science and Astronomy*
Ricardo Gomez, Ph.D. .... *Physics*
David L. Goodstein, Ph.D. .... *Physics and Applied Physics*

[1]Leave of absence, first term, 1980–81
[2]Leave of absence, 1980–81

Marshall Hall, Jr., Ph.D. .... *IBM Professor of Mathematics*
Ralph W. Kavanagh, Ph.D. .... *Physics*
Herbert B. Keller, Ph.D. .... *Applied Mathematics*
Heinz-Otto Kreiss, Docent .... *Applied Mathematics*
Robert B. Leighton, Ph.D. .... *Physics*
Gary Lorden, Ph.D. .... *Mathematics*
W. A. J. Luxemburg, Ph.D. .... *Mathematics*
James E. Mercereau, Ph.D., D.Sc. .... *Physics and Applied Physics*
Alan T. Moffet, Ph.D. .... *Radio Astronomy*
Gerry Neugebauer, Ph.D. .... *Physics*
J. Beverley Oke, Ph.D. .... *Astronomy*
Charles W. Peck, Ph.D. .... *Physics*
Thomas G. Phillips, Ph.D. .... *Physics*
Jerome Pine, Ph.D. .... *Physics*
H. David Politzer, Ph.D. .... *Theoretical Physics*
Herbert J. Ryser, Ph.D. .... *Mathematics*
Wallace L. W. Sargent, Ph.D. .... *Astronomy*
Maarten Schmidt, Ph.D., Sc.D.[1] .... *Astronomy*
Frank J. Sciulli, Ph.D.[1] .... *Physics*
Edward C. Stone, Jr., Ph.D. .... *Physics*
Kip S. Thorne, Ph.D. .... *Theoretical Physics*
John Todd, B.Sc. .... *Mathematics*
Thomas A. Tombrello, Jr., Ph.D. .... *Physics*
Rochus E. Vogt, Ph.D. .... *Physics*
David B. Wales, Ph.D. .... *Mathematics*
Robert L. Walker, Ph.D. .... *Physics*
Ward Whaling, Ph.D. .... *Physics*
Richard M. Wilson, Ph.D. .... *Mathematics*
Gerald B. Whitham, Ph.D. .... *Applied Mathematics*
Fredrik Zachariasen, Ph.D. .... *Theoretical Physics*
Harold Zirin, Ph.D. .... *Astrophysics*
George Zweig, Ph.D. .... *Theoretical Physics*

Sherman Fairchild Distinguished Scholars

Lennox Cowie, Ph.D. .... *Astronomy*
Kenneth I. Kellermann, Ph.D. .... *Radio Astronomy*
Christopher McKee, Ph.D. .... *Astronomy*
V. Radhakrishnan, Ph.D. .... *Radio Astronomy*
Barry Simon, Ph.D. .... *Mathematics*
Gerard 't Hooft, Ph.D. .... *Theoretical Physics*

Visiting Professors

Dany Leviatan, Ph.D. .... *Mathematics*
George Tiktopoulos, Ph.D. .... *Physics*

Associate Professors

Judith G. Cohen, Ph.D. .... *Astronomy*
David Hitlin, Ph.D. .... *Physics*

[1]Leave of absence, 1980–81

Alexander S. Kechris, Ph.D. .... *Mathematics*
Steven E. Koonin, Ph.D. .... *Physics*
Peter G. Wannier, Ph.D. .... *Radio Astronomy*

Visiting Associate Professor

Charles R. Johnson, Ph.D. .... *Mathematics*

Research Associates

Andrew Buffington, Ph.D. .... *Physics*
Peter Haff, Ph.D. .... *Physics*
Richard J. Powers, Ph.D. .... *Physics*
Anthony C. S. Readhead, Ph.D. .... *Radio Astronomy*
John H. Schwarz, Ph.D. .... *Theoretical Physics*
George A. Seielstad, Ph.D. .... *Radio Astronomy*
Petr Vogel, Ph.D. .... *Physics*
Steven Wolfram, Ph.D. .... *Theoretical Physics*

Visiting Associates

Stig I. Andersson, Ph.D. .... *Mathematics*
Joseph E. Avron, Ph.D. .... *Mathematics*
Lee Chang, Ph.D. .... *Physics*
Ronald J. Crowley, Ph.D. .... *Physics*
Carl L. De Vito, Ph.D. .... *Mathematics*
Max Dresden, Ph.D. .... *Mathematics*
William A. Feldman, Ph.D. .... *Mathematics*
John L. Hayden, Ph.D. .... *Mathematics*
Anthony Hey, D.Phil. .... *Theoretical Physics*
Charles H. Holbrow, Ph.D. .... *Physics*
Sir Fred Hoyle, D.Sc. .... *Physics*
Martin H. Israel, Ph.D. .... *Physics*
Jiang Fong-liang, M.S. .... *Physics*
Douglas E. Jones, Ph.D. .... *Physics*
Bernard Julia, Ph.D. .... *Theoretical Physics*
Stella H. Law, Ph.D. .... *Physics*
Li Giu-ru, M.S. .... *Physics*
Shi-Guang Lian, Ph.D. .... *Radio Astronomy*
Roberto A. Mena, Ph.D. .... *Mathematics*
Berndt Muller, Ph.D. .... *Physics*
Yuanxum Qiu, Ph.D. .... *Physics*
Stefan Pokorski, Ph.D. .... *Theoretical Physics*
James F. Porter, Ph.D. .... *Mathematics*
Gregory Shields, Ph.D. .... *Astronomy*
Dennis Sivers, Ph.D. .... *Theoretical Physics*

Assistant Professors

Jack F. Conn, Ph.D. .... *Mathematics*
Kwok-Yung Lo, Ph.D. .... *Radio Astronomy*
W. Hugh Woodin, Ph.D. .... *Mathematics*
Peter Young, Ph.D. .... *Astronomy*

Senior Research Fellows

G. John Dick, Ph.D. .... *Applied Physics*
Siu Au Lee, Ph.D. .... *Physics*
Jens Ludwig, Ph.D. .... *Physics*
Kenneth Marsh, Ph.D. .... *Astrophysics*
Robert L. Messner, Ph.D. .... *Physics*
Richard A. Mewaldt, Ph.D. .... *Physics*
Ronald L. Moore, Ph.D. .... *Astrophysics*
Steven H. Pravdo, Ph.D. .... *Physics*
B. Thomas Soifer, Ph.D. .... *Physics*
Ryszard Stroynowski, Ph.D. .... *Physics*

Instructors

Michael J. Hoffman, Ph.D.[1] .... *Mathematics*
A. J. Janssen, Ph.D.[1] .... *Mathematics*
Richard P. Morton, Ph.D.[1] .... *Mathematics*
Robert Roth, Ph.D.[1] .... *Mathematics*
Anton R. Schep, Ph.D. .... *Mathematics*
William A. Squires, Ph.D.[1] .... *Mathematics*
Peter Taborek, Ph.D.[2] .... *Physics*
Eitan Tadmor, Ph.D.[1] .... *Applied Mathematics*

Lecturers

Alan S. Jacobson, Ph.D. .... *Physics*
Barry Thomas, Ph.D. .... *Physics*

Research Fellows

Yoram Alhassid, Ph.D.[3] .... *Physics*
Jan Ambjørn, Ph.D. .... *Theoretical Physics*
Rose Mary Baltrusaitis, Ph.D. .... *Physics*
Stephen A. Becker, Ph.D. .... *Physics*
Charles Beichman, Ph.D. .... *Physics*
William Bieber, Ph.D. .... *Physics*
Todd Boroson, Ph.D. .... *Astronomy*
Carlton M. Caves, Ph.D. .... *Physics*
David L. Chenette, Ph.D. .... *Physics*
Haldan Cohn, Ph.D. .... *Theoretical Astrophysics*
Christopher Cosgrove, Ph.D.[4] .... *Theoretical Astrophysics*
Brian Davis, Ph.D. .... *Physics*
Avishai Dekel, Ph.D. .... *Theoretical Astrophysics*
K. R. Sandhya Devi, Ph.D. .... *Physics*
Pietro Fre, Ph.D. .... *Theoretical Physics*
Sylvester J. Gates, Jr., Ph.D. .... *Theoretical Physics*
James L. Gimlett, Ph.D. .... *Physics*
Thomas G. Gottschalk, Ph.D. .... *Theoretical Physics*
Joseph E. Griffith, Ph.D. .... *Physics*

[1]Harry Bateman Research Instructor
[2]Robert A. Millikan Research Instructor
[3]Chaim Weizmann Research Fellow
[4]Richard Chace Tolman Fellow

Michael J. Harris, Ph.D. .... *Physics*
John G. Hoessel, Ph.D. .... *Astronomy*
Richard J. Hughes, Ph.D. .... *Theoretical Physics*
Michael Jaroszynski, Ph.D. .... *Theoretical Astrophysics*
Arieh Konigl, Ph.D. .... *Theoretical Astrophysics*
Nikolaos Kylafis, Ph.D. .... *Theoretical Astrophysics*
John Lacy, Ph.D. .... *Physics*
Geoffrey P. Maddison, Ph.D. .... *Physics*
Colin Masson, Ph.D. .... *Radio Astronomy*
Grant J. Mathews, Ph.D. .... *Physics*
Charles J. Melcher, Ph.D. .... *Physics*
John A. Nousek, Ph.D. .... *Physics*
David Novikoff, Ph.D. .... *Physics*
David G. Payne, Ph.D. .... *Theoretical Astrophysics*
Thomas A. Prince, Ph.D. .... *Physics*
James J. Russell, Ph.D. .... *Physics*
David G. Sandler, Ph.D. .... *Physics*
L. Elizabeth Seiberling, Ph.D. .... *Physics*
Warren D. Siegel, Ph.D. .... *Theoretical Physics*
Robert Spero, Ph.D. .... *Physics*
Friedrich-Karl Thielemann, Ph.D. .... *Physics*
Theodore Tomaras, Ph.D. .... *Theoretical Physics*
Stephen Unwin, Ph.D. .... *Radio Astronomy*
Charles C. Watson, Ph.D. .... *Physics*
Alwyn Wootten, Ph.D. .... *Radio Astronomy*
Alice Wu, Ph.D. .... *Physics*
Laurence G. Yaffe, Ph.D.[1] .... *Theoretical Physics*
Kar Woo Yung, Ph.D. .... *Physics*
John L. Zyskind, Ph.D. .... *Physics and Planetary Science*

Members of the Professional Staff

Martin S. Ewing, *Senior Research Engineer*
Herbert E. Henrikson, *Senior Design Engineer*
Keith Matthews, *Scientist*
Richard B. Read, *Senior Engineer*
Donald Skelton, *Engineer*
Barbara A. Zimmerman, *Computing Analyst*

Graduate Students 1980–81

Applied Mathematics
David Leslie Brown
Geoffrey Samuel Chesshire
Elizabeth Ann Crooks
John Alan Fawcett
Charles Edward Goodhart
Thomas Michael Hagstrom
Michael Edwin Henderson
Lars Eric Hernquist
Fai Ma
Michael David Prendergast
Douglas Alan Reinelt
Luis Guillermo Maria Reyna
David Kenneth Rollins
Saleh Ahmed Tanveer
Daniel Herbert Turnbull
Daniel Ian Zwillinger

[1]Richard Chace Tolman Fellow

Applied Physics
Elliott Rowe Brown
Jeffrey Eugene Ungar

Astronomy
Graham Berriman
John Anthony Biretta
Kirk Daniel Borne
Alexei Vladimir Filippenko
James Arthur Fillmore
Keith Douglas Horne
Stephen Morris Lichten
Roger Paul Linfield
Thomas Glenn Lockhart
Matthew Arnold Malkan
Jeffrey Ross Pier
Douglas Mark Rabin
Russell Ormond Redman
Robert Michael Rich
Abhijit Saha
Donald Patrick Schneider
William Lawrence Sebok
Richard Stanley Simon
Richard Alan Wade
Howard Kwong Chew Yee
Kenneth Harbour Young

Mathematics
Gary Ray Becker
Philip Cotter
Mark Crawshaw
Joel Christopher Fowler
Philip James Hanlon
Dean Robert Hart
Ralph Elwood Howard
Ilias George Kastanas
Michael Robert Lewy
Hong-Chuan Lin
Hajo Luers
Jack H. Lutz
Igor Mikolic-Torreira
Claire O'Keefe
Bruce Michael Ian Rands
Gregory Paul Tollisen
Frans Gerhardus Johannes Wiid
John Charles Wolfskill

Physics
Hideaki Aoyama
Gregory John Ball
James Hugh Bayless
Howard Louis Berg
Robert Eugene Blair
Anthony Michael Bloch
Norman Bobroff
Arnold Ian Boothroyd
Mark John Bowick
Hugh Herbert Breneman
Richard Laurence Brenner
Eugene David Brooks III
Ariel Caticha
Nestor Felipe Caticha Alfonso
Yia-chung Chang
Yam Ki Chu
Daniel Mark Coffman
Christopher Alan Cole
Walter Richardson Cook
Barbara Hope Cooper
Murray Scott Daw
Eva Maria Dohrn
Mark F. Dumke
Charles David Edwards, Jr.
David James Ennis
Mark Harold Finger
Richard Alan Flammang
Bradley Arnold Flanders
Michael David Foote
George Michael Fuller
Cornelis Adolf Gehrels
John Richard Gilbert
Mark Golomb
Marc Howard Goroff
Jeffrey Mark Greif
Gothard Carson Grey
Erich Nathan Grossman
Rajan Gupta
Yekta Gursel
Craig Warren Gustafson
Jeffrey John Hamilton
Jeffrey Alan Harvey
Brian Frederick Hatfield
Jay Hauser
William Donald Hazelton
Mark Hereld

David Hans Hough
Andrew Thompson Hunter
Kenneth Alan Jensen
Sarbmeet Singh Kanwal
Jaisam Kim
Jeffrey George Koller
Steven James Komie
Dale Edward Koop
Richard M. Kremer
Keith E. Krombel
Heemin Kwon
Nai-Hang Kwong
Koon Hang Lau
Hyuk Lee
James Roy Lee
Pui-Tang Leung
Graeme Lowe
Douglas Alan MacDonald
David Brian MacFarlane
Narayan Krishna Mahale
Neil Marcus
John Kevin Markey
Olivier Christian Martin
Ivan Jorge Matus Bloch
Michael Charles McNab
Charles Kenneth Meins, Jr.
Markus Meister
Marcus Holden Mendenhall
Geoffrey Blount Mills
Richard Gerard Milner
Donald Paul Mitchell
Eric Daniel Mjolsness
Lawrence Paul Muirhead
John Anthony Murphy
Daniel Nadeau
Brian John Newport
Joseph Michael Nilsen
Mats Nordahl
Jane Elizabeth Nordholt
John Joseph Nugent
John Lawrence Osborne
Steven William Otto
Apoorva Dayaram Patel
Richard Allan Partridge
Peter Anton Perry
Michael Steven Pettersen
Milind Vasant Purohit
Mohit Randeria
Ian H. Redmount
David Benjamin Reiss
Jeffrey David Richman
Leonid Zinovy Rivkin
Larry James Romans
Ann Judith Rosenthal
Augusto Sagnotti
Raghvendra Sahai
Balachandran Sathiapalan
Bonny Laura Schumaker
Kristen Sellgren
Michael P. Shatz
Run-lie Shia
Byron Bong Siu
Robert Thomas Skelton
John David Spalding
Srinivas Sridhar
Stuart Reh Stampke
Wai Mo Suen
Gayle Arden Sugiyama
Anthony Emerson Terrano
Stephen Trentalange
Tsun-yan Tse
Michael Patrick Tuite
John Reinhold Valainis
Mark Alan Voelker
Michael Ben Weimer
Michael James Wengler
Roy David Williams
Brian David Wilson
Jack Leach Wisdom
Hitoshi Yamamoto
James Frederick Zumberge

Sherman Fairchild Distinguished Scholars

1979–80

Lennox L. Cowie, Ph.D.
Research Astronomer and Associate Professor, Princeton University Observatory

1980–81

Rutherford Aris, Ph.D., D.Sc.
Professor of Chemical Engineering, University of Minnesota, Twin Cities
George F. Carrier, Ph.D.
T. Jefferson Coolidge Professor of Applied Mathematics, Harvard University
Robert G. Coleman, Ph.D.
Research Geologist, U. S. Geological Survey
Richard A. Easterlin, Ph.D.
Professor of Economics, University of Pennsylvania
Mostafa Amr El-Sayed, Ph.D.
Professor of Chemistry, University of California, Los Angeles
Malcolm L. H. Green
Professor of Inorganic Chemistry, Balliol College, University of Oxford
Kenneth I. Kellermann, Ph.D.
Staff Member, National Radio Astronomy Observatory, Green Bank
Gerald H. Kramer, Ph.D.
Professor of Political Science and Economics; Staff Member, Cowles Foundation for Research in Economics, Yale University
John J. Lambe, Ph.D.
Principal Staff Scientist, Ford Motor Company, Dearborn
Allan J. Lichtman, Ph.D.
Assistant Professor of History, The American University
Bo G. Malmström, Fil.dr.
Professor and Head, Department of Biochemistry, University of Göteborg
Christopher McKee, Ph.D.
Professor of Physics and Astronomy, University of California
Venkataraman Radhakrishnan, B.Sc.
Director, Raman Research Institute, Bangalore, India
Barry Simon, Ph.D.
Professor of Mathematics and Physics, Princeton University
Gerard 't Hooft, Promotie
Professor, Institute for Theoretical Physics, Utrecht

Athletics and Physical Education

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

Full-Time Staff

Clint Dodd, B.S.
E. Leroy Neal, M.A.
Lin Parker, M.A.
Edward T. Preisler, B.A.

Part-Time Staff

David E. Beck, B.A.
Dean G. Bond, B.A.
Donald R. Cameron, B.Sc.
Harold G. Cassriel, B.S.
George Clovis
John L. Lamb
Elizabeth Oberstein, M.A.
Tsutomu Ohshima, B.A.
Mike Poizner, M.A.

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.

Willis H. Booth Computing Center

Charles B. Ray, *Director*
Kiku Matsumoto, *Deputy Director*

Staff Members

James V. Bys
Albert Fuwu Chang
Meribeth B. Cooper
Joseph H. Dailey
James P. Elliott
Edith P. Huang
Robert S. Logan
Dallas W. Oller, Jr.
William C. Peterson
Donald D. Rintala
Hector R. Valdez
Kimo Yap
Dimitrios Zorbas

Environmental Quality Laboratory

Norman H. Brooks, *Director*

Staff Council

Norman H. Brooks,[1] *Chairman*
Glen R. Cass[1]
John Ferejohn[1]
Richard C. Flagan
Leroy E. Hood
Robert C. Y. Koh
Lester Lees[1]
E. John List[1]
James J. Morgan
Roger G. Noll
R. Talbot Page
Charles R. Plott
James P. Quirk
John H. Seinfeld[1]
Fredrick H. Shair
Leon T. Silver

Research Staff

Norman H. Brooks, Director; James Irvine Professor of Environmental and Civil Engineering
Miles G. Bogle, Research Fellow in Environmental Engineering
Glen R. Cass, Assistant Professor of Environmental Engineering
Vicente Costanza, Research Fellow in Chemical Engineering
John Ferejohn, Professor of Political Science

[1]Executive Committee

Richard C. Flagan, Assistant Professor of Environmental Engineering Science
Robert E. Forsythe, Assistant Professor of Economics
Morton S. Isaacson, Research Engineer
Robert C. Y. Koh, Research Associate in Environmental Engineering Science
Lester Lees, Professor of Environmental Engineering Science and Aeronautics
E. John List, Professor of Environmental Engineering Science
Gregory J. McRae, Senior Research Engineer
James J. Morgan, Professor of Environmental Engineering Science; Vice President for Student Affairs
Roger G. Noll, Professor of Economics; Chairman, Division of the Humanities and Social Sciences
R. Talbot Page, Research Associate in Economics
James P. Quirk, Professor of Economics
John H. Seinfeld, Louis E. Nohl Professor and Executive Officer of Chemical Engineering
Fredrick H. Shair, Professor of Chemical Engineering
Euisoon Shin, Research Fellow in Economics
Brent D. Taylor, Senior Research Engineer, Member of the Professional Staff
James W. Tilden, Senior Research Engineer
Wade Wells, Hydrologist (on assignment to EQL by U.S. Forest Service)
Louis L. Wilde, Assistant Professor of Economics

Consultants

James E. Krier, Professor of Law, UCLA
Vito A. Vanoni, Professor of Hydraulics, Emeritus

Graduate Students 1979–80

MD Khairul Alam *(Engineering)*
Richard Ashman *(Engineering)*
Donna Berry *(Social Science)*
William Brownlie *(Engineering)*
Martha Conklin *(Engineering)*
H. Andrew Gray *(Engineering)*
Robert Hahn *(Social Science)*
James Houseworth *(Engineering)*
Mark Isaac *(Social Science)*
Gregory McRae *(Engineering)*
Thomas Palfrey *(Social Science)*
Asha Paranjape *(Social Science)*
James Patton *(Engineering)*
Armistead Russell *(Engineering)*
Venkatraman Sadanand *(Social Science)*
Jed Waldman *(Engineering)*

Health Center

Gregory Ketabgian, M.D. .... *Director of Health Services*
Marlene Coleman, M.D. .... *Attending Physician*
Barbara Fass, Ph.D. .... *Institute Psychologist*
Judson James, M.D. .... *Attending Physician*
Warren Jones, M.D. .... *Consulting Psychiatrist*
Jack Lindheimer, M.D. .... *Consulting Psychologist*
Haig Manjikian, M.D. .... *Attending Physician*
Robert Drezner, Ph.D. .... *Institute Psychologist*

Industrial Relations Center

Victor V. Veysey, M.B.A., *Director, Industrial Relations Center; Lecturer in Business Economics and Industrial Relations*

Jet Propulsion Laboratory

Administered by Caltech for the National Aeronautics and Space Administration

Bruce C. Murray, *Director*
C. H. Terhune, Jr., *Deputy Director*

Advisory Council

Dr. Philip H. Abelson
Editor, *Science*
Dr. Arden Albee
Professor of Geology, Caltech;
Chief Scientist, JPL
Mr. Norton Belknap
Senior Vice President,
Exxon International Company
Mr. Walter Burke
Caltech Trustee, and President of
Sherman Fairchild Foundation, Inc.
Dr. Robert Christy
Professor of Theoretical
Physics, Caltech
Dr. Lee A. DuBridge
President Emeritus, Caltech, and
Life Trustee of Caltech
Dr. Eugene G. Fubini
E. G. Fubini Consultants, Ltd.
Mr. John Gardner
Chairman, President's Commission on
White House Fellowships, and
Founding Chairman, Common Cause
Dr. David Goodstein
Professor of Physics and Applied
Physics, Chairman of the
Faculty, Caltech
Dr. Barclay Kamb
Professor of Geology and Geo-
physics; Chairman of the Division of
Geological and Planetary Sciences,
Caltech
Dr. Roger Noll
Professor of Economics and Chairman
of the Division of the Humanities and
Social Sciences, Caltech
Dr. Bernard M. Oliver
Vice President, Research and Develop-
ment, Hewlett-Packard Company
Dr. Allen Peterson
Professor of Electrical Engineering and
Co-Director, Stanford Center for Radar
Astronomy, Stanford University
Dr. John R. Pierce
Professor of Engineering Emeritus,
Caltech; Chief Technologist, JPL
Mr. Stanley R. Rawn, Jr.
Caltech Trustee, and President of
Marline Resources Company, Inc.
Dr. Eberhardt Rechtin
President, Aerospace Corporation
Mrs. Mary L. Scranton
Caltech Trustee
Dr. Edward Stone
Professor of Physics, Caltech
Dr. John M. Teem *(Council Chairman)*
President, Association of Universities
for Research in Astronomy, Inc.
Mr. Lew R. Wasserman
Caltech Trustee, and Chairman and Chief
Executive Officer of MCA, Inc.

Ex Officio:
Dr. Marvin Goldberger
President, Caltech
Mr. David Morrisroe
Vice President for Business and Finance
and Treasurer, Caltech
Dr. John D. Roberts
Vice President and Provost,
Dean of the Faculty, Caltech

Past Members:

Mr. Benjamin Biaggini
Dr. Harry Gray
Mr. Robert Gilmore
Hon. Shirley Hufstedler
Dr. James J. Morgan
Dr. Ray Owen
Dr. Simon Ramo
Dr. Robert Sharp
Dr. Robert W. Vaughan[1]
Dr. Rochus Vogt
Mr. William Zisch

[1]Deceased

Institute Libraries

Johanna E. Tallman, *Director*

Janet Casebier, Humanities and Documents Librarian
Roderick J. Casper, Public Services Librarian, MPS
Judith R. Goodstein, Institute Archivist, MPS
Duane M. Helgeson, Physical Sciences Librarian
Donald McNamee, Catalog Librarian
Edward R. Moser, Serials Librarian
Dana L. Roth, Sciences Librarian, MPS

Representatives for the Departmental Libraries

Clarence R. Allen, Ph.D.
Tom M. Apostol, Ph.D.
John F. Benton, Ph.D.
Felix H. Boehm, Ph.D.
Charles J. Brokaw, Ph.D.
Norman H. Brooks, Ph.D.
Francis S. Buffington, Ph.D.
Judith Cohen, Ph.D.
Donald E. Coles, Ph.D.
Paco A. Lagerstrom, Ph.D.
Charles H. Papas, Ph.D.
Rolf H. Sabersky, Ph.D.
Walter A. Schroeder, Ph.D.
Nicholas W. Tschoegl, Ph.D.
Victor V. Veysey, M.B.A.

Musical Activities

Olaf Frodsham .... *Director of Choral Music*
Monica Roegler .... *Assistant Director of Choral Music*
William Bing .... *Jazz Band Director*
Kim Kowalke .... *Symphony Orchestra Director*
James Rötter .... *Wind Ensemble Director*
James Boyk .... *Interpretive Music Class*

OFFICERS AND FACULTY

Marvin Leonard Goldberger, Ph.D., D.H.L., *President; Professor of Theoretical Physics*

B.S., Carnegie Institute of Technology, 1943; Ph.D., The University of Chicago, 1948. California Institute, 1978-.

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-.

Edward N. Adams, Ph.D., *Visiting Professor of Computer Science*

B.S., Southwestern University (Memphis), 1943; M.S., The University of Wisconsin, 1947; Ph.D., 1950. Staff Member, IBM Research (Yorktown Heights), 1959-. California Institute, 1980-81.

Andreas Aebi, Ph.D., *Lecturer in German*

M.A., University of Southern California, 1970; Ph.D., 1974. Lecturer in French, California Institute, 1978; Lecturer in German, 1978-.

William Scott Agnew, Ph.D., *Research Fellow in Chemistry*

A.B., University of California (Los Angeles), 1968; Ph.D., 1976. California Institute, 1976-.

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

B.S., Massachusetts Institute of Technology, 1957; M.S., California Institute, 1958; Ph.D., Rensselaer Polytechnic Institute, 1962. Associate Professor, California Institute, 1967-76; Professor, 1976-.

Thomas Bellis Ake III, Ph.D., *Research Fellow in Astronomy*

B.S., Case Western Reserve University, 1971; M.S., 1974; Ph.D., 1977. California Institute, 1978-.

Arden Leroy Albee, Ph.D., *Professor of Geology; Chief Scientist, Jet Propulsion Laboratory*

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, Geological and Planetary Sciences, 1971-79; Chief Scientist, 1979-.

Alex Peter Alder, Ph.D., *Research Fellow in Chemistry*

Dipl., Federal Institute of Technology (Zurich), 1975; Ph.D., 1980. California Institute, 1979-.

Jack Leland Alford, Ph.D., *Visiting Associate in Civil Engineering*

B.S., California Institute, 1942; M.S., 1946; Ph.D., 1950. Professor and Chairman, Department of Engineering, Harvey Mudd College, 1959-. Visiting Associate, California Institute, 1979-80.

Yoram Alhassid, Ph.D., *Weizmann Research Fellow in Physics*

B.Sc., The Hebrew University, 1974; Ph.D., 1978. California Institute, 1979-.

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 Chairman, Division of Geology, 1967-68.

Mark Andrew Allen, Ph.D., *Research Fellow in Planetary Science*

B.A., Columbia University, 1971; Ph.D., California Institute, 1976. Research Fellow, 1978-.

John Morgan Allman, Ph.D., *Associate Professor of Biology*

B.A., University of Virginia, 1965; A.M., The University of Chicago, 1968; Ph.D., 1971. Assistant Professor, California Institute, 1974-77; Associate Professor, 1977-.

Jan Ambjorn, Ph.D., *Research Fellow in Theoretical Physics*

B.S., University of Copenhagen, 1973; Ph.D., 1977. California Institute, 1980-81.

Carl David Anderson, Ph.D., Sc.D., LL.D., Nobel Laureate, *Board of Trustees Professor of Physics, Emeritus*

B.S., California Institute, 1927; Ph.D., 1930. Research Fellow, 1930-33; Assistant Professor, 1933-37; Associate Professor, 1937-39; Professor, 1939-76; Chairman, Division of Physics, Mathematics and Astronomy, 1962-70; Board of Trustees Professor Emeritus, 1976-.

David Maurice Anderson, Ph.D., *Senior Research Fellow in Biology*

B.A., California State University (Fresno), 1970; M.A., 1972; Ph.D., Purdue University, 1977. Research Fellow, California Institute, 1977-80; Senior Research Fellow, 1980-.

(KF) Supported by the Koepfli Fund (LOA) Leave of Absence (PT) Part Time

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-.

Robert Charles Anderson, Ph.D., *Research Fellow in Chemistry*

B.Sc., University of Waterloo, 1974; Ph.D., 1978. California Institute, 1978-.

Stig Ingvar Andersson, Ph.D., *Visiting Associate in Mathematics*

M.Sc., University of Göteborg, 1969; Ph.D., 1975. Docent, 1978-. California Institute, 1979-80.

Fred Colvig Anson, Ph.D., *Professor of 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, 1973-77.

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-.

Gordon Appleby, Ph.D., *Mellon Postdoctoral Instructor in Anthropology*

A.B., Middlebury College, 1967; M.A., Stanford University, 1969; Ph.D., 1978. California Institute, 1978-.

Rutherford Aris, Ph.D., D.Sc., *Sherman Fairchild Distinguished Scholar*

B.Sc., University of London, 1948; Ph.D., 1960; D.Sc., 1964. Professor of Chemical Engineering, University of Minnesota, 1963-. California Institute, 1976; 1980-81.

James Patrick Ary, Ph.D., *Senior Research Fellow in Biomedical Engineering*

B.S., St. Mary's College of California, 1969; Ph.D., The Ohio State University, 1976. Research Fellow in Biology, California Institute, 1976-79; Senior Research Fellow, 1979-.

David Asai, Ph.D., *Research Fellow in Biology*

B.S., Stanford University, 1975; M.S., 1975; Ph.D., California Institute, 1979. Research Fellow, 1979-80.

Michael Aschbacher, Ph.D., *Professor of Mathematics*

B.S., California Institute, 1966; Ph.D., University of Wisconsin, 1969. Bateman Research Instructor, California Institute, 1970-72; Assistant Professor, 1972-74; Associate Professor, 1974-76; Professor, 1976-.

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-.

Joseph E. Avron, D.Sc., *Visiting Associate in Mathematics*

B.Sc., Technion (Haifa), 1970; D.Sc., 1975. Assistant Professor, Princeton University, 1980-. California Institute, 1980-81.

Ronald Frederick Ayres, Ph.D., *Visiting Associate in Computer Science* (PT)

B.S., California Institute, 1974; Ph.D., 1979. Senior Member, Engineering Staff, Xerox Corporation, 1978-. Visiting Associate, California Institute, 1980-.

Vasil K. Babamov, Ph.D., *Research Fellow in Chemistry*

B.S., University of Skopje (Yugoslavia), 1965; Ph.D., University of Illinois (Urbana), 1977. California Institute, 1978-.

Charles Dwight Babcock, Jr., Ph.D., *Professor of Aeronautics* (LOA)

B.S., Purdue University, 1957; M.S., California Institute, 1958; Ph.D., 1962. Research Fellow, 1962-63; Assistant Professor, 1963-68; Associate Professor, 1968-74; Professor, 1974-.

Robert Fox Bacher, Ph.D., Sc.D., LL.D., *Professor of Physics, Emeritus*

B.S., The University of Michigan, 1926; Ph.D., 1930; Sc.D., 1948. Professor of Physics, California Institute, 1949-76; Chairman, Division of Physics, Mathematics and Astronomy; Director, Norman Bridge Laboratory of Physics, 1949-62; Provost, 1962-70; Vice President and Provost, 1969-70; Professor Emeritus, 1976-.

Stanley H. Bacon, *Lecturer in Electrical Engineering* (PT)
California Institute, 1977-.

Raphael Badoud, Ph.D., *Research Fellow in Chemistry*
Dipl., University of Fribourg, 1973; Ph.D., 1978. California Institute, 1978-.

James E. Bailey, Ph.D., *Professor of Chemical Engineering*
B.A., Rice University, 1966; Ph.D., 1969. California Institute, 1980-.

James Frank Baker, Ph.D., *Visiting Associate in Biology*
B.S., Florida State University, 1972; Ph.D., Brown University, 1977. Assistant Professor, Pitzer College, 1978-. Research Fellow, California Institute, 1976-78; Visiting Associate, 1978-80.

John Dickson Baldeschwieler, Ph.D., *Professor of Chemistry*
B.Chem.E., Cornell University, 1956; Ph.D., University of California, 1959. Professor, California Institute, 1973-; Chairman, Division of Chemistry and Chemical Engineering, 1973-78.

Rose Mary Baltrusaitis, Ph.D., *Research Fellow in Physics*
B.A., Northwestern University, 1971; Ph.D., Princeton University, 1977. California Institute, 1979-.

Nadav Bar-Chaim, Ph.D., *Research Fellow in Applied Physics*
B.Sc., Hebrew University, 1967; M.Sc., Tel-Aviv University, 1973; Ph.D., 1978. California Institute, 1978-.

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-.

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-.

Alan Howard Barr, Ph.D., *Research Fellow in Biology*
B.S., Rensselaer Polytechnic Institute, 1973; M.S., 1976; Ph.D., 1979. California Institute, 1980-81.

Robert Hinrichs Bates, Ph.D., *Professor of Political Science*
B.A., Haverford College, 1964; Ph.D., Massachusetts Institute of Technology, 1969. Assistant Professor, California Institute, 1969-75; Associate Professor, 1975-79; Professor, 1979-.

Peter W. Bearman, Ph.D., *Visiting Associate in Aeronautics*
Ph.D., University of Cambridge, 1965. Lecturer, Department of Aeronautics, Imperial College, 1969-. California Institute, 1980.

Jesse Lee Beauchamp, Ph.D., *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, 1971-74; Professor, 1974-.

Richard H. Becker, Ph.D., *Senior Research Fellow in Geochemistry*
B.S., Brooklyn College, 1965; Ph.D., The University of Chicago, 1971. California Institute, 1978-.

Stephen A. Becker, Ph.D., *Research Fellow in Physics*
B.A., Northwestern University, 1972; M.S., Case Western Reserve University, 1974; Ph.D., University of Illinois, 1979. California Institute, 1980-81.

Charles Beichman, Ph.D., *Research Fellow in Physics*
A.B., Harvard College, 1973; M.S., University of Hawaii, 1975; Ph.D., 1979. California Institute, 1979-80.

Paul Murray Bellan, Ph.D., *Assistant Professor of Applied Physics*
B.Sc., University of Manitoba, 1970; M.A., Princeton University, 1972; Ph.D., 1975. California Institute, 1977-.

Welcome W. Bender, Ph.D., *Visiting Associate in Biology*
A.B., Harvard College, 1971; Ph.D., California Institute, 1978. Postdoctoral Fellow, Stanford University, 1978-. Visiting Associate, California Institute, 1980-81.

Irving S. Bengelsdorf, Ph.D., *Lecturer in Science Communication* (PT)

B.S., University of Illinois, 1943; M.S., The University of Chicago, 1948; Ph.D., 1951. Lecturer, California Institute, 1971-; Director of Science Communication, 1971-.

Henri Benoit, Sc.D., *Visiting Associate in Chemical Engineering*

B.S., L'École Normale Supérieure (Paris), 1945; Sc.D., University of Strasbourg, 1950. California Institute, 1979-.

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-.

Seymour Benzer, Ph.D., D.Sc., *James G. Boswell Professor of Neuroscience*

B.A., Brooklyn College, 1942; M.S., Purdue University, 1943; Ph.D., 1947. Research Fellow, California Institute, 1949-50; Visiting Associate, 1965-67; Professor, 1967-75; Boswell Professor, 1975-.

John Edward Bercaw, Ph.D., *Professor of Chemistry*

B.S., North Carolina State University, 1967; Ph.D., The University of Michigan, 1971. Arthur Amos Noyes Research Fellow, California Institute, 1972-74; Assistant Professor, 1974-77; Associate Professor, 1977-79; Professor, 1979-.

Sacvan Bercovitch, Ph.D., *Visiting Professor of Literature and Cultural Studies*

B.A., Sir George Williams University, 1961; Ph.D., Claremont Graduate School, 1965. Professor, Columbia University, 1970-. California Institute, 1980-81.

Howard C. Berg, Ph.D., *Professor of Biology*

B.S., California Institute, 1956; M.A., Harvard University, 1960; Ph.D., 1964. Professor, California Institute, 1979-.

Mary Guyer Berg, Ph.D., *Lecturer in Literature* (PT)

B.A., Cornell University, 1961; M.A., Harvard University, 1963; Ph.D., 1969. California Institute, 1980-81.

Glenn L. Berge, Ph.D., *Staff Member, Owens Valley Radio Observatory*

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, 1972-77; Staff Member, 1978-.

John William Bieber, Ph.D., *Research Fellow in Physics*

B.S., Kutztown State College, 1972; M.S., University of Maryland, 1974; Ph.D., 1977. California Institute, 1978-.

Gerald J. Bierman, Ph.D., *Lecturer in Systems Engineering* (PT)

B.S., Brooklyn College, 1960; M.S., M.E.E., New York University, 1963; Ph.D., Polytechnic Institute of Brooklyn, 1967. Tracking and Orbit Determination Section, Jet Propulsion Laboratory, 1971-. California Institute, 1978-79; 1980-81.

Richard John Bing, M.D., *Visiting Associate in Chemistry and Chemical Engineering*

M.D., University of Munich, 1934; M.D., University of Bern, 1935. Professor of Medicine, University of Southern California; Director, Cardiology and Intramural Medicine, Huntington Memorial Hospital, 1969-. Research Associate in Engineering Science, California Institute, 1970-72; Visiting Associate in Biomedical Engineering, 1972-78; Visiting Associate in Chemistry and Chemical Engineering, 1978-.

Gerhard Binsch, Ph.D., *Visiting Associate in Chemistry*

B.S., University of Stuttgart, 1959; M.S., University of Munich, 1961; Ph.D., 1963. Professor of Theoretical Organic Chemistry, 1972-. California Institute, 1980.

Dorwin L. Birt, Ph.D., *Senior Research Fellow in Biology*

B.S., Purdue University, 1968; Ph.D., Indiana University, 1973. Research Fellow, California Institute, 1974-77; Senior Research Fellow, 1977-.

Daniel Lloyd Birx, Ph.D., *Visiting Associate in Physics*

Ph.D., University of California (Santa Barbara), 1977. Research Associate, 1977-. California Institute, 1978-79.

John J. Bisaha, Ph.D., *Research Fellow in Chemistry*

B.A., Rutgers University, 1975; M.S., Cornell University, 1978; Ph.D., 1980. California Institute, 1980-81.

Steven G. Blanchard, Ph.D., *Research Fellow in Chemistry*

B.S. Loyola University (New Orleans), 1975; Ph.D., California Institute, 1980. Research Fellow, 1980-81.

Roger D. Blandford, Ph.D., *Professor of Theoretical Astrophysics*

B.A., Magdalene College, University of Cambridge, 1970; Ph.D., University of Cambridge, 1974. Assistant Professor, California Institute, 1976-79; Professor, 1979-.

Jean Marie Michel Bletry, Ph.D., *Research Fellow in Materials Science*

M.S., Faculté des Sciences d'Orsay, 1968; Ph.D., Université Scientifique et Médicale et Institute National Polytechnique de Grenoble, 1979. California Institute, 1980-81.

Malcolm I. G. Bloor, Ph.D., *Visiting Associate in Applied Mathematics*

B.Sc., University of Manchester, 1962; Ph.D., 1966. Senior Lecturer, University of Leeds, 1977-. California Institute, 1979.

James Andrew Boa, Ph.D., *Visiting Associate in Applied Mathematics*

B.Sc., University of Toronto, 1970; Ph.D., California Institute, 1974. Assistant Professor, State University of New York (Buffalo), 1974-. Visiting Associate, California Institute, 1979.

Felix Hans Boehm, Ph.D., *Professor of Physics* (LOA)

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-.

Miles Gilbert Vere Bogle, Ph.D., *Research Fellow in Environmental Engineering Science*

B.Sc., University of Auckland, 1968; Dipl., Imperial College, University of London, 1971; Ph.D., University of Auckland, 1980. California Institute, 1980-81.

Henri Frederic Bohnenblust, Ph.D., *Professor of Mathematics, Emeritus*

A.B., Federal Institute of Technology, Zurich, 1928; Ph.D., Princeton University, 1931. Professor, California Institute, 1946-74; Dean of Graduate Studies; 1956-70; Executive Officer for Mathematics, 1964-66; Professor Emeritus, 1974-.

Aage Bohr, Ph.D., *Visiting Associate in Physics*

Ph.D., University of Copenhagen, 1945. Professor, 1956-. California Institute, 1964; 1980.

Martha W. Bond, Ph.D., *Research Fellow in Biology*

A.B., The University of Rochester, 1969; Ph.D., University of Pennsylvania, 1979. California Institute, 1978-.

James F. Bonner, Ph.D., *Professor of Biology* (PT)

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-.

Lyman Gaylord Bonner, Ph.D., *Associate in Chemistry; Administrator for Student Affairs*

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 of Student Relations, 1969-80; Registrar, 1977-; Administrator, 1980-.

Kim Border, Ph.D., *Assistant Professor of Economics*

B.S., California Institute, 1974; Ph.D., University of Minnesota, 1979. Assistant Professor, California Institute, 1979-.

Nicole Terrisse Borderies, Ph.D., *Research Fellow in Planetary Science*

M.S., Université Paul Sabatier (Toulouse), 1976; Ph.D., 1980. California Institute, 1980-81.

Emilio Bordignon, Ph.D., *Visiting Associate in Chemistry*

Ph.D., University of Padua, 1963. Professor, University of Venice, 1971-. California Institute, 1974; 1975; 1976; 1978; 1979; 1980.

Todd Boroson, Ph.D., *Research Fellow in Astronomy*

B.S., California Institute, 1976; Ph.D., University of Arizona, 1980. Research Fellow, California Institute, 1980-81.

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-.

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Murray Gell-Mann, Ph.D., Sc.D., D.Sc., Nobel Laureate, *Robert Andrews Millikan Professor of Theoretical Physics*
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Spyros D. Georgatos, M.D., *Research Fellow in Biology*
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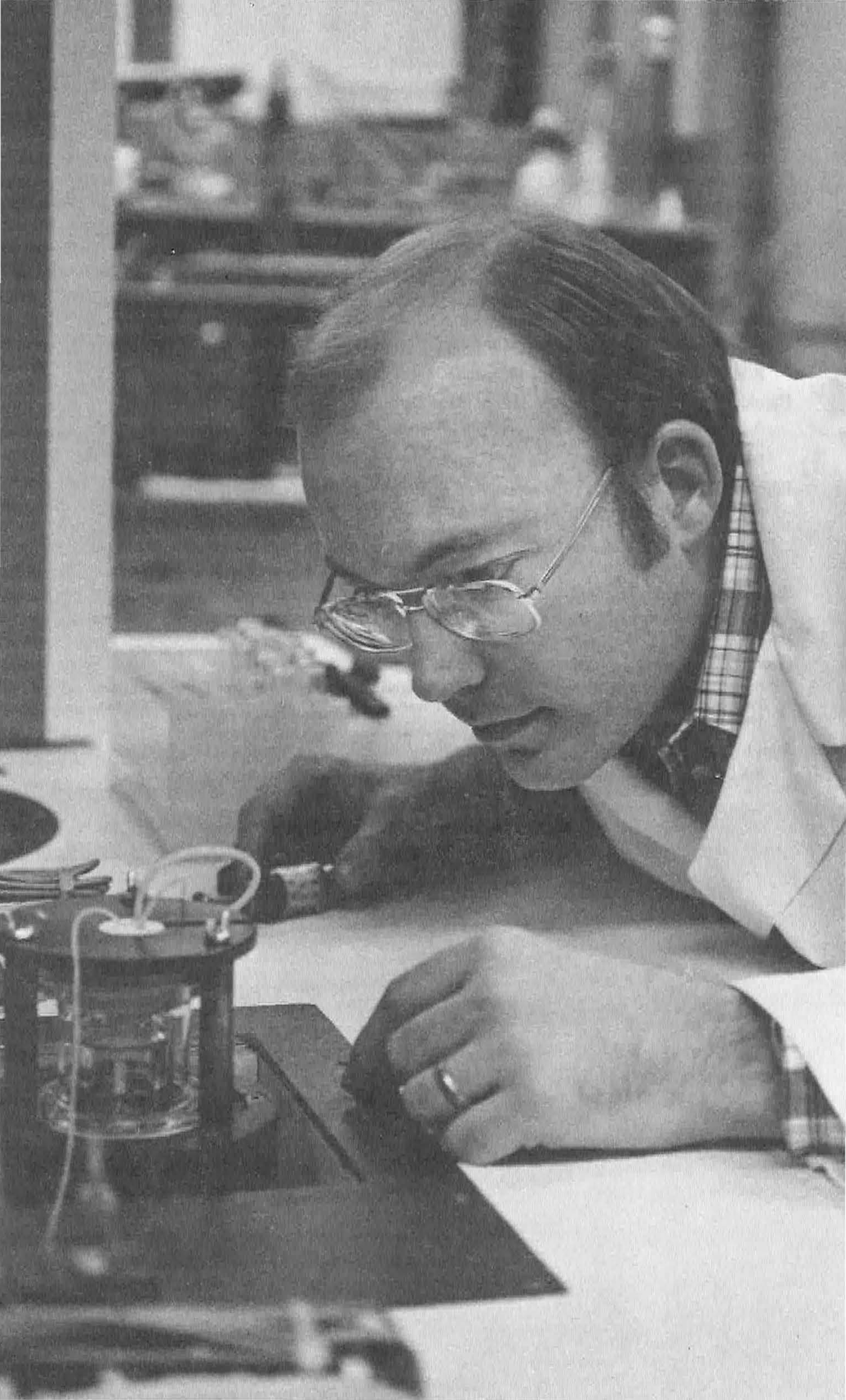
John L. Zyskind, Ph.D., *Research Fellow in Physics*
B.S., California Institute, 1973; M.S., 1976; Ph.D., 1979. Research Fellow, 1979-.



Section II

GENERAL INFORMATION

The California Institute of Technology is an independent, privately supported institution, officially classed as a university. Caltech carries on instruction on both undergraduate and graduate levels, and, including its off-campus facilities, it is also one of the world's major research centers. Fully accredited by the Western Association of Schools and Colleges, "Caltech has achieved international influence far disproportionate to its size," according to *Time* magazine.

The Institute is organized into six divisions: Biology; Chemistry and Chemical Engineering; Engineering and Applied Science; Geological and Planetary Sciences; The Humanities and Social Sciences; and Physics, Mathematics and Astronomy.

The primary purpose of the undergraduate school of the California Institute of Technology, as stated by the original trustees, is "to 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 for both undergraduate and graduate students because of the contacts between a relatively small group of students (approximately 830 undergraduate and 900 graduate students) with the members of a relatively large research staff (approximately 740 faculty members).

President Goldberger says, "Our small size enables us to form a community of scientists, a scholarly intimacy that cannot be found anyplace else." Advancement in understanding is best acquired by intimate association with creative workers who are, through research and reflection, extending the boundaries of knowledge.

The Undergraduate Program

Caltech offers a four-year undergraduate course with options available in applied mathematics, applied physics, astronomy, biology, chemical engineering, chemistry, economics, electrical engineering, engineering and applied science, geochemistry, geology, geophysics, history, independent studies program, literature, mathematics, physics, planetary science, and social science. Each leads to the degree of Bachelor of Science.

All options require students to take courses in chemistry, humanities, mathematics, physics, and the social sciences. Course work is rigorous and students are encouraged to participate in research. The undergraduate program is thus designed to provide an intensive exposure to a wide spectrum of intellectual pursuits.

Near the end of the first year, students select an option, and during the second year they begin to specialize. However, the major concentration in chosen fields and professional subjects occurs during the third and fourth years.

Caltech also encourages a reasonable participation in extracurricular activities—publications, music, drama, and public affairs—largely managed by the students themselves. Three terms of physical education are required, and intercollegiate and intramural sports are encouraged.

In short, every effort is made to provide undergraduate students with well-rounded, integrated programs that will not only give them sound training in their professional fields, but that will also develop character, intellectual breadth, and physical well-being.

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, computer science, electrical engineering, engineering science, environmental engineering science, geological and planetary sciences, materials science, mathematics, mechanical engineering, physics, and social science.

Graduate students constitute a comparatively large proportion (slightly over 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 that is engendered on the Institute campus.

High Standards

In order to utilize Caltech's resources most effectively, two general lines of procedure are followed. First, the Institute restricts the number of fields it offers for 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 local 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 that conferred Bachelor of Science degrees in electrical, mechanical, and civil engineering.

In 1910 Throop Polytechnic Institute moved from its crowded quarters in the center of Pasadena to a new campus of 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 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 830 undergraduates, 900 graduate students, and 740 faculty (including postdoctoral fellows).

The Institute also attracted financial support from individuals, corporations, and foundations. In January 1920 the endowment had reached half a million dollars. In February of that year it was announced that $200,000 had been secured for research in chemistry and a like amount for research in physics. Other gifts followed from trustees and friends who could now feel pride in the Institute as well as hope for its future. The Southern California Edison Company provided a high-voltage laboratory, with the million-volt Sorensen transformer. Philanthropic foundations bearing the names of Carnegie, Rockefeller, and Guggenheim came forth with needed help when new departments or projects were organized.

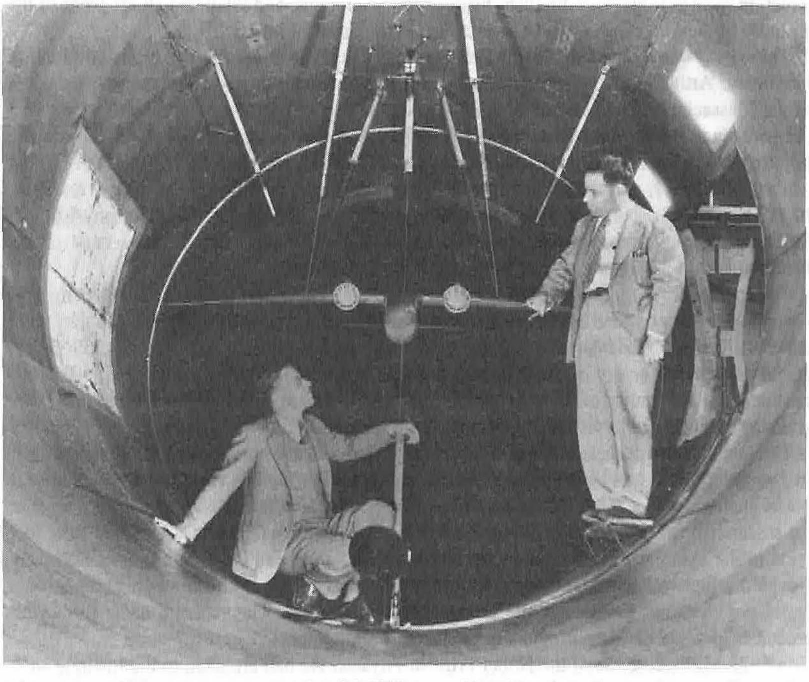
In 1923 Millikan received the Nobel Prize in Physics. He had attracted to the Institute such men as Charles Galton Darwin, Paul Epstein, and Richard C. Tolman. In 1924 the Ph.D. degree was awarded to nine candidates.

It was inevitable that the Institute would enlarge its fields; it could not continue to be merely a research and instructional center in physics, chemistry, and engineering. But the trustees pursued a cautious and conservative policy, not undertaking to add new departments except when the work done in them would be at the same high level as that in physics and chemistry. In 1925 a gift of $25,000 from the Carnegie Corporation of New York made possible the opening of a department of instruction and research in geology. A seismological laboratory was constructed, and Professors John P. Buwalda and Chester Stock came from the University of California to lead the work in the new division.

This same year William Bennett Munro, chairman of the Division of History, Government, and Economics at Harvard, joined the Institute faculty. Offerings in economics, history, and literature were added to the core of undergraduate instruction.

In 1928 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 Kármán, included graduate study and research at the level of the other scientific work at the Institute, and GALCIT (Graduate Aeronautical Laboratories at the California Institute of Technology) was soon a world-famous research center in aeronautics.



Assistant Professors of Aeronautics Clark Millikan and Arthur Klein work in the wind tunnel sometime in 1929-30.

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 used jointly 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.

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 the national defense and 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 contracts with the Office of Scientific Research and Development. Rockets, jet propulsion, and antisubmarine warfare were the chief fields of endeavor. The Jet Propulsion Laboratory in the upper Arroyo Seco continues under Institute management to carry on a large-scale program of research for the National Aeronautics and Space Administration in the science and technology of unmanned space exploration. The Laboratory launched the first U.S. satellite, Explorer I, in 1958, and held major responsibilities for the Ranger, Surveyor, Mariner, Viking, and Voyager 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 the 1950s, in response to the growing technological component of societal problems, the Institute began to expand the fields in which it had substantial expertise. In the late 1960s and early 1970s several economists and political scientists were added to the Institute faculty, who initiated theoretical and applied studies of issues at the interface of their disciplines. A graduate program in social sciences was added in 1972. Caltech students could now engage their talents in the development of the basic scientific aspects of economics and political science, and begin to use the principles from these sciences together with those from the physical sciences to formulate and address public policies.

In 1945 Robert A. Millikan retired as chairman of the Executive Council but served as vice chairman of the Board of Trustees until his death in 1953. Dr. Lee A. DuBridge became president of Caltech on September 1, 1946. Formerly chairman of the physics department and dean of the faculty at the University of Rochester, he came to the Institute after five years as wartime director of the MIT Radiation Laboratory—and remained 22 years.

DuBridge was also committed to the concept of a small, select institution offering excellence in education. Facts and figures are only part of the story, but the statistical record of change during the DuBridge administration indicates how he held to that concept. The 30-acre campus of 1946 grew to 80 acres; the $17 million endowment grew to 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 1391. In 1968, the year DuBridge left, it was 1492.

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. Six new campus buildings were dedicated under Brown's regime, and a major development campaign for $130 million was under way when he resigned to become Secretary of Defense under President Carter in 1977.

Dr. Marvin L. Goldberger, appointed president by the Board of Trustees in March 1978, assumed his new duties in July. He received his B.S. at Carnegie Institute of Technology (now Carnegie-Mellon University) and his Ph.D. at The University of Chicago. He came to Caltech from Princeton University where he was the Joseph Henry Professor of Physics.

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 $135,000,000 and those invested in endowment about $200,000,000. Very substantial grants and contracts from the federal government support many research activities.

Today Caltech has about 13,500 alumni scattered all over the world, many eminent in their fields of engineering and science. Ten of them and seven members of the faculty have received Nobel Prizes.

Caltech Nobel Laureates

Robert A. Millikan	physics	1923
Thomas Hunt Morgan	physiology & medicine	1933
*Carl D. Anderson, BS '27, PhD '30	physics	1936
Edwin M. McMillan, BS '28, MS '29	chemistry	1951
Linus Pauling, PhD '25	chemistry	1954
	Peace Prize	1962
William Shockley, BS'32	physics	1956
George W. Beadle	physiology & medicine	1958
Donald A. Glaser, PhD '50	physics	1960
Rudolf Mössbauer	physics	1961
Charles H. Townes, PhD '39	physics	1964
*Richard Feynman	physics	1965
*Murray Gell-Mann	physics	1969
*Max Delbrück	physiology & medicine	1969
Leo James Rainwater, BS '39	physics	1975
Howard M. Temin, PhD '60	physiology & medicine	1975
William Lipscomb, PhD '46	chemistry	1976
Robert W. Wilson, PhD '62	physics	1978

*In residence

BUILDINGS AND FACILITIES

Gates and Crellin Laboratories of Chemistry: first unit, 1917; second unit, 1927; third unit, 1937. The first two units were the gifts of Messrs. C. W. Gates and P. G. Gates of Pasadena; the third unit was the gift of Mr. and Mrs. E. W. Crellin of Pasadena. Gates has been retired and is empty because of damage sustained in the February 9, 1971, earthquake.

Norman Bridge Laboratory of Physics: first unit, 1922; second unit, 1924; third unit, 1925. The gift of Dr. Norman Bridge of Los Angeles, president of the Board of Trustees, 1896-1917.

High Voltage Research Laboratory, 1923. Built with funds provided by the Southern California Edison Company. Retired in 1959 with basic research completed and rebuilt in 1960 as the Alfred P. Sloan Laboratory of Mathematics and Physics.

Dabney Hall, 1928. The gift of Mr. and Mrs. Joseph B. Dabney of Los Angeles.

Guggenheim Aeronautical Laboratory, 1929. Built with funds provided by the Daniel Guggenheim Fund for the Promotion of Aeronautics. A substantial addition was built in 1947.

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 teaching, research, and administrative staffs of the Institute and the Huntington Library and Art Gallery; for The Associates of the California Institute of Technology; and for others who have demonstrated their interest in advancing the objectives of the Institute. The gift of Mr. and Mrs. Allan C. Balch of Los Angeles. He was president of the Board of Trustees, 1933-1943.

Undergraduate Houses, 1931:

Blacker House. The gift of Mr. and Mrs. R. R. Blacker of Pasadena.

Dabney House. The gift of Mr. and Mrs. Joseph B. Dabney of Los Angeles.

Fleming House. Built with funds provided by some 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. Built with funds provided by the International Education Board and the General Education Board, and named in honor of Mr. Henry M. Robinson of Pasadena, member of the Board of Trustees, 1907–1937, and of the Executive Council of the Institute.

Charles Arms Laboratory of the Geological Sciences, 1938. The gift of Mr. and Mrs. Henry M. Robinson of Pasadena, in memory of Mrs. Robinson's father, Mr. Charles Arms.

Seeley W. Mudd Laboratory of the Geological Sciences, 1938. The gift of Mrs. Seeley W. Mudd of Los Angeles, in memory of her husband.

Franklin Thomas Laboratory of Engineering: first unit, 1945; second unit, 1950. Funds for the first unit were allocated from the Eudora Hull Spalding Trust with the approval of Mr. Keith Spalding, trustee. Named in honor of Dean Franklin Thomas, professor of civil engineering and first 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. Built with funds provided by the trust established by Mr. Scott Brown of Pasadena and Chicago, who was a member and director of the Caltech Associates.

Norman W. Church Laboratory for Chemical Biology, 1955. Built with funds provided through a gift and bequest by Mr. Norman W. Church of Los Angeles, who was a member of the Caltech Associates.

Eudora Hull Spalding Laboratory of Engineering, 1957. Built with funds allocated from the Eudora Hull Spalding Trust.

Archibald Young Health Center, 1957. The gift of Mrs. Archibald Young of Pasadena, in memory of her husband, who was a member and director of the Caltech Associates.

Physical Plant Building and Shops, 1959. Built with funds provided by many donors to a 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. Built with funds provided by the Lloyd Foundation and other donors to a 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. Built with funds provided by the trustees of the Carl F Braun Trust Estate in his memory.

Keck House. The gift of Mr. William M. Keck, Jr., of Los Angeles.

Marks House. The gift of Dr. David X. Marks of Los Angeles.

Mosher-Jorgensen House. The gift of Mr. Samuel B. Mosher of Los Angeles and Mr. Earle M. Jorgensen of Los Angeles. Mr. Jorgensen is a member of the Board of Trustees.

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, named in honor of Dr. Theodore von Kármán, professor of aeronautics at the Institute, 1929-1949.

Firestone Flight Sciences Laboratory, 1962. The gift of the Firestone Tire and Rubber Company.

Winnett Student Center, 1962. The gift of Mr. P. G. Winnett of Los Angeles, a member of the Board of Trustees, 1939–1968.

Beckman Auditorium and Baxter Hall of the Humanities and Social Sciences

Willis H. Booth Computing Center, 1963. Built with funds given by the Booth-Ferris Foundation of New York and the National Science Foundation. Named in memory of Mr. Willis H. Booth, a member of the Caltech Associates.

Beckman Auditorium, 1964. The gift of Dr. and Mrs. Arnold O. Beckman of Corona del Mar. Dr. Beckman, an alumnus, was a member of the Institute's faculty from 1928 to 1939, a member of the Board of Trustees since 1953, chairman of the Board from 1964 to 1974, and is now chairman emeritus.

Harry G. Steele Laboratory of Electrical Sciences, 1965. Built with funds provided by the Harry G. Steele Foundation and the National Science Foundation.

Central Engineering Services Building, 1966.

Robert A. Millikan Memorial Library, 1967. Built with a gift from Dr. Seeley G. Mudd and named in honor of Dr. Robert Andrews Millikan, director of the Bridge Laboratory of Physics and chairman of the Executive Council of the Institute, 1921–1945.

Arthur A. Noyes Laboratory of Chemical Physics, 1967. Built with funds provided by the National Science Foundation and Mr. Chester F. Carlson, an alumnus, and named in honor of Arthur Amos Noyes, director of the Gates and Crellin Laboratories of Chemistry and chairman of the Division of Chemistry and Chemical Engineering, 1919–1936.

Central Plant, 1967.

George W. Downs Laboratory of Physics and Charles C. Lauritsen Laboratory of High Energy Physics, 1969. The Downs wing was built with funds provided by George W. Downs and the National Science Foundation. The Lauritsen wing was built with Atomic Energy Commission funds and named in honor of Dr. Charles C. Lauritsen, a member of the Institute faculty, 1930–1968.

Keith Spalding Building of Business Services, 1969.

Donald E. Baxter, M.D., Hall of the Humanities and Social Sciences, 1971. Built with funds provided by Mrs. Delia B. Baxter of Atherton and named in honor of her late husband, Donald E. Baxter, M.D. Additional funds were given by Dr. and Mrs. Simon Ramo and the U.S. Department of Health, Education and Welfare. Dr. Ramo is a member of the Board of Trustees.

The Earle M. Jorgensen Laboratory of Information Science, 1971. Built with the gift of Mr. and Mrs. Earle M. Jorgensen, with additional funds provided by the Booth-Ferris Foundation and other private donors. Mr. Jorgensen is a member of the Board of Trustees.

The Mabel and Arnold Beckman Laboratories of Behavioral Biology, 1974. The gift of Dr. and Mrs. Arnold O. Beckman of Corona del Mar. Dr. Beckman is chairman emeritus of the Board of Trustees.

Seeley G. Mudd Building of Geophysics and Planetary Science, 1974. Built with funds provided by Dr. Seeley G. Mudd, Mrs. Roland Lindhurst, Mr. and Mrs. Ross McCollum, Mr. and Mrs. Henry Salvatori, and the U.S. Department of Health, Education and Welfare.

Off-Campus Facilities

Kresge Building, Seismological Laboratory, 1928 (of the Division of Geological and Planetary Sciences), 220 North San Rafael Avenue, Pasadena. Named in recognition of a gift from The Kresge Foundation of Troy, Michigan.

William G. Kerckhoff Marine Biological Laboratory, 1930, Corona del Mar. Rehabilitated with funds provided by the National Science Foundation in 1966.

Jet Propulsion Laboratory, 1944, 4800 Oak Grove Drive, Pasadena. Administered by the Institute; owned and supported by the National Aeronautics and Space Administration.

Palomar Observatory, 1948, San Diego County. Site of the 200-inch Hale Telescope, built by the Institute with funds from Rockefeller sources.

Owens Valley Radio Observatory, 1958, Big Pine. Built with funds provided by the Winnett Foundation, the Office of Naval Research, the National Science Foundation, and the Oscar G. and Elsa S. Mayer Charitable Trust.

Big Bear Solar Observatory, 1969, Big Bear Lake. Built with funds provided by the National Science Foundation and the Max C. Fleischmann Foundation of Nevada.

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 a capacity of about 250,000 volumes and provides seats for about 200 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 contains circulation services and the rare books room. The various divisional collections are on floors four through nine. The basement contains photocopy equipment, the Institute archives, and mail and distribution facilities. A microform reading room and the government documents collection are located on the fifth floor. Millikan Memorial is open daily throughout the school year from 8 a.m. to 1 a.m. and during the summer from 9 a.m. to midnight.

In addition to this central library there are library collections elsewhere on campus in aeronautics-energy research, astrophysics, chemical engineering, earthquake engineering, electrical engineering, Environmental Quality Laboratory, geology, environmental engineering, bioinformation systems and computer science, management, and public affairs. The libraries collectively subscribe to about 5300 journals and serials and contain about 370,000 volumes.

THE INDUSTRIAL RELATIONS CENTER

The objectives of the Industrial Relations Center are to increase and disseminate knowledge and 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.

The staff of the Center participates in the education of undergraduate and graduate students of the California Institute of Technology, stressing the fundamentals of management and employer-employee relations.

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 Center awards a certificate for satisfactory completion of the Engineering/Management Program.

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 370/3032 computer and two VAX computers, which, in addition to servicing batch processing functions, provide for a variety of user communication modes through a large number of remote typewriter consoles at various locations on the campus.

POSTDOCTORAL APPOINTMENTS

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 Research 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. The California Institute of Technology is subject to the requirements of Executive Order 11246 and is an affirmative action employer. All interested persons are encouraged to apply.

SPECIAL PROGRAM

The Sherman Fairchild Distinguished Scholars Program

The Sherman Fairchild Distinguished Scholars Program brings renowned scholars to Caltech from industry, government, and the academic community. Through this program, Caltech's faculty and student body have an opportunity to be influenced in both teaching and research by the wisdom and experience of eminent world leaders in various fields. The emphasis in the program is on giving faculty and students exposure to Fairchild Scholars in all academic divisions—through teaching, seminars, lectures, and research—and establishing a forum for the exchange of ideas among Fairchild Scholars, Caltech faculty, students, and industry about new directions and ideas in science and engineering.

It is possible to have 15 to 20 Scholars in residence on the campus at any one time. Appointments may be lengthened or shortened to accommodate the needs of the Scholar and the Institute but are usually for one year.

STUDY AND RESEARCH

Aeronautics

The Guggenheim Aeronautical Laboratory, the Karman Laboratory of Fluid Mechanics and Jet Propulsion, and the Firestone Flight Sciences Laboratory form the Graduate Aeronautical Laboratories, widely known as GALCIT. In this complex are housed the Applied Mathematics group, the Jet Propulsion Center, and the Hydrodynamics Laboratories, as well as the various disciplines making up the broad field known as Aeronautics.

Areas of Research

Aeronautics has evolved at Caltech from a field of basic research and engineering—once primarily related to the development of the airplane, it is now related to a wide discipline encompassing a broad spectrum of basic as well as applied problems. Starting from a need to better understand fluid dynamics and structural mechanics, research at GALCIT has traditionally been guided through pioneering areas that, more often than not, have anticipated subsequent technological demands. Thus, for example, research in compressible fluid mechanics began before the advent of supersonic flight; in plasma dynamics before the importance of controlled fusion was recognized; in extracting energy from the wind before the advent of the energy crisis; in turbulent mixing before the appearance of the chemical laser and the need for optimizing combustion. Similarly, research in the use of shell structures began before their widespread use in aircraft, and in fracture mechanics of polymers before composite materials became an important component of aerospace structures. This tradition places a high premium on in-depth understanding of fields both closely and remotely related to the behavior of fluids and structures such as physics, applied mathematics, meteorology, materials science, electronics, and even astrophysics. As a consequence, GALCIT students are known and sought after for their broad yet intensive education and because they are capable of dealing with new and challenging problems.

The major areas of study and research currently pursued by the Aeronautics group at Caltech are briefly described below:

Physics of Fluids. Fluid dynamics as a discipline is as much a part of physics as of engineering. Physics of fluids refers to research in areas closer to applied physics than to direct technical applications. Present active research includes work on the flow properties of liquid helium II, in particular, turbulence and shock wave propagation in the superfluid, the development of laser scattering diagnostic techniques for fluid-flow measurements, and work with gaseous discharges for laser applications.

Technical Fluid Mechanics. Research at GALCIT includes a long history of work on subsonic and supersonic turbulent boundary layers, shear flows and separated flows. These areas are related to a variety of modern technological problems and, in addition, to the traditional aeronautical problems of drag, wing stall, and jet mixing. Additional areas of activity include the effects of winds on buildings; aerodynamics of automobiles and trucks; turbulent mixing in chemical lasers; turbulent combustion; fires in buildings (turbulent mixing and flow fields driven by fire-produced buoyancy); hydrodynamics and two-phase flows; supersonic diffusers.

Structural Mechanics. GALCIT is investigating both the static and dynamic behavior of structures. Work on the buckling of imperfect shells includes theoretical and experimental studies. Nonlinear problems in steady-state vibrations of shell structures as well as wave propagation in continuous media are being investigated. Other fields include structural optimization and design, as well as aero- and hydro-elasticity.

Mechanics of Fracture. An active effort is being made to understand the mechanisms of fracture. Aspects that are studied include quasi-static and dynamic crack growth phenomena in brittle solids, polymers and advanced composites, fatigue and failure of adhesive bonds.

Aeronautical Engineering and Propulsion. Research work in the field of aeronautics includes studies of airplane trailing vortices, extraction of energy from the wind (windmills), control theory and space mission analysis. Research work in the propulsion area has centered on the fluid dynamic problems associated with gas turbine components (principally axial flow compressors and combustion chambers) and rocket engine combustion chambers, especially solid propellant rocket instability.

Aero-Acoustics. A number of topics in the broad field of aero-acoustics are actively under study at GALCIT. They include jet noise, combustion noise, sonic boom, nonlinear acoustics and hydro-acoustics.

Energy Engineering Research at GALCIT. A large part of the research at GALCIT is related to energy engineering. This is obviously true for work on windmills, fuel-efficient vehicles, and gas turbines. Less obvious is the fact that understanding of turbulent mixing is crucial for practically all heat transfer and combustion problems, and that research on the fluid dynamics of two-phase flows and fracture mechanics is in part motivated by nuclear reactor safety.

The Daniel and Florence Guggenheim Jet Propulsion Center conducts a large portion of its instruction and research in close cooperation with the aeronautics group. The fields of study covered are described 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, as well as special apparatus, including laser equipment and a line of high-speed cameras offering recording at rates from still to 250,000 frames per second, 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. A portable, computer-controlled data acquisition system is used extensively by the several research groups.

Applied Mathematics

The broad aim of the applied mathematics program at Caltech is to stimulate and explore the interplay between mathematics and the various non-mathematical disciplines. On the one hand an active group of pure mathematicians devote themselves mainly to the more abstract and foundational branches of mathematics, and on the other hand faculty members from other disciplines follow a 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 that 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 other divisions supervise research and offer courses of special interest. Close contact is maintained with experimental programs in fluid and solid mechanics. Special notice should be taken of the computer science and bioinformation systems group at Caltech, which provide 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 graduate program is one leading mainly to the Ph.D. degree. The curriculum consists of two types of courses: those that survey the methods used in applied mathematics, and those that have a special applied mathematics flavor and represent active research interests of the members of the faculty. Among the latter have been wave motion, perturbation theory, fluid mechanics, stochastic processes, linear programming, numerical analysis of partial differential equations, group theory applied to physics, and advanced elasticity. 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.

The present group primarily interested in applied mathematics consists of approximately 25 students and 8 professors. Also, each year many distinguished visitors either come to present lectures or remain in residence for large parts of the academic year.

Areas of Research

Research is particularly strong in fluid mechanics, elasticity, dynamics, numerical analysis, ordinary and partial differential equations, integral equations, linear and nonlinear wave propagation, bifurcation theory, perturbation and asymptotic methods, stability theory, variational methods, applications of group theory, and related branches of analysis.

Applied Mechanics

Areas of Research

Advanced instruction and research leading to degrees of Master of Science and Doctor of Philosophy in Applied Mechanics are offered in such fields as elasticity, plasticity, wave propagation in solid and fluid media, fluid mechanics, dynamics and mechanical vibrations, finite element analysis, stability and control, and certain areas in the fields of propulsion, heat transfer, and generation of energy.

Research studies in these areas that illustrate current interests include: linear and nonlinear vibrations, structural dynamics and design for earthquake and wind loads, linear and nonlinear problems in static and dynamic elasticity, plasticity and viscoelasticity, wave propagation in elastic and viscoelastic media, mechanics of fluid-structure interaction, diffraction of elastic waves by cavities and inclusions, boundary layer problems in plates and shells, stratified flow and unsteady cavity flow.

Physical Facilities

In addition to the regular facilities at 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 vibration tests of buildings, dams, and other structures, and for the recording and analysis of strong-motion earthquakes. Another specialized laboratory is the heat transfer laboratory, which contains a forced convection heat transfer loop and facilities for studying the performance of high speed pumps.

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 makes it possible to have a faculty with a wide interest in the application of modern physics to technology, without losing close interaction with "pure subjects." At present, members of four divisions, Engineering and Applied Science, Physics, Mathematics and Astronomy, Chemistry and Chemical Engineering, and Geological and Planetary Sciences, participate in instruction and research in applied physics leading to a B.S. degree as well as to M.S. and Ph.D. degrees.

The program is designed for students who are deeply interested in physics but at the same time are fascinated by the interrelation of physical problems and technological development, i.e., students who like to work with problems in physics that originate from or result in applications. A sharp division between "pure" and "applied" physics or between applied physics and engineering cannot be drawn, and the option of applied physics should be considered a bridge rather than a divider. A student is expected to have a thorough background in physics, as well as a broad background in related fields of technology.

Members of the faculty involved with the educational and research activities in applied physics remain members of their respective divisions. Graduate students who choose the applied physics option 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 to the study of matter in bulk than the "pure" physicist. Since it is expected that a comparatively large proportion of the student body will be interested in experimental research, a special effort has been made to set up challenging laboratory courses and to provide an opportunity to do a senior thesis.

For first-year graduate students and adventurous seniors, a set of basic courses covering broad areas in applied physics is available, supplemented by a set of more specialized courses often closely related to a specific research effort.

Areas of Research

Research activities cover a broad spectrum, ranging from cryogenics to plasmas, from rarefied gas flow to high pressures and shock waves in solids, from neuron 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, and 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. In 1948, the California Institute of Technology and the Carnegie Institution of Washington recognized the advantages in the creation of a great astronomical center in which scientific programs 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. Consequently, for more than 30 years the two institutions together have shared their facilities in optical astronomy—the Palomar Observatory and the Big Bear Solar Observatory, which are operated by Caltech, and the Mount Wilson and Las Campanas Observatories, which are operated by the Carnegie Institution. Within this collaborative arrangement, equipment and facilities are made available for the astronomical investigations of the Caltech and Carnegie astronomers, research fellows, and students. In addition, academic activities as well as the operation of the Owens Valley Radio Observatory are the responsibility of the Institute's Division of Physics, Mathematics and Astronomy. The division also conducts work in theoretical aspects of astrophysics and in laboratory astrophysics.

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 astronomical research in space and in the ground-based study of the planetary system. There is close cooperation between these groups and the students and astronomers interested in planetary physics and space science.

As a result of the cooperation possible over a broad range of astronomy, astrophysics, and radio astronomy, unsurpassed opportunities exist at the California Institute for advanced study and research. Courses of study depend upon a broad and thorough preparation in physics, mathematics, and other relevant subjects; the faculty offers advanced instruction in astronomy, astrophysics, solar physics, planetary physics, radio astronomy, astronomical instrumentation, and observations with large telescopes.

Areas of Research

Both observational and theoretical astrophysics are actively pursued.Topics of current interest in optical and infrared astronomy include observational cosmology; chemical abundances in normal and peculiar stars; spectroscopic and spectrophotometric studies of quasars, 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.

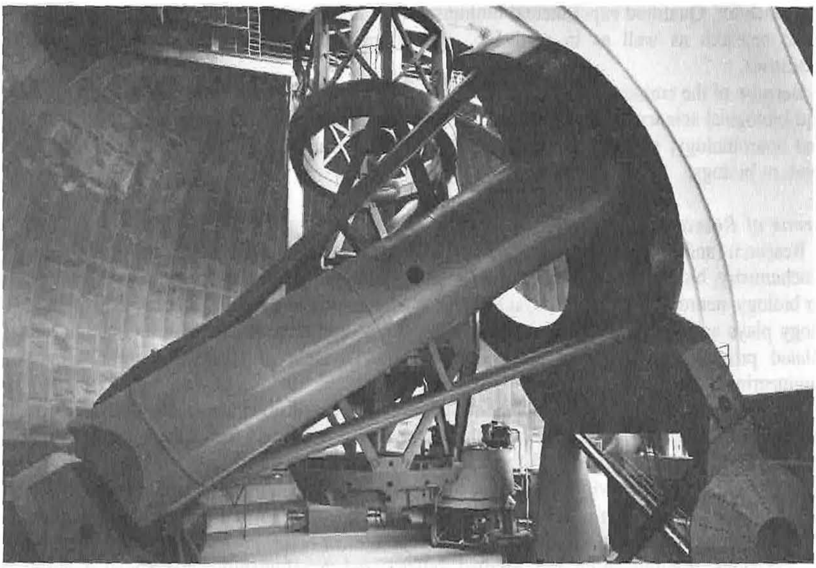
Active research in planetary and solar system astronomy is pursued in cooperation with groups in the Division of Geological and Planetary Sciences.

The research in radio astronomy covers 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 of 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. Graduate student thesis research may be conducted at any of these facilities or at the Mount Wilson and Las Campanas Observatories, which are operated by the Carnegie Institution of Washington. The great light-collecting power of the 200-inch Hale Telescope permits advanced studies of the size, structure, and motions of the stars of the galactic system; of the distance, motion, and nature of remote galaxies and quasi-stellar radio sources; and of many phenomena bearing directly on the constitution of matter. The 48-inch 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 on Palomar Mountain supplement each other as well as the telescopes on Mount Wilson. The 200-inch Hale Telescope reaches as far as possible into space in a given direction, while the 48-inch Schmidt photographs upon a single plate an entire cluster of distant galaxies or a star cloud in our own Galaxy. At Palomar a 60-inch telescope was completed in 1969. It is used for photoelectric observations, image-tube spectroscopy, and photography.



The 200-inch Hale Telescope pointing to zenith; seen from the east

A multipurpose solar equatorial telescope has been installed at an observing station at Big Bear Lake. The unique atmospheric conditions in this area make possible investigations of the fine structure of the solar atmosphere. Emphasis is on high-resolution spectroscopy, magnetography, and cinematography.

Special apparatus for detection and measurement of radiation in the far infrared has been fitted to various telescopes for the study of planets, very cool stars, and dust clouds.

The Owens Valley Radio Observatory is a radio-quiet location 400 km north of Pasadena near Big Pine, California. Facilities include a variable spacing interferometer for centimeter and decimeter wavelengths consisting of one 40-m and two 27-m parabolic antennas. This instrument is used for both continuum and spectral-line mapping of radio sources. The 40-m antenna is frequently used alone for spectroscopic studies or together with antennas at other observatories for very long baseline (VLB) interferometric studies of small-diameter sources. A new 10-m paraboloid with an extremely precise surface, permitting operation at wavelengths as short as one millimeter, has just been completed. Two more similar antennas are being built to constitute a variable spacing interferometer for millimeter wavelengths.

These antennas are complemented by a wide range of low-noise receivers, a 1024 channel auto/cross-correlation spectrograph, and various sophisticated data recording systems to permit a very wide range of studies of continuum and line radiation from solar system, galactic, and extragalactic radio sources over the range from meter to millimeter wavelengths. In cooperation with the Jet Propulsion Laboratory, a multi-baseline processor for VLB observations is operated in the Robinson Laboratory.

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 of the current expansion of our programs in the study of behavior and neurobiology, students at the Institute have an unusual opportunity to be introduced to modern biology.

Areas of Research

Research (and graduate work leading to the Ph.D. degree) is chiefly in the following fields: biochemistry, biophysics, cell biology, developmental biology, genetics, immunology, molecular biology, neurobiology, neurophysiology, psychobiology, and virology. Biochemical methodology plays an important role in many of these fields, and 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 that offer new possibilities for expanded insight into long-standing problems.

Neurobiology and behavioral biology are receiving increasing emphasis within the Division. A comprehensive program of research instruction has been formulated to span the disciplines from neuron physiology to the study of animal and human behavior. 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 four buildings, the William G. Kerckhoff Laboratories of the Biological Sciences, the Gordon A. Alles Laboratory for Molecular Biology, the Norman W. Church Laboratory for Chemical Biology, and the Mabel and Arnold Beckman Laboratories of Behavioral Biology. They contain classrooms and undergraduate laboratories, facilities to house experimental animals, and numerous laboratories equipped for biological, biochemical, biophysical, physiological, and psychological research at the graduate and doctoral levels. 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 tissue culture.

About 50 miles from Pasadena, at Corona del Mar, is the William G. Kerckhoff Marine Laboratory. The building houses several laboratories for 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 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 toward the study of the fundamentals of chemical and transport principles and their application to the analysis and synthesis of complex chemical systems. These interests lead the faculty and students into problems as diverse as the chemical processes occurring in various organs of the body, the chemistry of polluted atmospheres, the chemistry of coal conversion to synthetic fuels, the behavior of materials under conditions of unusual temperature and pressure, surface chemistry, and the fundamentals of heterogeneous catalysis and their application in chemical and petrochemical processes and in the development of synthetic fuels.

Areas of Research

The chemical engineering program is well equipped for instruction and research leading to the degrees of Master of Science and Doctor of Philosophy in Chemical Engineering. Major areas in which graduate research is currently concentrated include air pollution, aerosol dynamics, biochemical and biomedical engineering, fluid mechanics, liquid-state physics, polymers, plasma chemistry, coal conversion and combustion, desulfurization of fuels, heterogeneous catalysis and surface chemistry, optimal control and estimation theory, and the physics and chemistry of two-phase systems. In particular, research includes:

1. Biochemical engineering: Dynamics of microbial populations in chemical reactors.

2. Biomedical: Transport in tissues, artificial organs, and the cardiovascular system. Pulmonary bioengineering. Gas sterilization.

3. Energy: Coal conversion to synthetic fuels by pyrolysis and gasification. Coal and fuel oil desulfurization by selective oxidation. Petroleum reservoir engineering and recovery methods.

4. Environmental: Atmospheric chemical reactions and fluid mechanics. Computer simulation of the urban atmosphere. Application of tracer techniques. Chemistry and physics of aerosols, gas/particle conversion processes and relationship of particulate pollution to sources. Chemistry and particulate mechanics in flowing water systems.

5. Fluid mechanics: Rheology and transport properties of suspensions and polymer solutions. Mechanics of non-Newtonian fluids. Interfacial fluid mechanics and transport processes. Numerical simulation of fluid motion.

6. Heterogeneous catalysis and surface chemistry: Adsorption and catalytic reactions on well-characterized surfaces using low-energy electron diffraction, Auger-electron spectroscopy, x-ray and uv-photoelectron spectroscopies, characteristic electron energy loss spectroscopy, inelastic electron-tunneling spectroscopy, and mass spectrometry. Theoretical modeling of solids, solid surfaces, and gas-surface interactions.
7. Optimal control and estimation theory with applications to chemical reactors and to petroleum reservoir engineering.
8. Plasma chemistry and engineering: Diffusion. Homogeneous and heterogeneous reactions.
9. Polymers: Mechanical properties of elastomers and block copolymers. Behavior of elastomers under pressure. Physics of elastomer networks.
10. Structure and dynamics of liquid systems: Macromolecular modeling and hydrodynamics. Rayleigh and Brillouin laser light scattering studies of super-cooled liquids, macromolecular solutions and particulate suspensions; critical phenomena, macromolecular dynamics and conformation in quiescent and flowing solutions; transport properties of liquids, molecular relaxation phenomena in liquids and amorphous solids. Structure of simple liquids by x-ray diffraction.

Physical Facilities

Chemical engineering is housed in the Eudora Hull Spalding Laboratory of Engineering. All of the laboratories are particularly well equipped both for instruction and for research.

Chemistry

Caltech's chemistry program offers exciting opportunities for study and research in many areas of chemical science. Eminent faculty and strong programs are available in structural chemistry, chemical dynamics and reaction mechanisms, synthesis, theoretical chemistry, biochemistry, and biophysical chemistry. Active interaction exists between chemistry and other disciplines at Caltech, especially applied physics, biology, chemical engineering, and geology. There is strong interest on the part of the faculty in both teaching and research, and the undergraduate and graduate programs are designed to encourage the greatest possible amount of freedom, creativity, and flexibility.

Areas of Research

Caltech has long had a reputation for excellence in chemistry in the areas of molecular structure and the nature of chemical bonding. This tradition is continuing. Work in structural chemistry ranges from x-ray crystallographic structural determinations of covalent compounds, transition metal complexes, intermetallic compounds, proteins and nucleic acids, to investigations of the stereochemistry of organic molecules, conformation of oligopeptides and enzymes, and dynamical structures of lipid bilayers by nmr spectroscopy. Active programs in other areas of spectroscopy include laser Raman, electron impact and photoelectron spectroscopy, and mass spectroscopy.

Much of the current research in chemistry is directed at finding out how chemical reactions work in both chemical and biological systems. Chemical physics programs in this area include studies of gas phase reactions and processes using ion cyclotron resonance and molecular beam techniques. In organic chemistry, dynamic research focuses primarily on the behavior of very reactive intermediates both in the gas phase and in solution. Catalysis by transition metals is receiving increasing emphasis among researchers in the inorganic and organometallic areas. Research in progress includes mechanisms of electrode surface chemistry and electrocatalysis, uses of transition metal complexes as homogeneous and heterogeneous catalysts, solar energy conversion and storage, and nitrogen fixation. Micellar catalysis and reactions of molecules on active surfaces are also receiving attention. A number of biochemical projects are aimed at obtaining detailed information about biochemical reactions catalyzed by enzymes, including electron transfer reactions promoted by metalloproteins.

A significant amount of synthetic chemistry is involved in many of the above projects, but in addition several groups have chemical synthesis as a primary goal of their research. These include projects aimed at the synthesis of natural products and of molecules required for the testing of structural theories. Efforts are also directed at the development of novel and synthetically useful chemical transformations.

Research in biochemistry and molecular biology includes studies of the mechanisms of enzyme catalysis and allosteric transitions, interactions between proteins and nucleic acids, structural elucidations of nucleic acids, particularly circular DNA's and genes, studies of membrane structure and function, protein-lipid interactions and mechanisms of ion and electron transport in biological membranes. Other areas now receiving increased emphasis include the chemistry of membrane proteins, glycoproteins and specific receptors for a variety of external stimuli and recognition processes, the fundamental process of photosynthesis, immunology and neurochemistry.

Our theoretical chemistry program encompasses work on the applications of quantum mechanics to the study of electronic states of molecules and solids. The emphasis of the work here is on excited states and reactions of molecules. Theoretical techniques are also being developed toward facilitating detailed understanding of reacting systems and energy randomization processes within molecules.

Physical Facilities

The laboratories of chemistry consist of four units providing space for about 240 graduate students and postdoctoral research fellows. Crellin Laboratory and an adjoining annex house several research groups, the divisional VAX 11/780 computer, the Southern California Regional High Field NMR facility, 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. Undergraduate laboratory instruction is carried out in a one-story annex to the Noyes Laboratory.

Civil Engineering

Civil engineering includes the research, development, planning, design, and construction associated with urban development, water supply, energy generation and transmission, water treatment and disposal, and transportation. Dealing with the function and safety of such public facilities as buildings, bridges, pipelines, dams, rivers, power plants, and harbors, it 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, increasing the scope of research. New problems have presented special challenges to the civil engineer well trained in the fundamentals of his or her profession. For this reason, in the advanced study of civil engineering at the Institute, the application of basic scientific principles and mathematics is emphasized for the solution of engineering problems.

Areas of Research

Graduate work leading to advanced degrees is chiefly in the following fields: structural engineering and applied mechanics; earthquake engineering; soil mechanics and foundation engineering; finite element analysis; hydraulics, which includes hydrodynamics, hydraulic engineering, hydrology and coastal engineering; and environmental engineering (see also Environmental Engineering Science). In 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 finite element methods for structural analysis; soil deformation under stress; lunar soil 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 the dynamics 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.

Computer Science

Computer science at Caltech includes work both on advanced software systems and on very large scale integrated circuits. We see the problems of both hardware and software design as having a great deal of common content, since in both areas the most difficult task is to handle the great complexity of useful systems. We are taking a unified approach to hardware and software; the student of computer science at Caltech will gain important perceptions in both areas. Our approach emphasizes the use of higher level languages and man/machine interaction.

Caltech has unusual strength in the design of very large scale integrated circuits. State of the art integrated circuit designs are prepared as class and research projects by students and faculty and sent to industrial suppliers for fabrication. The resulting circuits are assembled into computing systems.

Areas of Research

We are seeking new paradigms for computer design in which memory and logical processing are commingled in common circuits. Such designs can provide many orders of magnitude increase in computing power over conventional designs because not only can they include many thousands of processing elements, but they also locate these elements close to the data on which they operate, and thus avoid the speed limitations inherent in designs with a conventional memory bus.

A major research project to build better software tools for integrated circuit design is under way. These tools will make extensive use of interactive terminals and real-time computing to make the design of complex circuits substantially simpler.

The interaction of advanced software systems and machine design is forming a major part of our design work. We are aiming for systems in which the interaction between hardware and software is extremely graceful. Systems programming tasks are being allowed to influence hardware designs extensively.

High-level computer languages appropriate to specialized tasks are a major strength of our department. We have research problems under way that involve natural languages, graphical languages, algebraic languages, and languages for associative processing.

Retrieval of information from very large data bases is also a lively topic of interest. A major language and data base system is operational and in use in a variety of experiments involving both natural-language inquiry systems and efficiency of searching large data bases.

Electrical Engineering

Electrical engineering at the Institute comprises physical electronics, electronic circuits, and communication. Closely allied with the computer science program and 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, computer systems and information theory. This broad spectrum of subjects complementing the program in electronic circuits and circuit function design provides exceptional and challenging opportunities for both experimental and theoretical 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.

Research in the Solid-State Electronics Laboratories extends over a variety of subjects. They range from the transport of charge carriers in semiconductors to the atom movements occurring at semiconductor interfaces during device construction. Thin evaporated layers, in particular, are investigated from several viewpoints, e.g., as a means for epitaxial crystal growth and for the formation of electronic (Schottky) barriers at interfaces between layers. Closely related to these efforts are investigations on the metallurgy of thin evaporated layers. Conventional experimental tools are used for experimentation, as well as for 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 MeV Van de Graaff accelerator in the Kellogg Radiation Laboratory and the 400 keV ion implantation system in Steele Laboratory.

The Quantum Electronics Laboratory and the Laser Laboratory are engaged in research in the area of generation and control of coherent radiation and in the study of related physical phenomena. Research projects in progress include: generation and control of ultrashort pulses, integrated optical circuits, semiconductor injection lasers, applications of nonlinear optics, laser isotope separation, sub-millimeter wave techniques, dielectric waveguides, and electron beam devices.

Research in the Magnetics Laboratory involves studies of the dynamic processes in magnetic materials that are important to modern digital computer devices. Ferromagnetic resonance in thin films of ferromagnetic metals and garnets is used to explore surface pinning, magnetic parameter profiles, and energy loss mechanisms.

The Antenna Laboratory is a center for the theoretical study of antennas, radio wave propagation, gravitational electrodynamics, nonlinear shielding, electric and magnetic suspensions, and electromagnetic processes in condensed media.

The Power Electronics Laboratory deals with modern problems in analysis, design, and synthesis of electronics circuits as applied to efficient conversion, control, and regulation of electrical energy. The analysis techniques developed are extensively verified by experiments. Projects now in progress include the design and optimization of new optimum topology switching dc-to-dc converters, which offer the highest power efficiency, smallest size and weight, and best performance. A firm theoretical and experimental foundation is established for investigation in a number of research areas opened up by the current studies.

The Computer Architecture Laboratory specializes in the design of unique and powerful organizations for special and general-purpose computer systems, and their implementation in MOS large-scale integrated circuits.

The Communication Laboratory conducts experimental and theoretical work in a wide range of communication problems, including speech, hearing, and signal processing.

Engineering Science

Advanced programs of study leading to the degrees of Master of Science and Doctor of Philosophy in Engineering Science are offered by the Division of Engineering and Applied Science. The need for these programs has developed as the traditional frontiers of engineering and what was once called "pure science" have coalesced. Engineers are quick to learn of new research in plasma dynamics, the kinetic theory of gases, or flow and transport phenomena in biological systems, 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, mathematics, and biology.

Areas of Research

The study program of the engineering science student at Caltech emphasizes physics, applied mathematics, biology, geology, and those scientific disciplines that 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, transport and exchange in biological systems, information flow in biological systems, plasma physics, the physics underlying nuclear reactors, fission and fusion engineering, and the design and application of digital computers.

Bioinformation Systems

Areas of Research

This program combines information processing in living nervous systems with interactive computer concepts. Stimulated by extensive research on intelligence in living nervous systems, including vision and pattern recognition, essential new strategies have been developed for the understanding of complex systems that cannot be described by conventional mathematics.

Therefore, this program, in addition to extensive research on insects, crayfish, vertebrate visual systems and human vision, is also concerned with the development of new forms of man-computer interactions for more complex experimentation and new forms of identification theory and estimation theory for applications to these complex systems.

These computer-based techniques also include image processing and visual pattern analysis, and the complete group of interactive computer-based strategies is being applied to new forms of education in engineering and science.

Physical Facilities

In addition to the general Institute computing facilities operated by the Willis H. Booth Computing Center, this faculty has a substantial research facility of its own. This is based primarily on a group of DEC, PDP-11 computers and a special image processing system that serve both the research and educational needs of the discipline. Of particular importance is a specially equipped computer interactive classroom and student laboratory both for research on man-machine interactions and computer interactive education and for direct applications to 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, the primary areas of interest at present are in the fields of biosystems, environmental health engineering, transport processes, and hydro-mechanics of exterior and interior flows involving protozoa and bacteria.

Environmental Health Engineering. The environmental health group is concerned with the protection and control of our air environment and water supplies. Several of the research projects under way in this program have significant biological components.

Biomedical Transport Processes. Research in this field has applications to the design of life support systems (blood oxygenators and dialysis systems), to artificial organs, to an understanding of the relationships between blood flow and transport of metabolites to blood vessel walls, and to particle transport and deposition within the lungs.

Biological Fluid Mechanics. The basic research program in this area involves biophysical and hydrodynamic analysis and experimentation on flagellar locomotion and fluid propulsion by ciliated protozoa and ciliated organs in higher animals. Recent work has emphasized basic development of low-Reynolds-number fluid mechanics in Newtonian and non-Newtonian fluids. New research is being pursued in the subjects of intracellular movements, diffusion of macromolecules, transport of muco-ciliar systems in mammalian trachea, and the cause of cystic fibrosis. The research group is also interested in biofluid dynamics at high Reynolds number, including the swimming of fish and cetaceans and the flight of birds and insects. Recent work has required studies of metabolism and physiological functions in order to analyze fluid resistance and the scaling for creatures of various sizes.

The Biophysical Fluid Mechanics Laboratory, located in the Thomas Engineering Laboratories, is equipped with a microscope system (with a Nomarski interference contrast optic), a high-speed-cine-photomicrographic facility, and an automatic image processing unit for quantitative measurements of flows about moving microorganisms. It is also equipped with a versatile towing tank and flow measuring devices for investigating the swimming of fish and mechanical models.

Free Surface Flows and Geophysical Fluid Mechanics

Graduate research and studies are being continued in the development of the fluid mechanics of various free surface flow phenomena. These studies include cavity and wake flows, free jets, bubble dynamics, cavitation erosion, hydrofoil applications, water waves, and ship hydrodynamics. Interest also includes a theoretical study of tsunamis, or the ocean waves generated by certain types of earthquakes; this study has been conducted in close collaboration with a Keck Laboratory group. In collaboration with the Earthquake Engineering group, theoretical and experimental research and studies are being developed for predicting dynamic responses of dam-reservoir systems and liquid-fuel containers due to seismic ground excitations as well as for improving the future engineering design of such systems. Further geophysical interests in this area contain various studies of rotating and stratified flows.

In the area of energy engineering, new research has been initiated to develop effective means and devices for harnessing wind energy and the vast source of energy contained in ocean currents and ocean waves.

Environmental Engineering Science

This interdisciplinary graduate program is concerned with protection and control of man's environment. Research and instruction stress basic studies that aim to answer such questions as: How can we improve the air quality in our urban and industrial centers while maintaining clean air in pristine rural areas? How can we ensure the supply of water of adequate quality and quantity for population centers and industry? How can we safeguard our marine environment from pollution? What are the environmental consequences of alternative modes of energy production?

The academic disciplines of importance to the program in environmental science and technology include: chemistry of natural waters and atmospheres; physics and chemistry of disperse systems; marine biology and ecology; fluid mechanics of the natural environment; pollutant formation and control in combustion systems; theory and design of complex environmental control systems; environmental modeling and monitoring systems; processes of erosion and sedimentation; and environmental economics. Courses are offered in the environmental engineering science program and in other divisions of the Institute. Faculty members participating in this interdisciplinary program are from the Divisions of Engineering and Applied Science, Chemistry and Chemical Engineering, the Humanities and Social Sciences, and Geological and Planetary Sciences.

Areas of Research

Examples of recent and current research are: theoretical and experimental studies on fates of trace metals in the environment; coagulation of particles in seawater; chemistry of aerosols and rainfall in urban atmospheres; oceanic farming as a potential energy source; kinetics of oxidation processes in aqueous systems; dilution in turbulent shear flows; buoyant discharges in coastal waters; and pollutant formation and control in combustion.

Physical Facilities

The facilities in the W. M. Keck Laboratory of Environmental Health Engineering include modern instrumentation used in air and water pollution analyses. The Air Quality Laboratory, a specially designed facility located on the roof of the Keck Laboratory, is equipped with a

Lisa Anderson, graduate student in environmental engineering science, takes the pH of an artificial seawater, a medium used to test the reaction of the giant kelp Macrocystis pyrifera *to varying levels of metals.*

wide variety of instruments for the measurement of gaseous and particulate atmospheric pollutants. These instruments are interfaced with a computer data acquisition system for on-line data analysis. Several cascade impactors and several types of filter samplers are available for collecting samples of particulate matter for chemical analysis. An electron microscope and associated equipment for sample preparation are used for particulate characterization. Meteorological variables including wind speed, relative humidity, and temperature can be measured with instruments on hand in the laboratory.

The Water Quality Laboratory is equipped for trace element analysis (atomic absorption, polarography, electrometry), organic compound identification and determination, radiologic measurements, particle size determinations (conductance, electron microscopy, ultracentrifuge), and microbiological measurements.

The W. M. Keck Laboratory of Hydraulics and Water Resources includes: a 40-meter-long glass-walled flume with dual circulating water systems for turbulent density stratified shear flow studies. This flume is equipped with an advanced laser Doppler velocity measurement system that can be directly coupled to the laboratory computer for real-time analyses. The laboratory computer is a multi-task DEC 11T60 and can be used on several experiments simultaneously. The laboratory also has a flume with a computer-controlled generator system that can produce waves of specified profiles for special studies, and several other channels appropriate for sediment and diffusion studies.

The Kerckhoff Marine Laboratory of the Division of Biology, at Corona del Mar, is the base for work in marine ecology.

Environmental Quality Laboratory

The Environmental Quality Laboratory is a research center for multidisciplinary, policy-oriented studies of problems related to natural resources and environmental quality. The organization consists of faculty, students, staff, and consultants from various disciplines in engineering, natural and social sciences, and law. Since EQL is an independent research unit, faculty and students who participate in EQL activities are also associated with the appropriate academic divisions. EQL research projects, often closely related to individual research activities in the academic divisions, provide the framework for a comprehensive view of alternative solutions of natural resources and environmental control problems.

EQL research includes technical assessments, computer modeling, studies of environmental control options, and policy analyses. Areas of current or recent work include:

(a) *Air quality, especially in the South Coast Air Basin of California* (control of sulfate and nitrate air pollutants; visibility; development of advanced photochemical oxidant air quality models; economic analysis of tradable emissions licenses as an alternative for air pollution regulation; indoor air quality).

(b) *Water resources and water quality* (sediment management for streams and coastlines in southern California; water resources management options for California and for the Colorado River Basin; acid rain; pollution control for coastal waters; sewage sludge disposal).

(c) *Control of hazardous substances and residuals management* (toxic substances in air and water; risk assessment; economics of control of environmental carcinogens).

(d) *Energy policy, with emphasis on environmental tradeoffs* (studies of oil leasing and energy pricing; risk taking by regulated firms in the energy industry; financial viability and safety of nuclear power projects).

EQL contributes to the education and training of people to do multidisciplinary environmental and natural resources research by involving predoctoral students, postdoctoral fellows, and visiting faculty members in EQL research projects. Students who desire to work in EQL apply through an appropriate degree program, such as Environmental Engineering Science, Chemical Engineering, Mechanical Engineering, Geological Sciences, or Social Science.

Geological and Planetary Sciences

In the Division of Geological and Planetary Sciences, faculty members study the earth and planets in order to understand their origin, constitution, and development, and the effect of the resulting physical and chemical environments on the history of life, and on man. The approach to these problems is made with strong reliance on the basic sciences; close contact and interaction with the other divisions of the Institute are 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. A wide variety of studies are focused on the origins of igneous and metamorphic rocks in planetary interiors. These include radiogenic and stable isotopes and experimental petrology in addition to field and petrographic studies. The earliest history of the solar system can be approached by studies of lunar samples and meteorites. 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 well equipped for instruction and laboratory research in geology and geochemistry. They also house the division library; paleontologic, rock, and mineral collections; x-ray and electron microprobe facilities, and other facilities required for comprehensive studies in the earth sciences. Laboratories for trace-element studies and mass spectrometric and counting facilities for isotopic work are available to apply the techniques of nuclear chemistry to problems in the earth sciences. Equipment includes mass spectrometers, ultraclean chemical laboratories, and extensive mineral separation facilities.

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

A favorable opportunity for the study of the 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 Seeley G. Mudd Building of Geophysics and Planetary Science, adjacent to the Arms and Mudd Laboratories, provides research and teaching facilities for seismology, experimental geophysics, and planetary science. The Seismological Laboratory of the Institute, with excellent facilities including computers and extensive shops, is also located in the Seeley G. Mudd Building. The Kresge Laboratory is located about three miles west of the campus on crystalline bedrock affording firm foundation for the instrument piers and tunnels. These laboratories, together with a dozen portable and 17 permanent outlying auxiliary stations in southern California, which were built and are maintained with the aid of cooperative companies and organizations, constitute an outstanding center for education and research in seismology. In addition, special facilities are available at the Seismological Laboratory for the study of the behavior of rocks and minerals in the pressure and temperature environments of planetary interiors. These facilities include laboratories for performing ultrasonic and Brillouin scattering measurements of elastic constants of rocks and minerals at high pressures and temperatures. Ultra-high-pressure equations of state and shock effects in minerals are being studied in a shock wave laboratory.

Special, moderate-sized telescopes designed specifically for planetary work are available. A wealth of photographic information on the surfaces of Mars and Mercury is available from the Mariner missions and on the surfaces of Jupiter and its satellites from the Voyager missions. Radio and radar observations of the planets are made at the Owens Valley Radio Observatory and the JPL radar facility.

Rodman Paul, Edward S. Harkness Professor of History, teaches a freshman class in American history to a small class in an informal setting.

Humanities

Literature at Caltech spans the major periods of American, English, and European writing. Students can pursue interests ranging from Greek and Latin literature to a survey of drama from mysteries to absurdism; from "The Hero and Society" to "The Self in Literature."

History at Caltech examines the Western and non-Western past to understand the evolution of culture, science, institutions, and behavior. Quantitative methods drawn from the social sciences are applied to historical studies, and Caltech has become a major center of social scientific history, one of the most rapidly developing fields in history today.

Areas of Research

The faculty, interested in new approaches to studying literature, engage in active research directed to important issues in the humanities—the relationship between literature and psychology, literature and the pictorial arts, and literature and history.

Research in history covers a wide range of historical fields and specialties, including an examination of the political and economic effects of the disenfranchisement of blacks and poor whites in the American South after reconstruction; Anglo-American law as it applies to women's rights; the social, political, and intellectual development of science, particularly physics and genetics; and the confrontation of Asian and Western cultures. Numerous courses are offered in American, European, and Asian history.

The proximity of the Henry E. Huntington Library and Art Gallery, one of the great research libraries in the world, offers rich opportunities for staff and students, and a close but informal relationship is maintained between the Institute and visiting scholars at the Library.

Independent Studies Program

Independent Studies is an educational alternative for undergraduates whose goals cannot be satisfied with a normal undergraduate option. The student gathers a three-person faculty committee, representing at least two divisions of the Institute, and chooses his or her own scholastic requirements under this committee's supervision. Approval must also be obtained from the Independent Studies Committee, a standing committee of the faculty. The Independent Studies Program has no facilities of its own. Areas of study and research may be selected from any part of the Institute.

(For complete description see page 210.)

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

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

D. Structure
   1. Theoretical and experimental transmission electron microscopy and diffraction studies of crystal defects and alloy phases
   2. X-ray studies of crystal defects and alloy phases.

Physical 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, 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, and mechanical properties. Computing facilities are available in the Computing Center.

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

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; differential geometry; 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; recursion theory; set theory; 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. The main mathematics library with its outstanding collection of journals is housed nearby in the Robert A. Millikan Memorial Library.

The Willis H. Booth Computing Center central computing facility serves the entire campus. Students are encouraged to use the computer as a research tool. Two remote consoles are located in Sloan Laboratory; one is a graphic display terminal.

Mechanical Engineering

The way in which the term "mechanical engineering" is being used today embraces essentially all of those engineering aspects of a project that 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 nuclear- and fossil-fuel power plants, as well as all types of energy production and conversion installations, transportation systems, propulsion devices, and pollution control. At the Institute, many of the basic disciplines are offered that are required for such applications. They are described in the following paragraphs under the headings of Design, Mechanics, Thermal and Fluids Engineering, Nuclear Energy, and Jet Propulsion.

Design

Engineering design is an interdisciplinary opportunity for putting theory into practice and bringing together on a common ground some of the more specialized branches of engineering. An imaginative practical approach is emphasized for the solution of real problems involving various disciplines. General areas of interest include system design in the broad sense, automatic control, problem modeling, and the appropriate use of analog and digital techniques in optimization. Opportunities exist for analytical studies as well as for the design and fabrication of hardware and for the testing and evaluation of the product. A close relationship with people 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 currently 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.

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, boiling heat transfer and two-phase flow, friction and heat transfer in complex fluids and granular media, as well as studies in cavitation, turbomachinery, and some related areas of hydrodynamics.

Laboratory facilities are available for research in a large number of areas, especially heat transfer, pump dynamics, cavitation, hydrofoil analysis, flow visualization, and internal combustion engines.

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. It also includes courses in heat transfer, fluid flow, and structures—disciplines that are essential for the design of nuclear power plants. 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 to provide facilities for postgraduate education and research in jet propulsion and rocket engineering. Students wishing to pursue courses of study and research in jet propulsion take degrees in aeronautics or mechanical engineering. The program generally emphasizes basic subjects (such as combustion, two-phase flow, turbomachinery, fire research, acoustics) that are applicable to a wide variety of engineering problems. The experimental facilities of the Jet Propulsion Center are located in the Karman Laboratory of Fluid Mechanics and Jet Propulsion. Some of the facilities of the Jet Propulsion Laboratory have also been used under special arrangement.

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. Experiments in elementary particle physics are carried out at the major accelerator centers, principally at the Fermi National Accelerator Laboratory near Chicago and at the Stanford Linear Accelerator Center (SLAC). Current activities include a major program for the study of neutrino interactions at high energies at Fermilab, a study of the production of charmed hadronic states in hadron collisions at Fermilab, the study of neutral particles emitted in e^+e^- colliding beams at SLAC, construction of a new detector, the "Mark III," for the SLAC colliding beams, and involvement in one of the initial experiments at the new high energy e^+e^- facility (PEP) just being completed at SLAC.

A phenomenology group carries on an active program concentrating on the comparison of theories and experimental data. Current interests involve quantitative tests of quantum chromodynamics (QCD) for lepton and high transverse momentum processes.

Kellogg Radiation Laboratory. Three conventional Van de Graaff accelerators and a 12-MeV tandem accelerator are used to study nuclear structure and reactions, with particular emphasis on nuclear phenomena of importance in astrophysics. Parity violation induced by hadronic neutral weak currents is under study in the nuclei ^{18}F and ^{21}Ne, and in the scattering of polarized 800 MeV protons by protons (at Los Alamos). The Kellogg accelerators are also used for atomic studies with high-velocity atomic beams, for investigations of the solid state, for elemental abundance analysis of lunar and meteoritic samples, and for investigations of nuclear processes with potential application to controlled thermonuclear fusion. A new accelerator with unique combination of high beam current and high stability in both energy and beam current is under construction; it is expected to begin operation in the summer, 1981.

Nuclear and Particle Physics. This laboratory is engaged in the study of elementary particles and nuclei at low energies. Tests of space and time symmetries in nuclear disintegrations are conducted with the use of nuclear orientation at cryogenic temperatures. Experiments with muons and pions are being carried out at the Los Alamos Meson Physics Facility. A study of neutrino induced reactions and a search for neutrino oscillations is now taking place at the Laue-Langevin Institute in Grenoble, France.

Cosmic Rays. Measurements of energy and mass spectra of charged particles in space are carried out with sophisticated detectors carried on spacecraft and balloons. The data obtained are of interest for astrophysical phenomena such as element building in stars, astrophysical particle accelerators, and supernovae explosions. There is also a joint effort with the Jet Propulsion Laboratory in gamma ray astronomy.

Infrared Astronomy. Astrophysical observations from 1μm to 1mm wavelengths are carried out with ground-based telescopes at Mt. Wilson and Palomar and in Chile, with the NASA airborne observatory, and with an infrared telescope in Hawaii.

X-ray Astronomy. Observations in x-ray astronomy are carried out with rocket, satellite, and ground-based optical observing programs. The research covers all phases from detector design to theoretical work on models for x-ray sources.

Low Temperature. Investigations on the fundamental nature of superfluidity and superconductivity—with primary emphasis on macroscopic quantum aspects—are carried out in this laboratory. Cryogenic techniques also form the basis for studies into other areas such as two-dimensional thermodynamics and superconducting electronics.

Radio Astronomy. One 40-meter and two 27-meter antennas are used either individually or in 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. A new correlator for very-long-baseline interferometer observations is also in operation. Three 10-meter antennas and receivers for millimeter wave observations, including interferometry, have been under construction, and the first is now in operation. A fourth will be built for infrared observations at high altitudes.

Gravity. A new program in experimental gravity and related areas, with emphasis on the detection of gravitational waves, has begun.

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 quasistellar radio sources and pulsars.

Physical Facilities

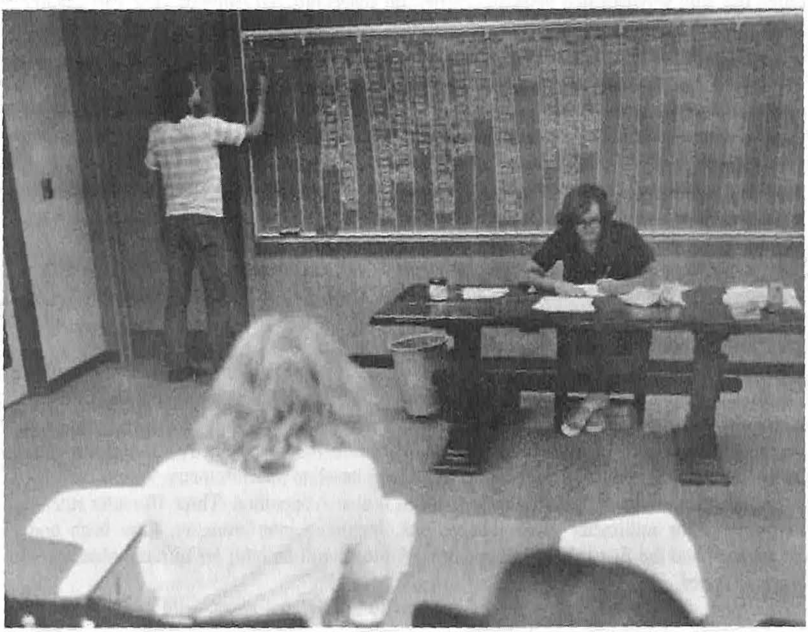
The physics department is housed in six buildings grouped together on the south side of the campus: Norman Bridge Laboratory, Alfred P. Sloan Laboratory of Mathematics and Physics, W. K. Kellogg Radiation Laboratory, George W. Downs Laboratory of Physics, C. C. Lauritsen Laboratory of High Energy Physics, and the Synchrotron Laboratory. Members of the staff also carry out research at the Mount Wilson and Palomar Mountain Observatories, and at the Owens Valley Radio Observatory.

Social Science

Social science at Caltech offers a unique program closely integrating the fields of economics, law, political science, quantitative history, and anthropology. The program takes an engineering approach to social science—designing institutions to solve problems—and involves extensive use of scientific methods and mathematical modeling. Students can use their considerable quantitative talents to great advantage in this area.

The application of experimental methods in economics and political science was pioneered at Caltech. An exciting innovation in teaching as well as in research, experimental economics enables the student actually to participate in different kinds of market activities, and experience how supply and demand work in each context.

The program offers a comprehensive knowledge of economic, political, and legal institutions. Particular emphasis is placed on studying the relationships among economics, politics, and public policy in a vigorous scientific manner.



The focus of the graduate program in social science is on social change, and is highly analytical. Here Research Fellow in Economics George Fox, with graduate student Thomas Palfrey, records the results of a classroom experiment based on the behavior of the stock market.

Areas of Research

The social science program is characterized by collaborative, multidisciplinary research. Often using innovative experimental methods, faculty in economics, political science, and law explore such areas as group decisionmaking, voting procedures, and market behavior.

Among the areas of basic and applied research are government regulation of business, the effect of consumer information on the prices and quality of goods and services, the design of institutions to solve environmental problems, the relationship between the structure and operating rules of a market and its performance, the adaptation of auction mechanisms to nonmarket as well as market situations, and the strategies of candidates and voters in democratic elections.

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, and students should consult their listings and descriptions of opportunities. Students are encouraged to undertake research of such scope and caliber as to merit the preparation of a senior thesis. The requirements for such thesis research vary from option to option, and the individual option representatives should be consulted.

STUDENT LIFE

Student Houses. The seven undergraduate student houses are situated on both sides of the Olive Walk near the eastern end of the campus. The original four—Blacker, Dabney, Fleming, and Ricketts—were built in 1931 from the plans of Mr. Gordon B. Kaufmann in the Mediterranean style to harmonize with the adjacent Athenaeum. The other three, designed by Smith, Powell and Morgridge, and generally consistent in appearance with the older group, were completed in 1960, and are named 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 elected officers, and has wide power to arrange its own social events and preserve its own traditions. The immediate supervision of the activities of each house is the responsibility of the house Resident Associate, generally a married graduate student or younger faculty member. All houses are under the general supervision and control of 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. 91126, to facilitate the handling of their mail at the campus post office.

Interhouse Activities. The president of each undergraduate house represents that house on the Interhouse Committee (IHC). While the seven houses are generally autonomous, the IHC exists to ensure that conflicts between houses do not develop and to deal with matters that affect the houses in general. In particular, the IHC is responsible for the freshman selection process by which the houses choose their members.

In conjunction with the athletic department, the IHC conducts two intramural sports programs: the Interhouse and Discobolus trophy competitions. Interhouse competition consists of round-robin tournaments in football, softball, swimming, basketball, tennis, track, and volleyball, while the Discobolus competition allows individual houses to challenge one another in a wide variety of sports.

Other interhouse activities include joint dances, usually involving two or three houses, which are held once or twice each term.

Faculty-Student Relations. Faculty-student coordination and cooperation with regard to campus affairs 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 a faculty adviser. The adviser takes an interest in the freshman's progress and provides advice on any questions or problems that the freshman may have.

Option Advisers. Each member of the three undergraduate upper classes is assigned an option adviser, a faculty member in the option in which the student is enrolled. The adviser takes an interest in the student's selection of courses, progress toward a degree, and, eventually, in assisting the student toward satisfactory placement in industry, or in graduate school. Normally, the association between student and adviser, which is primarily professional, is established before the beginning of the sophomore year and continues through graduation.

Athletics. The California Institute supports a well-rounded program of competitive athletics. As a member of the Southern California Inter-Collegiate Athletic Conference, intercollegiate competition is carried on in 12 sports with such schools as Claremont-Harvey Mudd, La Verne, Occidental, Pomona-Pitzer, Redlands, and Whittier. Athletes who distinguish themselves locally are able to compete at regional and national levels.

The athletic facilities include a football field, a standard running track, a soccer field, baseball and softball diamonds, and eight tennis courts. The Scott Brown Gymnasium and Alumni Pool provide attractive, modern facilities for participation in badminton, basketball, volleyball, swimming, and water polo. In addition, Caltech owns five Flying Junior sailboats that serve both instructional and competitive interests.

The Institute sponsors a vigorous program of intramural competition in seven sports. The Interhouse Trophy is awarded annually to the house accumulating the most points in this competition. The Varsity Rating Trophy is awarded to the house having the greatest participation in intercollegiate sports. A third trophy, Discobolus, is a bronze replica of Myron's famous statue of the discus thrower. A challenge trophy, open to competition in any sport, it remains in the possession of a house only so long as that house can defeat the challengers.

ASCIT. The undergraduate student body forms the membership of a corporation known as the Associated Students of the California Institute of Technology, Inc., or ASCIT. Governed by a board of directors consisting of nine elected officers, ASCIT is involved in many aspects of student life. It operates the coffeehouse, a casual nighttime spot near campus offering refreshment and diversion. ASCIT subsidizes the Friday night ASCIT movies, a weekly presentation of late vintage popular films, and partially subsidizes Cinematech, a Saturday night series of film classics.

Besides overseeing the many student publications and coordinating activities and policies, the ASCIT Board of Directors administers the corporation's finances. Often ASCIT sponsors special activities, such as ballroom dancing classes or the Caltech Musical.

The student government is active in campus affairs. The student members of each standing faculty committee ensure that undergraduate opinion is considered seriously. Excellent informal relations between students and faculty and between students and administration promote mutual concern and goodwill. Recently the annual ASCIT Award for Excellence in Teaching was instituted to reward outstanding performance.

Overall, the relationship between students and the rest of the campus is characterized by a marked concern. Caltech is fortunate in that the faculty, administration, Board of Trustees, and others take a genuine interest in students' welfare.

Graduate Student Council. The Graduate Student Council performs essentially the same functions for the graduate students that the Board of Directors of ASCIT does for the undergraduates.

Honor System. The Honor System, embodied in the phrase, "No member shall take unfair advantage of any other member of the Caltech community," is the fundamental principle of conduct for all students. More than merely a code applying to conduct in examinations, it extends to all phases of campus life. It is the code of behavior governing 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 a violation should occur, the appropriate board investigates 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; a student handbook, which gives a survey of student activities and organizations and serves as a campus directory; and an annual review of the quality of teaching in the various courses. These publications are staffed entirely by students. Through them ample opportunity is provided for any student who is interested in obtaining valuable experience not only in creative writing, photography, art work, and in the journalistic fields of reporting and editing, but in the fields of advertising and business management as well.

Musical Activities. The Institute provides qualified directors and facilities for a wind ensemble, a jazz band, several choral music groups, a symphony orchestra jointly with Occidental College, a number of small chamber ensembles, and a weekly interpretive music class. A series of chamber music concerts is given on Sundays in Dabney Lounge. There are other musical programs in Beckman and Ramo Auditoriums.

Student Societies and Clubs. There are at the Institute more than seventy societies and clubs covering a range wide enough to satisfy most interests. The American Chemical Society, the American Institute of Chemical 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. 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. Established in 1916 when Caltech was still Throop College of Technology, the Caltech Y has been closely related to the Institute. As the oldest student organization on campus, it has involved people of diverse religious, ethnic, and political orientation in its leadership and activities; the Y has also pioneered through the years in providing numerous special services to the students.

The Caltech Y primarily centers on the student as a person. Responsible for a major portion of the informal, non-classroom educational activities at the Institute, it is the largest organization on campus serving students and faculty, with a major focus on ethical values.

Formally scheduled events range from the presentation of guest speakers of national or international renown, evening programs spotlighting a multitude of topical areas, unstructured noon discussions with faculty and others, and noon concerts on the Olive Walk, to weekend finals lounges known as "Decompression Chambers," the Cinematech Film Series, trips to the L.A. Philharmonic, to Mammoth Mountain to ski, and pre-college camping expeditions.

In addition, the Y provides an emergency loan fund, a used book exchange, camping and backpacking equipment rental, a 24-hour Xerox machine, a voter registrar, the campus lost and found, and a lounge with a stereo. The Caltech Y is a major center of campus activity.

Public Events. Beckman and Ramo Auditoriums serve as the home of the professional performing arts program on the Caltech campus. Each year, more than 150 public events, ranging from the traditional Earnest C. Watson Caltech Lecture Series to dramatic, film, and concert attractions (featuring world renowned artists), are presented at Caltech. The auditoriums also serve as the stage for the annual Caltech Musical and the Caltech Glee Club Christmas and Spring Concerts. Tickets, often with discounts available, are offered to Caltech students for all events in Beckman and Ramo Auditoriums. Located in the Office of Public Events are a Ticket Agency (handling tickets not only for Caltech events, but also for most southern California entertainment, sports, and cultural events) and the campus Audio-Visual Services Unit (where projectors, tape recorders, and video equipment may be obtained).

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 items as greeting cards, sweatshirts, and sundries. There is, on open shelves, an extensive collection of paperbacks and other books of general interest.

STUDENT HEALTH

Medical Examination. Before initial registration, each applicant is required to submit a Report of Medical History and Physical Examination on a form that will be sent at the time of notification of admission. Students who have been absent from the Institute for two years or more may also be required to submit this report.

Student Health Services. The Archibald Young Health Center, which includes a dispensary and an infirmary, provides for undergraduate and graduate students the following services: (1) office consultation and treatment by 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 medications, prescription drugs, and other supplies at cost; (5) infirmary care; and (6) psychological counseling through the services of staff psychologists. Services are available for faculty and staff on a limited basis, covering only emergency care, on-the-job injuries, and inoculations.

During the summer, a special health fee of $35 is charged to students who have not been enrolled during the preceding school term.

Student Health Insurance. In addition to services available at the Health Center, coverage under a hospitalization insurance plan is provided to all full-time students and, during the summer, to students registered for the previous term. This plan covers basic hospital and surgical costs. In addition, an extended benefits plan co-insures costs not covered by the basic plan. Benefits continue for twelve months, on campus and off campus, provided students remain enrolled through the school year.

Medical Coverage of Dependents. A student's spouse and all unmarried dependent children under 19 years of age are eligible for coverage under the hospitalization plan. In addition, student spouses may enroll for a modest fee in a plan that makes them eligible for all services offered at the Health Center. Children are not eligible for these services. Application for dependents' insurance should be made at the time of registration for any one school term. Rates for dependent coverage are available at the Health Center.

Medical Responsibility of the Student. The responsibility for securing adequate medical attention in any contingency, whether emergency or not, is solely that of the student, whether the student is residing on or off campus. Apart from providing the opportunity for consultation and treatment at the Health Center as already described, the Institute bears no responsibility for providing medical attention.

Any expenses incurred in securing advice and attention in any case are entirely the responsibility of the student, except as already specified. To secure payment from the insurance plan and substantiate a claim for services rendered away from the Institute, the student is required to retain bills for such services and present them with appropriate documentation when medical claims are made. The Health Center office staff will help in preparing claim forms.

NOTICES AND AGREEMENTS

Nondiscrimination

The California Institute of Technology is committed to the concept of equal educational opportunity for all. Individuals are considered for admission to student status, and all services, facilities, programs, and activities are administered in a nondiscriminatory manner without regard to race, religion, color, sex, national or ethnic origin or nondisqualifying handicap in accordance with the existing laws and regulations including Title IX of the Education Amendments of 1972, Title VI of the Civil Rights Act of 1964, and Section 504 of the Rehabilitation Act of 1973 as amended.

The Grievance Procedure described below is the Institute's official avenue for redress of grievances of alleged discrimination by sex. Dr. Cornelius J. Pings, Vice Provost, is the Institute official responsible for investigating complaints of sex discrimination.

Student Grievance Procedure

There are at Caltech a variety of routes, most of them informal, by which student complaints are brought to consideration and resolution. These routes normally depend on the nature of the complaint. In academic matters, for example, they begin with teacher-student conversations and extend to the Deans, the Division Chairmen, the Registrar, and various committees having faculty and student members. Undergraduate housing matters relate primarily to the house government organizations, and to the Resident Associates and the Master of Student Houses. The Dean of Graduate Studies often serves as ombudsman in graduate student matters. The Graduate Student Council and the Associated Students of Caltech may become responsibly involved in important complaints. Sometimes *ad hoc* groups are formed to consider and make recommendations in particular areas. And so on.

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

The first step in this procedure is to submit the matter to the Vice President for Student Affairs, who is the ombudsman for student grievances. He will work with the grievant in attempting to resolve the matter. If the grievant is dissatisfied with the results, the grievant may appeal the case to the Grievance Committee. This committee consists of two members of each of the categories—undergraduate students, graduate students, faculty, and administration—appointed, respectively, by the ASCIT Board of Directors, the Graduate Student Council, the Chairman of the Faculty, and the President of the Institute. The Chairman of the Committee, non-voting except in the case of a tie, is also appointed by the President. The grievant may present the case to the Committee, present documents in support of the case, request that witnesses be called, and be assisted by another member of the Caltech community who is not an attorney. The Committee will present its conclusions and recommendations to the President of the Institute and the President's decision will be final. A more detailed statement of student grievance procedure is available from the Vice President for Student Affairs.

Employment Experience of Recent Graduates

A survey was made at the end of June 1979 of the future plans of those students who had graduated at the commencement ceremony on June 8, 1979.

Of those receiving the B.S. degree, about whom we have definite information, 56% had been accepted for admission to graduate school for further education, 36% had accepted employment, 2% were in military service, and 6% were still seeking employment or graduate school admission. The median salary of those accepting employment was $1600 per month. At the M.S. level, 57% were continuing in graduate school, 35% were employed at a median salary of $1810 per month, 4% were in military service, and 4% were still seeking. Of those receiving the Ph.D. degree, 1% were continuing in school, 96% were employed at a median salary of $2230 per month, 2% were in military service, and 1% were still looking.

Student Retention

Most undergraduates enter the Institute at the freshman level. Of those, over the last several years, 71% have graduated from the Institute with Bachelor of Science degrees in the options of their choice. Of students registering at the Institute for the first time as sophomores or juniors, 84% have graduated. At the graduate level 91% of the students entering graduate either with the degree of Master of Science or of Doctor of Philosophy or, occasionally, with both.

Patent Agreement

Students at Caltech have many opportunities to work in laboratories or in shops, sometimes on individual projects and sometimes as part of a group activity. It is not unusual under these circumstances for inventions to be made, and it is important that the student's rights in patents on inventions he or she may have made be protected. The Institute's policy generally is to reserve to itself rights in inventions made by staff members with the use of Institute facilities or in the normal course of their Institute duties. The student's position is different, however, and students generally retain all rights except in inventions made under circumstances such that rights clearly belong to the Institute or to the sponsor of the research. In order to clarify this situation and to protect the rights both of the student and of the Institute, each entering student is asked to sign the following agreement:

1. The Institute agrees that I shall retain all rights in inventions made by me except when such inventions are first conceived or reduced to practice:
   1.1 in the course of the performance of work as a paid employee of the Institute;
   1.2 in the course of independent student research financed by or otherwise obligated to an outside grant or contract to the Institute or financed by a grant from the Institute;
   1.3 or when they arise out of work in the research program of an academic staff member.
2. The Institute agrees that rights to all other inventions made by me with the use of Institute facilities are to be retained by me.
3. I agree to notify the Institute promptly of any discovery, innovation or invention which is first conceived or first actually reduced to practice under the conditions of paragraphs 1.1, 1.2 or 1.3 above. I agree to assign to the Institute or its nominee all patent rights in the United States and foreign countries to any such invention, and to supply all information and execute all papers necessary for the purpose of prosecuting all patent applications and fulfilling obligations that may arise from such inventions. The Institute will bear the expenses for such patent applications.

It is understood that the student will share in the same manner as a member of the academic staff such royalty income from patents as the Institute may receive on inventions assigned to it as a result of this agreement.

It is also understood that the Institute relies on the foregoing agreement when it signs contracts with others and obligates itself with respect to discoveries, innovations or inventions made in the course of research conducted at the Institute under such contracts.

Access to Student Records

In accordance with Section 99.5 of Title 45 of the Code of Federal Regulations, the California Institute of Technology is using this means to inform students of their rights under Public Law 90-247, as amended.

1. The Institute maintains records for each student that include name, address, student identification number, information on parents, guardian, and spouse, general information on academic status at the Institute, previous school data, results of standardized admissions examinations, courses previously taken or being taken, credits, and grades. Applicants for Financial Aid have an additional file established holding those records.
2. The Registrar of the Institute is responsible for maintaining all of these records, except for those involving Financial Aid. They are available to the Registrar, to the Vice President for Student Affairs, to the Dean of Graduate Studies, to the Director of Financial Aid, to the Faculty of the Institute, and to their respective staffs for the normal academic and business purposes of the Institute. Records involving Financial Aid are maintained by the Director of Financial Aid, and are available to the Director and staff, to the Dean of Graduate Studies and staff, to the Faculty Committee on Scholarships and Financial Aid, and to the Faculty Committee on Graduate Study for the purpose of granting and administering the Institute's Financial Aid program. All of these records are also available to such other organizations and persons as are entitled to them under Part 99 of the Code

of Federal Regulations. None of these records nor any personally identifiable information contained therein, other than directory information (see below) will be made available to anyone else, other than the student, without written consent. Where consent is required and given, the student, upon request, will receive a copy of the records to be released. The Institute will keep a record, available to the student and kept with his or her file, of all persons and organizations, other than those authorized within the Institute, requesting or obtaining access to the files. This record will indicate specifically the legitimate interest that each person or organization obtaining access to the records has in such records.

3. Students are allowed access to their records as follows: A student may inspect his or her academic transcript during normal working hours. To see other records, the student must provide a written request to the Registrar or to the Director of Financial Aid or to the Dean of Graduate Studies or their deputies, as appropriate. A mutually convenient time will be arranged within 10 working days after receipt of the request for the student to examine the records in his or her file. At that time the student may examine all records in the file with the exception of those specifically exempted by Part 99 of the Code of Federal Regulations. The student may obtain copies of any of the records available to him or her; the cost will be $.44 for the first page copied and $.12 for each additional page. All reasonable requests for explanations or interpretations of the records will be honored, and if inaccurate, misleading or otherwise inappropriate data are found in the records, they will be promptly corrected or deleted. The student also has the right to insert into the records a written explanation respecting the contents of such records. If the student and the Registrar, or the Director of Financial Aid, or the Dean of Graduate Studies, or their deputies, do not agree on any item contained in the records, the student may submit a written request to the Vice Provost for a hearing to challenge the content of the records. The Vice Provost will schedule such a hearing within 30 days after receipt of the request and will notify the student reasonably in advance of the hearing of its date, time, and place. The hearing will be before a Board composed of the Vice Provost, the Vice President for Student Affairs, or their designated alternates, and at least one disinterested member of the Faculty who shall be appointed by the Chairman of the Faculty Board. None of those hearing the challenge may have a direct interest in the outcome. The student will be afforded a full and fair opportunity to present evidence relevant to the issues raised and may be assisted or represented by individuals of his or her choice at his or her own expense, including an attorney. The decision of the board on the correctness of the record, as determined by majority vote, will be in writing, will be rendered within 10 days after the conclusion of the hearing, and will be final. This decision will be based solely upon the evidence presented at the hearing and will include a summary of the evidence and of the reasons for the decision.

   If, as a result of the hearing, the Institute decides that the information in the files is inaccurate, misleading, or otherwise in violation of the privacy or other rights of the student, the Institute shall amend the records accordingly and so inform the student in writing. However, if, as a result of the hearing, the Institute decides that the information is not inaccurate, misleading, or otherwise in violation of the privacy or other rights of a student, it shall inform the student of the right to place in the records a statement commenting on the information in the records and/or setting forth any reasons for disagreeing with the decision of the Institute.

4. The Institute considers the following to be directory information: student's name, home town address, telephone listing, date and place of birth, major field of study, participation in officially recognized activities and sports, weight and height of members of athletic teams, dates of attendance, degrees and awards received, the most recent previous educational agency or institution attended by the student, and the student's thesis title.

5. No student can be required, nor will be asked, to waive rights under Part 99 of the Code of Federal Regulations. However, a student may voluntarily waive right of access to

confidential statements made by third parties respecting admission to educational agencies or institutions, applications for employment, or the receipt of an honor or honorary recognition. In case of waiver, the confidential statements will be used solely for the purposes for which they were specifically intended, and the student will, upon request, be notified of the names of all persons making such confidential statements. If a student should desire to so waive right of access, so as to facilitate the obtaining of a confidential statement of this nature, he or she should contact the Registrar for the necessary form.

6. The Institute reserves the right to destroy from time to time any and all records that it maintains on a student, except to the extent that the law requires their maintenance for a longer period of time. However, records, access to which has been requested under Part 99 of the Code of Federal Regulations, are not allowed to be and will not be destroyed until such access has been granted, or a decision to deny such access has been arrived at as described in (3) of this section.
7. The Institute also maintains for each student a medical record showing history, treatment, etc. These records are maintained at the Young Health Center and, while specifically excluded from Public Law 90-247, are still available for inspection by the individual student on request.

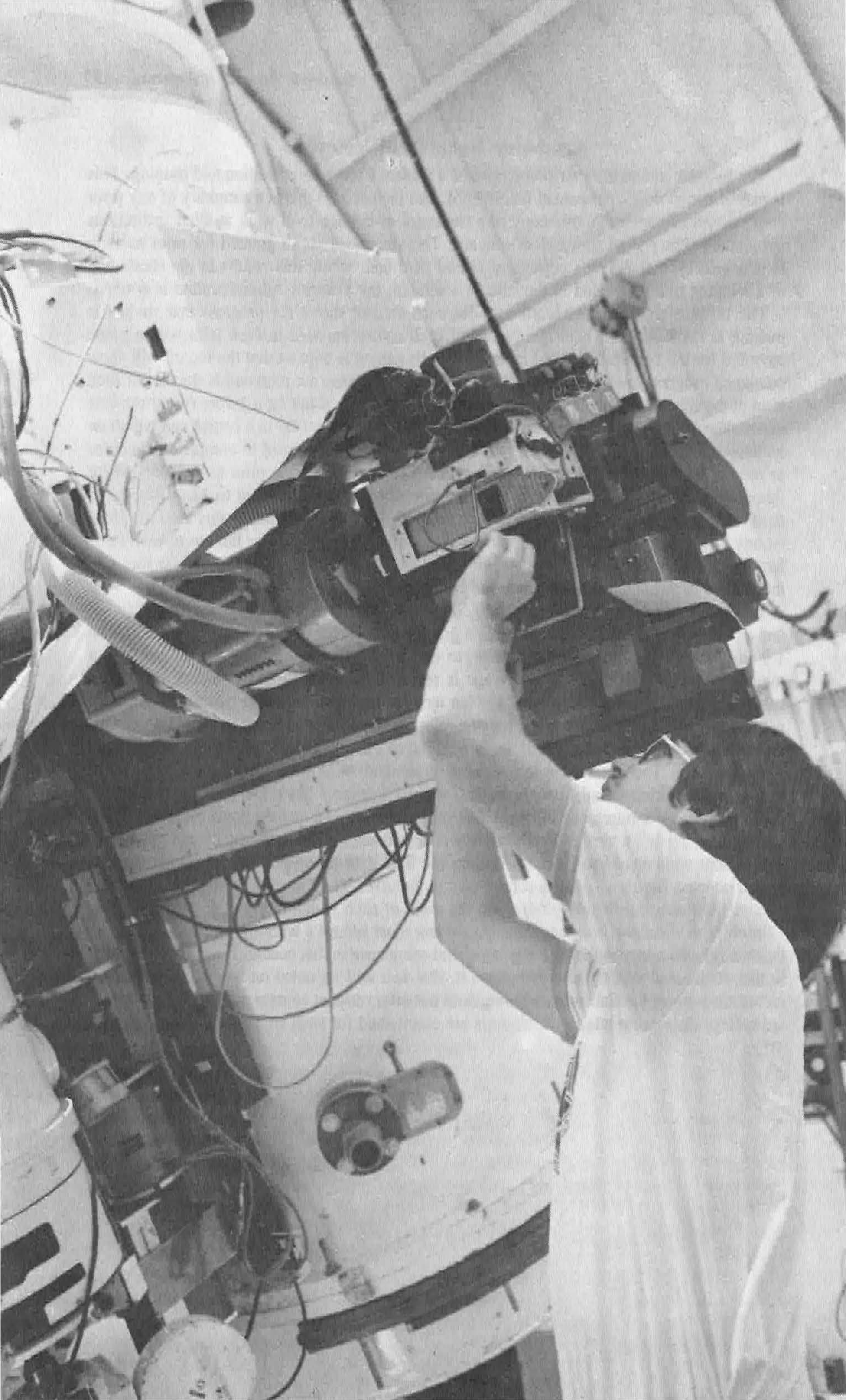
Academic Records of Veterans

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

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

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

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



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 coeducational; 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.

ADMISSION TO THE FRESHMAN CLASS

The freshman class of approximately 210 is selected on the basis of (a) high grades in certain required high school subjects, (b) results of College Entrance Examination Board tests, and (c) recommendations and personal qualifications. The specific requirements in each of these groups are described below. Personal interviews with applicants and two or three of their teachers are held at their schools whenever feasible. An application fee of $10 is due at the time an application for admission is submitted. The fee is not refundable whether or not the applicant is admitted or cancels application, but it is applied on the first-term bills of those who are admitted and register in September. Checks or money orders should be made payable to the California Institute of Technology.

Application for Admission

An application form may be obtained by writing to the Office of Admissions, California Institute of Technology, Pasadena, California 91125. 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 January 15. (Application to take entrance examinations must be made directly to the College Board at an earlier date.)

Transcripts of records covering three years of high school should be submitted as soon as possible following the application. Students should arrange for a supplemental transcript covering the first semester of the senior year, or the first quarter if they attend a school operating on the quarter system, to be sent as soon as such records are available, but not later than March 1.

High School Credits

Each applicant must be thoroughly prepared in at least fifteen units of secondary school work, each unit representing one year's work in a given subject in an approved high school at the rate of five periods 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 are in their fourth year of a mathematics program of the type outlined above. The Level II test does not presuppose an advanced placement course in mathematics. Note that the Scholastic Aptitude and the Level II Mathematics Tests must be taken, and that the choice lies only among Physics, Chemistry, Biology, and English—of which two must be taken. No substitution of other tests can be permitted. 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.

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.* A student seriously interested in the Institute would be well advised to take the Level II Mathematics Test by the December administration if possible. 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 or she can make special arrangements to take the tests nearer home.

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. Applications for 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

Enclosed with the Institute's application form are three recommendation forms, which the applicant should distribute to three teachers at the applicant's high school who are best acquainted with the capabilities and preparation of the applicant 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 at the school he or she is attending. It is not possible to visit all of the schools involved. 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 a notice is received giving the time and date when a representative will visit the 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 or she subsequently cancels the 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 student will be sent an acknowledgement, and will be permitted to register, provided a physical examination is satisfactory. It is assumed that any academic work in progress will be completed in a satisfactory manner.

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 June 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 or her credentials on file by October 15 of the senior year. (If the candidate is applying for financial aid, the application should be filed with the College Scholarship Service by the same date.) Early decision applicants will be notified by December 10 whether they have 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 final rejection is received 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 that 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 (or, in exceptional cases, Chemistry 41, Chemistry of Covalent Compounds), rather than Chemistry 1, General and Quantitative Chemistry. It is assumed that such students have reasonable competence in the following areas: 1) *elementary* theories of atomic structure and electronic theories of valence, 2) chemical stoichiometry, 3) computations based upon equilibrium relationships, and 4) elementary chemical thermodynamics. For those students who qualify for Advanced Placement in Chemistry, the Institute requirement of 18 units of Ch 1 abc can be satisfied by completing with passing grades 2 terms of either (i) Ch 2 abc (9 units each term) or (ii) Ch 41 abc (9 units each term). The student's qualification for Advanced Placement in Chemistry will be determined in a personal interview with the Ch 2 instructor.

Humanities and Social Sciences. Students will not be admitted to upperclass humanities and social science courses until or unless they have successfully completed three terms of freshman humanities, or have been excused therefrom by their instructor (through the divisional Freshman Requirements Committee), or obtained (from that committee) an exemption in a particular case.

Literature and History. Students will *not* be released from the freshman humanities requirement as a result of the Advanced Placement examination in English or history. All students must take the first term of freshman humanities. Students who do exceptionally well will be exempted if they wish from taking the second and third terms.

Mathematics. Normally, an entering freshman will take Ma 1 abc, Freshman Mathematics. This course will cover the calculus of functions of one variable; an introduction to differential equations; vector algebra; analytic geometry in two and three dimensions; infinite series. The course will be divided into a lecture part, discussing primarily the mathematical notions of the calculus and the other topics listed above; and a recitation part, providing active practice in the applications of corresponding mathematical techniques.

During the summer, entering freshmen will be invited to outline their advanced training in mathematics and take a placement examination. The appropriate course and section for each student will be determined on the basis of this information. Those students whose preparation permits them to begin with Ma 2 a will receive credit for Ma 1 abc. Exceptionally well-prepared students may receive additional credit for Ma 2 abc.

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.

Financial Aid: Grants and Loans

For information regarding financial aid for entering students, see pages 178-182. When determining financial need, the Office of Financial Aid uses standard student expense budgets that include the following components: actual tuition and fees, room and board, an allowance for meals not covered in the Institute board contract, books and supplies, and personal expenses. A travel allowance, which varies with the distance between Pasadena and the student's home but in no case exceeds $600, is added to the total budget. The budget for students who live at home or with relatives or friends to whom they pay nothing for board and lodging is approximately $1,500 less. Further information on tuition and other costs, and on loans and financial payment plans, is given on pages 182-184.

New Student Orientation

All freshmen are expected to attend the New Student Orientation as a part of the regular registration procedure. Upperclass transfer students are not required to attend.

The orientation, usually off campus, 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 or she can meet classmates and a number of the upperclass students and faculty. Thus the new student can begin to feel at home at Caltech and share in the common agreement on intellectual and moral standards before the pressure of academic work begins.

ADMISSION TO UPPER CLASSES BY TRANSFER FROM OTHER INSTITUTIONS

The Institute admits to its sophomore or junior class a small number of students who have made satisfactory records at other institutions of collegiate rank and who do satisfactorily on the transfer entrance examination. Transfer students are not normally admitted to the senior year. In general only students whose grades, especially those in mathematics and science, are well above average are permitted to take the entrance examinations.

No application fee is charged in the case of transfer students, but 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 are 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 161-165.

An applicant for admission as a transfer student must write to the Office of Admissions of the California Institute of Technology stating his or her desire to transfer, the choice of engineering or one of the options in science or humanities, and the number of years of calculus and of physics that will have been completed by the date of transfer. A postage-free return postcard for this purpose may be obtained from the Admissions Office upon request. At the same time he or she must present a transcript of the record to date, showing in detail the character of his or her previous training and the grades received both in high school and college. Transcripts should also clearly indicate courses in progress in the latter half of the year. After the postcard 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 either a preliminary letter or the postcard provided by the Admissions Office and transcripts have been received and evaluated. Transcripts are held in the files until such a letter or postcard 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 162) to send the scores to the Institute. If the SAT has not been taken previously, it must be taken by the March 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 Upperclass Admissions and the departments concerned, on the basis of the applicants' previous records and the results of their examinations.

It is not possible to give definite assurance that a transfer student entering the sophomore year will graduate in three years or that one entering as a junior will graduate in two years. Much depends on the amount and nature of the credit granted at the time a student registers in September and on the possibility of fitting deficiency make-ups into the regular schedule.

The first-year chemistry course at the California Institute differs from those given at many other colleges because of the inclusion of a substantial amount of quantitative analysis in the laboratory work. A transfer student who has had a one-year college course in inorganic chemistry and qualitative analysis will be considered to have met the first-year chemistry requirements, provided, of course, that grades have been satisfactory. Those wishing to major in biology, chemistry, or geology will be required to take certain portions of freshman chemistry if they have not had the equivalent laboratory work elsewhere.

The transfer examination in chemistry is required only of those wishing to major in chemistry or chemical engineering. This examination is the same for both sophomore and junior standing and covers general chemistry. Transfer students entering the junior year in chemistry will be able to take the sophomore organic chemistry course during their first year at the Institute.

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 attending schools abroad 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 February 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 a 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 averages, receive the recommendation of the junior college 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 153). 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. If the application is cancelled, the registration fee is *not* refundable unless cancellation is initiated by the Institute.

Financial aid is awarded transfer students on the same basis as for freshmen. To apply for aid, 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 prior to May 1.

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 that 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; Bryn Mawr College, Bryn Mawr, Pennsylvania; 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. The colleges currently in the program include Antioch, Pomona, Swarthmore, and Williams. Under these programs, a student can visit another campus for a period ranging from one term to a full academic year, without the formalities of transfer proceedings or written applications. Any student interested in the informal program should check with the Dean of Students for details.

ROTC

Through arrangements with the University of Southern California, two-, three-, and four-year Air Force Reserve Officers Training Corps (AFROTC) programs are available to all qualified full-time students. Academic units earned in this program count toward fulfillment of graduation requirements. Students desiring this credit should request that an official transcript be forwarded to Caltech. Successful completion of the AFROTC program leads to a commission as a Second Lieutenant in the Air Force Reserve. Two- and three-year scholarships are available to qualified students on a competitive basis. Four-year scholarships for incoming students must be applied for before December 15 in the year prior to entering college. All scholarship recipients receive full tuition, required fees and books, and $100 a month. All qualified cadets are provided 25 hours of flying training during their final year in the program. For additional information contact the Department of Aerospace Studies (AFROTC) at the University of Southern California, Los Angeles, California 90007, (213) 741-2670.

For students interested in the Army ROTC, a similar program is available at the University of California at Los Angeles (UCLA). For additional information contact the office of the Dean of Students at Caltech.

REGISTRATION REGULATIONS

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 registration area when completed. Students are not registered until they have both

a. turned in a signed registration card with their 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.

Students are required to maintain continuity of registration until the requirements for the Bachelor of Science degree are fulfilled, except in the case of an approved leave of absence. If continuity is broken by withdrawal without leave, reinstatement is required before academic work may be resumed.

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 or she does not either complete satisfactorily or drop. A course is considered dropped when a drop card is completed and returned to the Registrar's Office. A student may not at any time withdraw from a course that is required for graduation in his or her option without permission of the 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 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.

Withdrawal from the Institute

Formal separation from the Institute is effected by filing a completed withdrawal card with the Registrar. The effective date of withdrawal is the date of the signature of the Dean or Associate Dean of Students. Unless the student withdraws with an approved leave of absence (see next section), he must petition for reinstatement. Reinstatement rules are the same as those listed under scholastic requirements. No courses or grades will appear on the permanent record card of a student who withdraws on or before drop day of any term. The card of a student who withdraws with leave of absence during the period between drop day and the end of the term will show the list of registered courses. Students withdrawing without leave of absence during that period will receive grades as reported by the instructor. If no grade is reported, an "F" will be recorded.

A student withdrawing at any time during a term without filing a formal withdrawal card will be considered to have withdrawn at the end of the term. Any grades reported by the instructors will be recorded on the permanent record card; the grade of "F" will be recorded for all other courses.

Leave of Absence

Leave of Absence must be sought by written petition, and if granted must be filed with the Registrar together with a completed withdrawal card. Leave of up to one year can be granted by the appropriate dean for a student who is in good standing. A student in good standing is defined as a student who does not have to meet special academic requirements as a result of reinstatements. 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.

The Institute may place a student on medical leave of absence if the Dean of Students or the Dean of Graduate Studies, as appropriate, is persuaded by medical opinion submitted to him that the student's continuation at the Institute would be seriously detrimental to the academic performance of other students or to the personal safety of the student or other members of the Institute. A decision by either Dean to place a student on medical leave of absence is subject to automatic review within seven days of the action by the Vice President for Student Affairs (or his designee). Nothing in this statement precludes access to the normal student grievance procedure.

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 or her 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 $43 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 or she 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 change to an "F" if the student receives an "F" for the following term. The grade may not be used in this way for two successive terms nor for the last term of the course.

If a freshman is enrolled in a course in which the instructor gives letter grades, the Registrar will record "P" for all passing grades. No grades given to a freshman will be used in computing the cumulative grade-point average.

For 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. 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 that 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 Undergraduate Academic Standards and Honors Committee, 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 authorize 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. Students receiving such grades should consult with their instructors at the beginning of the next term in residence. Any condition or incomplete not so removed becomes a failure 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 or she may register to repeat the subject in a subsequent term and receive credit without regard to the previous grade, the new grade and units being counted as for any other course. 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 course may have subsequently been repeated. Physical education units and credits, and grades of "P" are not included in computing grade-point average.

Pass-Fail Grading: The following regulations apply:
1) Freshmen receive Pass-Fail grades in all courses by virtue of their classification as freshmen by an admissions committee or, for students whose status after the first year is uncertain, by the Undergraduate Academic Standards and Honors Committee.

2) All other students, undergraduate and graduate, in courses with numbers under 200 will receive letter grades unless the course designated is "Graded Pass-Fail" or unless, when it is allowed, the student files with the Office of the Registrar a completed Pass-Fail Course Selection Card not later than the last day for dropping courses.

3) In courses with numbers 200 or greater that are not designated either "Graded Pass-Fail" or "Letter grades only," the instructor may decide separately for each student what class of grades to use.

4) All research courses shall be designated "Graded Pass-Fail." All reading courses, seminar courses, or other courses that do not have a formal class structure shall be designated "Graded Pass-Fail" unless the option secures an exemption from the Curriculum Committee or the Graduate Studies Committee and from the Faculty Board.

5) A grade on the Pass-Fail system should be "P" if it would have been a "D" or better on the letter grade system. (Note that there is no "D – " grade.) The standards of failure in courses in which only Pass-Fail grades are used should be the same as they would be if the course were letter graded.

6) Any instructor may, at his or her discretion, specify prior to preregistration that his or her course, if not classified by the above regulations, is to be graded on a "Letter grades only" basis or is to be graded Pass-Fail only, subject to possible review by the responsible option. The Registrar must be notified of such specification two weeks before the beginning of preregistration.

7) Each term any student may select, subject to such requirements as may be imposed by the option, one elective course in which he or she is to be graded on a Pass-Fail basis if it is not designated as "Letter grades only" and is not specifically required for the degree in his or her option. To make this election, a completed Pass-Fail Course Selection Card must be submitted to the Office of the Registrar on or before the last day for dropping courses that term. This election may be reversed or reinstated at any time before the deadline. The election must be approved and the card signed by the student's adviser. The instructor must be notified and should sign the card to indicate that this has been done; the instructor must allow any eligible student to make this election.

8) Of the units offered to satisfy the requirements for the Bachelor of Science degree, no more than 81 may be in courses graded Pass-Fail because of the student's election.

Scholastic Requirements

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

Ineligibility for Registration. Undergraduates who register for programs that 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 have accumulated 27 or more units of E or F, exclusive of P.E., are ineligible to register for subsequent terms and must petition the Committee for reinstatement if they wish to continue as students. The Dean of Students or the Associate Dean may act on the petition if the student has received fewer than 42 units of E or F, exclusive of P.E. For other petitions action can be taken only by the Committee. Freshmen who have been reinstated will be ineligible to register if in any subsequent term of their freshman year they obtain 6 or more units of E or F exclusive of P.E. In this situation, action can be taken only by the Committee. Freshmen who receive no grades of E or F during the entire freshman year are academically eligible to register for the sophomore year.

Undergraduate students, except freshmen, are ineligible to register for another term:

(a) If they fail during any one term to obtain a grade-point average of at least 1.4.

(b) If they fail to obtain a grade-point average of at least 1.9 for the academic year. Students who have completed at least three full terms of residence at the Institute and have been registered for their senior year shall no longer be subject to the requirement that they make a grade-point average of at least 1.9 for the academic year. Seniors 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) Undergraduate students, including seniors, who have been *reinstated* and who fail to make a grade-point average of at least 1.9 on a full load of at least 36 units for the following term are ineligible to register.

(d) If a late grade makes a student ineligible after the start of the next term, the permanent record card shall show the ineligibility and a reinstatement. If the late grade is reported to the Registrar before midterm deficiency notices are due for the subsequent term, the student shall be held to the condition in (c) above.

Students ineligible for registration because of failure to meet the requirements stated in the preceding paragraphs may submit a petition to the Undergraduate Academic Standards and Honors Committee for reinstatement, giving any reasons that may exist for their previous unsatisfactory work and stating any new conditions that may lead to better results. Each such petition will be considered on its merits. *For the first such ineligibility,* the petition will be acted upon by the appropriate dean, after consultation with the student and examination of the record. At the dean's discretion, such cases may be referred to the Undergraduate Academic Standards and Honors Committee for action. *All subsequent reinstatements must be acted upon by the Committee.* Reinstated students who again fail 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 students may, if they wish, appear before the Committee or, on request by the Committee, they may be required to appear. A second reinstatement will be granted only under exceptional conditions.

Departmental and Option Regulations

Continuing in an Option. Students whose grade-point averages are less than 1.9 at the end of an academic year in a specific group of subjects designated by their department or option may, at the discretion of their department, be refused permission to continue the work of that option. Such disbarment does not prevent the students from continuing in some other option or from repeating courses to raise their average in their original option. Students without an option will fall under the direct jurisdiction of the Dean of Students. Students may remain without an option for no more than one year.

Change of Option. An undergraduate in good standing at the Institute shall be permitted to transfer into any option of his or her choice provided he or she has (a) a 1.9 G.P.A. in subjects required for graduation in that option or in a specific group of subjects designated by that option or (b) permission of the option representative or committee. A change of option is effected by obtaining a Change of Option petition from the Registrar's Office. The completed petition must then be signed by the option representative for the new option (who will assign a new adviser), and filed with the Registrar's Office. Institute regulations require that a student who has made normal progress at the Institute be able to change options at any time up to the end of the sophomore year without penalty either as to time to graduation or as to excessive unit requirements in any term.

Term Examinations will be held in all subjects unless the instructor in charge of any subject shall arrange otherwise. No student will be exempt from these examinations. When conflicts exist in a student's schedule, it is the student's responsibility to report the conflict to the instructor in charge of one of the conflicting examinations and make arrangements for another time.

Graduation Requirement. To qualify for graduation a student must complete the prescribed work in one of the options with a passing grade in each required subject and with a grade-point average of 1.9. A grade of "F" in an elective course need not be made up, provided the student has received passing grades in enough other accepted units to satisfy the minimum total requirements of the option.

Graduation in the Normally Prescribed Time. Any undergraduate student who fails to complete the requirements for graduation at the end of 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. 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 students in the sophomore and junior classes, based on the scholastic records of the students.

Graduation with Honor. Under present regulations graduation with honor may be granted, with the approval of the faculty, to 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 or her division and the Committee on Undergraduate Academic Standards and Honors, with the approval of the faculty. Beginning with the academic year 1981–82, however, these regulations will be changed to read as follows: "Students who have achieved a high scholastic standing or who have carried out creative research of high quality may be recommended to the Faculty for graduation with honor by the Committee on Undergraduate Academic Standards and Honors. The Committee shall consider for graduation with honor those students who have achieved an overall grade-point average of 3.5 and others who, on the basis of exceptional creativity, have been recommended to the Committee by a faculty member or by a Division of the Institute."

Excess of or Fewer than Normal Units (Overloads and Underloads). An undergraduate who wishes to register in any term for more than 58 units must obtain the recommendation of his or her 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. If denial of this petition may require that the student add courses, the student should petition at least one week before the last day for adding classes. A student may not drop a course or courses if this results in registration for fewer than 36 units, unless the prior approval of the Undergraduate Academic Standards and Honors Committee is obtained. Approval to register for fewer than 36 units will not be given to any student other than seniors except in extraordinary circumstances. It is the strict policy of the Committee that no student will be allowed to carry an underload for more than one term as an undergraduate.

Miscellany

Transfer of Credit from Other Institutions. Regularly enrolled students who want to obtain credit for college courses taken elsewhere should have a copy of the transcript of their work sent to the Registrar's Office. The student should then obtain an "Allowance of Credit" form from the Registrar's Office; credit will be granted when this form, with the appropriate signatures, is returned to the Office.

Selection of Option. At the beginning of the third term freshmen must notify the Registrar's Office of their selection of an option in engineering, humanities, social sciences, or science to be pursued in subsequent years. Upon the selection of an option, a freshman will be assigned an adviser in that option, whose approval must then be obtained for preregistration for the following year.

An undergraduate may be allowed to major in two options, not in the same division, for the Bachelor of Science degree. In order to do so he or she must obtain the approval of the Curriculum Committee prior to the beginning of the senior year. He or she will then be assigned an adviser in each option.

Candidacy for the Bachelor's Degree. A student must file with the Registrar a declaration of his or her candidacy for the degree of Bachelor of Science on or before the first Monday of November preceding the date on which he or she expects to receive the degree. All subjects required for graduation, with the exception of those for which the candidate is registered during the last term of his or her study, must be completed by the second Monday of May preceding commencement.

Transcripts of Records. A student, or former student, may request that official transcripts of his or her records be forwarded to designated institutions or individuals. Requests should be filed at the Registrar's Office at least five days before the date on which the transcripts are to be mailed.

PHYSICAL EDUCATION

Before 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 fitness.

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 before 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 classes is conducted in the gymnasium and pool on the day of General Registration. Students planning to enroll in sailing must pass a swimming test. Standards for evaluation of student performance will be clearly defined at the beginning of each class. Participation in intramural sports will count toward the successful completion of an instructional activity.

Student-designed programs of physical fitness 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 or her accomplishment of prestated objectives. It is assumed that students proposing their own programs of physical fitness are competent in these activities.

UNDERGRADUATE EXPENSES

For freshmen applying for admission, there is a $10 Application Fee. This fee is not refundable, but it will be applied to tuition fees upon registration.

For freshmen and transfer students, there is a $10 Registration Fee payable upon notification of admission, and it is not refundable. Housing contracts, accompanied by a $50 deposit, must be submitted 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 1980-81

General:

General Deposit	$ 25.00[1]
Tuition	5,229.00
Student Body Dues, including *The California Tech*	45.00[2]
Assessment for *Big T*	15.00[2]
	$5,314.00

	First Term	*Fee*
September 24, 1980	General Deposit	$ 25.00
(Freshmen)	Tuition	1,743.00
September 29, 1980	Associated Student Body Dues	15.00
(All Others)	Assessment for *Big T*	5.00
	Room and Board (for on-campus residence)	673.00
	Student House Dues	20.00
	Second Term	
January 5, 1981	Tuition	$1,743.00
	Associated Student Body Dues	15.00
	Assessment for *Big T*	5.00
	Room and Board (for on-campus residence)	590.00
	Student House Dues	20.00
	Third Term	
March 30, 1981	Tuition	$1,743.00
	Associated Student Body Dues	15.00
	Assessment for *Big T*	5.00
	Room and Board (for on-campus residence)	563.00
	Student House Dues	20.00

Tuition Fees for fewer than normal number of units:

Over 35 units	Full Tuition
Per unit per term	$ 48.00
Minimum tuition per term	480.00

Audit Fee $48.00 per lecture hour, per term.

[1]This charge is made only once during residence at the Institute.

[2]Fees subject to change by action of the Board of Directors of the Associated Students of the California Institute of Technology.

Other:

Student House Living Expenses, including 10 meals per week while Institute is in session (Room and Board rates are subject to change)

Room and Board	$1,826.00[1]
Dues	60.00
Meals not covered by board contract are available at Chandler Dining Hall (approx.)	677.00
Books and Supplies (approx.)	300.00
	$2,863.00

The following is a list of undergraduate student fees at the California Institute of Technology for the Academic Year 1980–81 together with the dates on which these charges are due. Fees are subject to change at the discretion of the Institute.

Refunds. Students withdrawing from the Institute or reducing their number of units during the first three weeks of a term are entitled to a partial refund of tuition based on the period of attendance. The schedule for the specific percentage of tuition to be refunded for specific days of attendance may be obtained in the Office of Student Accounts. The days in attendance are the number of days counted from the first day of the term to:

1. The date of approval of the request by the Dean of Students for *withdrawals;*
2. 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. Early termination of a room contract will be granted only with the approval of the Master of Student Houses.

ASCIT Dues. As a service to the Associated Students of the California Institute of Technology, Inc., or ASCIT, dues of $45 per year and an assessment of $15 for the college annual, the *Big T,* are collected by the Institute and turned over to ASCIT. A subscription to the student newspaper, *The California Tech,* is included in these dues and the balance is used in the support of student activities as deemed appropriate by the ASCIT Board of Directors. Students not wishing to join ASCIT or to purchase the *Big T* should so indicate at the time of registration.

General Deposit. Each new student is required at his or her first registration to make a general deposit of $25, to cover possible loss and/or damage of Institute property. Upon graduation or withdrawal from the Institute, any remaining balance of the deposit will be refunded.

Fees for Late Registration. Registration is not complete until the student has personally turned in the necessary forms for a program approved by his or her adviser and has paid tuition and other fees. A penalty fee of $10 is assessed for failure to register within five days of the scheduled dates.

Winnett Student Center. Winnett Student Center facilities are reserved for the use of Caltech students and their guests. A fee of fifty cents per year is charged to each member of the undergraduate student body ($1 for graduate students wishing to use the facilities) to help defray the expenses of the game room.

[1]A few single rooms are available that will rent for an additional 50 cents per day. Room contracts are on a term basis for all students.

Student Houses. Students in the Houses must supply their own blankets. Bed linens and towels are furnished and laundered by the Institute.

Application for rooms in the Student Houses may be made by addressing the Master of Student Houses, 0-54, California Institute of Technology, Pasadena, CA 91125.

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 past due may be refused registration for the term following that in which the past due charges were incurred. Transcripts will not be released until all bills have been paid or satisfactory arrangements for payment have been made with the Office of Student Accounts

FINANCIAL AID

Financial Aid for Entering Students

Financial aid is awarded to the extent of available funds by the Office of Financial Aid to students who have been admitted to the Institute and have demonstrated financial need.

Applications for financial aid must be made by submitting either a Financial Aid Form (FAF) or a Student Aid Application for California (SAAC). These forms may be obtained at most high schools and colleges or from the Caltech Office of Financial Aid. The forms should be submitted by February 1 directly to the appropriate office of the College Scholarship Service. Caltech must be designated as a recipient.

All applicants using the Financial Aid Form must also complete the FAF Supplement (on the reverse side of the FAF). California residents must use the Student Aid Application for California and the SAAC Additional Information form (reverse side of the SAAC) as their official financial aid application. (All California residents requesting financial aid from Caltech must also apply for a Cal Grant on the SAAC form [see below].) All applicants must also submit a copy of their parents' 1980 federal income tax return (including all schedules) directly to the Office of Financial Aid. If the tax forms have not been received by the time of the student's admission, a tentative offer of financial aid will be sent. A final offer of financial aid will only be made after the tax return is received and reviewed.

Transfer Applicants

Transfer students seeking financial assistance should obtain a FAF or SAAC from their current school or from the Caltech Office of Financial Aid. The Financial Aid Statement (either FAF or SAAC) and a copy of their parents' 1980 federal income tax return, complete with all schedules, should be sent directly to the Caltech Office of Financial Aid by June 1st. In addition, transfer applicants must submit a financial aid transcript from their former institution. These transcript forms are available in the Office of Financial Aid.

Financial Aid for Continuing Students

All continuing students are notified approximately February 1st of each year by the Financial Aid Office regarding financial aid application procedures for the forthcoming year. The deadline for the return of all forms, including parents' latest federal income tax return and schedules, is April 15th of each year. Renewal applications for succeeding years are required from all students except those holding honorary or prize awards. All students applying for renewal of financial aid must have maintained satisfactory progress as defined on page 173. In addition, students receiving Cal Grants A or B must file a separate application to renew their Cal Grants. Renewal material is automatically sent out in the spring by the California Student Aid Commission. Since this material is normally sent to parents' homes, parents should be alerted to watch for it and to complete their part as soon as possible.

Students' Rights and Responsibilities

The offer and acceptance of financial aid is a contract between the Institute and the student. This contract is based upon certain conditions and expectations that students should clearly understand before they apply for or accept financial assistance.

It is expected that students to whom awards are made will carry a full academic load of not less than 36 units 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.

The offer of aid assumes truthful and correct information on the part of the student and the parents. A student's eligibility is determined by the information provided by the applicant and the parents. If any individual deliberately falsifies information, that person will be refused all aid. If funds have been advanced on falsified data, the individual will be obligated to repay all money received. Any student who is successful in receiving outside assistance is required to notify the Financial Aid Office as soon as possible.

National Financial Aid Awards

Candidates for freshman financial aid are urged to make extensive inquiry of their school advisers and to watch their school bulletin board for announcements of scholarship contests. National Merit Scholarships and Westinghouse Talent Search Awards are two examples of the many awards available nationwide to talented students.

Grants Awarded by the State of California

The California Student Aid Commission awards Cal Grants on the basis of academic achievement and financial need. All students who are California residents seeking financial assistance from the Institute must apply for a Cal Grant. Students are urged to contact their high school counselors or the Caltech Office of Financial Aid for additional information. The deadline for submitting applications for Cal Grants will be in early February each year. Experience has shown that students who complete application procedures for a Cal Grant, demonstrate financial need, and gain admission to Caltech will receive a Cal Grant. The financial aid offer made by Caltech to California residents is, therefore, in addition to the expected amount that they will receive from the state.

Other State Scholarship Programs

Many other states besides California sponsor scholarship and grant programs for resident students. In some states, such as Pennsylvania and Vermont, these state grants may be used by students for study at colleges and universities outside of their home state. Students are urged to gain more information on their home state scholarship, grant, and sponsored loan programs through their high school advisers, local college financial aid offices, or from their state scholarship agency or division of higher education.

Financial Aid for Foreign Students

The financial aid information in this section also applies to foreign students. They should, however, note the following additional points when applying for financial assistance from the Institute: 1) Instead of the Financial Aid Form (FAF), foreign students must complete the Foreign Students' Financial Aid Application and Declaration, available from the Office of Financial Aid, and the application should be returned to the Caltech Office of Financial Aid, not to the College Scholarship Service; 2) travel allowances are not available for foreign students; and 3) certain grants and scholarships awarded by the Office of Financial Aid are restricted to U.S. citizens or permanent residents. The Office of Financial Aid will identify those awards for which foreign students are eligible and make such awards accordingly.

Financial Aid Funds

Applicants for admission who have a complete financial aid application on file will be considered for all financial aid administered by the Institute. Financial need can be met by either a single type of aid or by a combination of scholarships or grants, loans, and student employment.

Funds for scholarship awards are provided through the following gifts; it is not necessary to apply for any particular Caltech award by name.

Ethel Hazen Allen Scholarship
Alumni Association Scholarships
Alumni Scholarships
  Agbabian Associates
  Albert Erkel
  Hillman, Biddison & Loevenguth, Structural Engineers
  Johnson and Nielsen Associates, Structural Engineers
  Moore & Taber, Consulting Engineers and Geologists
Earle C. Anthony Trust
ARCS Foundation, Inc., Los Angeles Chapter
R. C. Baker Foundation Scholarship
Meridan Hunt Bennett Scholarships
Berry Holding Company Scholarships
Ivan F. Betts Memorial Award
Bing Scholarship
Robert Roe Blacker and Nellie Canfield Blacker Scholarship
Bookstore Scholarships
C F Braun & Co Scholarships
Harold Brown Scholarships of the American Association of Engineering Societies
California Foundation for Biomedical Research
Jerry Bruce Cross Memorial Scholarships
Cyprus Mines Corporation Scholarship
Kathleen Delbridge Scholarships
Robert S. and Nellie V. H. Dutton Scholarship
Eastman Kodak Company Scholarships
General Motors Corporation Scholarships
The Gnome Club Scholarship
H. Mark Goldenberg Memorial Fund Award
Goodyear Scholarship
Thomas Lain Gordon Memorial Scholarship Fund
Robert E. Gross-Lockheed Aircraft Corporation Scholarship
Harriet Harvey Scholarship
Hollywood Canteen Scholarship
Walter Humphry Scholarship
Earle M. Jorgensen Scholarships
JPL-Caltech Management Club Scholarship
Naozo and Tsuki Kashiwabara Scholarship Fund
Clarence F. Kiech Scholarship
Henry Kirshner Memorial Scholarship
Mackenzie Foundation Premedical Scholarship
George H. Mayr Foundation Scholarships
Anna and James McDonnell Memorial Scholarship
William C. McDuffie Scholarship
James Michelin Scholarship

Robert L. Minckler Scholarships
John Navas Scholarship
La Verne Noyes Scholarships
John R. and Laura C. Osborne Scholarships
Ralph M. Parsons Memorial Scholarships
Charlotte Palmer Phillips Foundation Scholarship
William M. Porter Memorial Scholarship
Evalyn Elizabeth Cook Richter Memorial Fund
Paul K. Richter Memorial Fund
Frank Schaak Fund
Virginia Steele Scott Scholarships
M. H. Sherman Scholarship Fund
Lois F. Spalding Scholarship
Harold O. Springer Scholarship
Standard Oil Company of California Scholarships
John Stauffer Charitable Trust Scholarship
Mrs. C. T. Chang Tang Memorial Scholarship
Timken-Sturgis Foundation Scholarships
Tomiyasu Scholarship
Tomiyasu/General Electric Scholarship
Walter and Sylvia Treadway Scholarships
Vernon O. Underwood Scholarship
Waltmar Foundation Scholarships
Alice Colby Wheeler Scholarship

In addition, scholarships are provided, without a named designation as to the source of funds, from a financial aid pool as a result of the following gifts.

Roland L. Andreau Scholarship
Edward C. Barrett Scholarship
Louis D. Beaumont Foundation Scholarships
Knowlton R. Birge Scholarship
Mary Huntington Carr Scholarship
William Duncan Chisholm Scholarship
Dorothy Hixon Clark Scholarships
Class of 1927 Scholarship
Earl S. Condon Scholarship
Matthew M. Corbett Scholarship
Amy Crellin Scholarship
Louise E. Dabney Scholarships
Leo P. Delsasso Memorial Scholarship
Alexander M. and Florence W. Drake Scholarship
L. L. Fentress Fund
Robert C. Gillis Scholarship
Florence A. Hampton Scholarship
Robert Haufe Memorial Scholarship
Gene B. Heywood Scholarship
The Holly Scholarship
Albert Hall Hughey Scholarships
John C. Lewis Memorial Student Aid Fund
Peter Madsen Undergraduate Scholarship Fund
David Lindley Murray Educational Fund
Frances W. Noble Scholarship

Pasadena Optimist Club Scholarship
Edgar H. Pflager Scholarship
Harry Leslie Remington Memorial Scholarship
Elbert G. Richardson Scholarships
Riley Scholarship
Frederick Roeser Loan, Scholarship and Research Fund
William E. Ross Memorial Fund
Elizabeth Thompson Stone Scholarship
William W. Stout Scholarship
Sutro & Co., Inc. Scholarship
Claudia Wheat Scholarship
Brayton Wilbur–Thomas G. Franck Scholarship

Student Aid Loan Funds

Loans are available to members of all undergraduate classes, including entering freshmen, who demonstrate need for such aid to continue their education. Loans are awarded as part of the total financial aid packages offered by the Office of Financial Aid. The three sources of loan funds, which are described below, are awarded to the extent of available funds.

1. California Institute loan funds are available in amounts not to exceed $2,500 in any one year, with a maximum of $7,500 during undergraduate residence. No interest is charged and no repayment of principal is required during undergraduate residence at Caltech, as long as residence is continuous (the term "residence" includes the usual vacation periods). For those who transfer or continue on to graduate school, interest is charged but repayment of principal is not required until termination of formal education. Repayment terms, including interest rates, may be obtained from the Office of Financial Aid or the Office of Student Accounts.

It is inadvisable for foreign students from countries with seriously adverse rates of exchange to borrow more than they can repay from savings earned in the United States.

Thanks to funds presented by a number of generous donors, the Institute is able to lend money through the specific loan funds listed below. Each fund is administered according to the specific wishes of the donor, but in general as outlined above.

The Institute Loan Funds include the following: ARCS Foundation, Gustavus A. Axelson, W. H. Bowen Memorial, Mildred R. and Leroy G. Brown Memorial, Olive Cleveland, Glenn L. Converse Memorial, Wilbur D. Crater Memorial, James D. Davis, George W. and Beatrice W. Downs, Joseph W. Drown, Hosea Lewis Dudey, Dudley Foundation, Claire Dunlap, Roy O. Elmore Memorial (Engineering), Ford Foundation, Susan Baker Geddes, Thomas Lain Gordon Memorial, Roy W. Gray, Raphael Herman, Vaino A. Hoover Student Aid, Howard R. Hughes, Thomas Jackson Memorial, Ruth Wydman Jarmie, Walter and Margaretta Kendall, Cecil L. Killgore, Eugene Kirkeby, Gustav D. Koehler, Frank W. Lehan, John McMorris Memorial, James K. Nason Memorial, Noble (Loan and Scholarship), James R. Page, Arthur W. Root, John E. Sherborne Memorial, Richard W. Shoemaker, Albert H. Stone, United States Steel Foundation, Lee Walker, Neal Wilson (Emergency).

2. Federal loans under the National Direct Student Loan (NDSL) Program are available to undergraduate students who are citizens or permanent residents of the United States. The program limits borrowing to $2,500 during the first two 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 until nine months after termination of formal education. Repayment of principal and interest begins twelve months after termination of formal education. During repayment interest is charged at the rate of 3 percent per annum on the unpaid balance.

3. The Higher Education Act of 1965 contains provision for student assistance through loans insured by the federal government (Title IV, Part B). Under the Guaranteed Student Loan Program (GSL) the maximum loan amount is $2,500 per academic year with an aggregate maximum of $7,500 for undergraduate education. Further information on this program, including application forms, may be obtained from the Office of Financial Aid.

UCB Tuition Loans. In addition to the above loans a bank plan is available under which any student in good standing may borrow up to $1,500 each year, not to exceed a maximum of $6,000. Repayment may be made in installments after graduation. Interest on the amount borrowed is charged at 1 percent over the bank's commercial prime rate at the time of the inception of the loan and is payable quarterly. The interest is the only payment made under this plan during the undergraduate years. On November 1, following graduation, the student begins repayment at the rate of $85 per month including interest. For those who go on to graduate school, repayment may be deferred until termination of formal education. If student status is discontinued, the repayment schedule of $85 per month will begin after a grace period of four months.

Institute loans, National Direct Student Loans, and UCB Tuition Loans may be used in combination, but the total that may be borrowed may not exceed $2,500 in any one year (maximum of $7,500).

Financial Payment Plans

Aside from loans, the following organizations offer financial payment plans to help cover the costs of education at Caltech:

1. Academic Management Services, 1110 Central Avenue, Pawtucket, Rhode Island 02861, offers a nine-month annual budget payment plan. Payment under this plan begins June 1. Cost of this program is a $35 annual fee. A Life Benefit Coverage is provided at no additional cost.

2. EFI Fund Management Corporation, 2700 Sanders Road, Prospect Heights, Illinois 60070. They offer a ten-month budget plan for annual cost of tuition, fees, room and board with option for a two-, three-, and four-year program offering 12 payments a year after the initial year. Payment under this plan begins in June. Cost of this program is a $25 annual fee. These programs offer optional insurance coverage to protect the budget plan selected.

3. The Knight Tuition Payment Plan, offered by the Richard C. Knight Insurance Agency, Inc., 26 O'Farrell Street, San Francisco, California 94108, offers two payment programs. Both programs include insurance protection that 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 Plan, which begins before the first payment is due at the Institute and ends before graduation. Cost of this plan is a $25 initial fee plus a $.90 per month service charge and a monthly insurance premium charge. The monthly payments earn interest at the rate of 5.25 percent per annum. The second plan offered is an Extended Repayment Plan that finances the cost of education up to 72 months (six years). Cost of this plan is a $25 initial fee plus interest at 12 percent and a monthly insurance premium charge.

4. The Tuition Plan Inc., Concord, New Hampshire 03301, offers a Deferred Monthly Payment Plan (Loan Program) to cover tuition, fees, and any related educational expenses of schooling over a period of one to four years. Life insurance is available to all insurable parents. Monthly repayment starts one month after the first check is received from the Tuition Plan. Cost of this program is for interest expense (which varies from 18 percent to 19 percent) and insurance premiums (if coverage is desired). The maximum number of months allowed for repayment is 96. A Prepayment Program is available that provides a prepaid program of monthly budgeted expenses in advance of each school term. Cost of this plan is a $25 initial fee plus a $.50 per month service charge. Insurance is available to insurable parents (if coverage is desired).

Student Employment

Students who desire part-time or summer employment may receive assistance from the Placement Office. If an undergraduate student is a financial aid recipient, any on-campus or JPL earnings must be considered part of the student's financial aid package. Because academic requirements are so demanding, undergraduate students must receive approval from the Dean of Students to work more than 16 hours per week. In addition, any freshman seeking employment must receive permission from the Dean before he or she may work. We do not recommend that freshmen seek employment during the academic year, at least until after they have had an opportunity to assess their academic workload.

College Work Study Program. This federally funded program is designed to pay part of the salaries of undergraduate and graduate students who are citizens or permanent residents of the United States. In addition to the above general employment constraints, College Work Study employment is limited to students who are employed by Caltech and JPL and who demonstrate financial need. Further information is available through the Office of Financial Aid; placement assistance can be obtained from the Placement Office.

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 for 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 that 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 Placement Office compiles an Annual Report giving information about employment of graduating students. Copies of this report are available from the Placement Service.

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.

Merit Based Scholarships

Funds for freshman and upperclass financial aid based upon merit are provided from the following sources:

Caltech Prize Scholarships
The Carnation Scholarships
Jeremy V. Cassaday Award

> For further information on determination of financial need, application procedures, and financial aid packages and programs, refer to the Caltech Financial Aid Information brochure or contact the Director of Financial Aid, California Institute of Technology, 208-40, Pasadena, California 91125.

PRIZES

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 $500 is awarded annually to one or more juniors or seniors for outstanding original research in mathematics, the winners being selected by members of the mathematics faculty. The funds for this prize come from winnings accumulated over the years by Caltech undergraduate teams competing in the William Lowell Putnam Mathematics Contest, an annual nationwide competition.

The Donald S. Clark Memorial 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 Henry Ford II Scholar Awards

The Henry Ford II Scholar Awards are funded under an endowment provided by the Ford Motor Company Fund, a nonprofit organization supported primarily by contributions from the Ford Motor Company. Each award, up to $5,000, will be made annually either to the engineering student with the best academic record at the end of the third year of undergraduate study, or to the engineering student with the best first-year record in the graduate program. The chairman of the Division of Engineering and Applied Science names the student to receive the award.

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 that will provide an award of $500 to a junior in the upper five percent of his or her class who shows outstanding promise for a creative professional career. The student is selected by the division chairmen and the deans together with the Undergraduate Academic Standards and Honors Committee.

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 to 1962 Vice President for Business Affairs. The prize of $750 is awarded annually to an undergraduate student in any class for original research, an original paper or an essay, or other evidence of creative scholarship beyond the normal requirements of specific courses. The student is selected by the division chairmen and the deans together with the Undergraduate Academic Standards and Honors Committee.

The Arie J. Haagen-Smit Memorial Fund

The Arie J. Haagen-Smit Memorial Award was established in 1977 to honor the memory of the late pioneering bio-organic chemist who discovered the chemical constituents of smog. Dr. Haagen-Smit was a member of the Caltech faculty for 40 years, and his family and friends have arranged for a prize of $500 to be given at the end of the sophomore or junior year to a student in biology or chemistry who has shown academic promise and who has made recognized contributions to Caltech. The selection is made by a committee of representatives from the biology and chemistry divisions and the deans.

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 throughout his or her undergraduate years at the Institute has made the greatest contribution to the student body and whose qualities of character, leadership, and responsibility have been outstanding. At the discretion of the deans, more than one award or none may be made in any year. The award, presented at commencement without prior notification, consists of a cash award and a certificate.

The Mary A. Earl McKinney Prize in English

The Mary A. Earl McKinney Prize in English was established in 1946 by Samuel P. McKinney, M.D., of Los Angeles. Its purpose is to 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 amounting to $750.

Robert L. Noland Leadership Scholarship

The Robert L. Noland Leadership Scholarship is a cash award of $1000 to a junior or a sophomore who exhibits qualities of outstanding leadership. The kind of leadership to be recognized is most often expressed as personal actions that have helped other people and that have inspired others to fulfill their capabilities. The scholarship was set up by Ametek in honor of their president, Robert L. Noland, a Caltech alumnus. One or two awards may be given each year.

The Don Shepard Award

Relatives and friends of Don Shepard, class of 1950, have provided this award in his memory. The award is presented to a student, the basic costs of whose education have already been met but who would find it difficult, without additional help, to engage in extracurricular activities and in the cultural opportunities afforded by the community. The recipients, 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 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 $750, funded from membership dues, to a senior selected for an outstanding piece of original scientific research. The student is selected by the division chairmen and the deans together with the Undergraduate Academic Standards and Honors Committee.

The Morgan Ward Prize

The Morgan Ward Prize was established by the Department of Mathematics in 1963 to honor the memory of Professor Morgan Ward in recognition of his long service to mathematics and to the Institute. The competition is open only to freshmen or sophomores. An entry consists of a mathematical problem together with a solution or a significant contribution toward a solution. One or more winners are selected by a faculty committee acting on the advice of student judges. Each prize of $75 is funded by the same source used to sponsor the Eric Temple Bell Prize.

The following prize is available only to U.S. citizens:

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 a graduating senior in engineering who 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 Science.

UNDERGRADUATE OPTIONS AND COURSE SCHEDULES

To qualify for a Bachelor of Science degree at the Institute, a student must obtain passing grades in each of the required courses listed below, must satisfy the additional requirements listed under the undergraduate options, and must achieve a grade-point average of not less than 1.9. The student must also register for programs that make normal progress toward a B.S. degree.

Students must register for the Institute requirements below, in the year specified, unless they have previous credit. If for some reason they are not able to complete the requirements at the proper time, they must register at the earliest possible opportunity. (The Curriculum Committee may in unusual cases excuse undergraduate students from any of the following Institute or option requirements upon presentation of petitions.)

The Institute unit system is described in the opening paragraphs of Section V.

Institute Requirements, All Options

Course	Units
1. Freshman Mathematics (Ma 1 abc)	27
2. Sophomore Mathematics (Ma 2 abc)	27
3. Freshman Physics (Ph 1 abc)	27
4. Sophomore Physics (Ph 2 abc or Ph 12 abc)	27
5. Freshman Chemistry (Ch 1 abc)[1]	18
6. Freshman Chemistry Laboratory (Ch 3 a)	6
7. Additional Freshman Laboratory	9
8. Humanities Courses (as defined below)	27
9. Social Sciences Courses (as defined below)	27
10. Additional Humanities and Social Sciences Courses	54
11. Physical Education	9

[1]This requirement can also be met by completing any two terms of Ch 2 abc or of Ch 41 abc.

Freshman Laboratory Requirement. All freshmen are required to take at least 15 units of laboratory work in experimental science including Ch 3 a (6 units). The additional 9 units of laboratory work must be chosen from APh 9 (6 units per term), Bi 1 (3 units), Bi 9 (3 units), Ch 3 b (5 units), Ch 4 ab (6 units per term), ChE 10 (3 units), E 5 (6 units), CS/EE 11 (6 units), Ge 1 (3 units), Ph 3 (6 units), Ph 4 (6 units).

Humanities and Social Science Requirements. All students must complete satisfactorily 108 units in the Division of the Humanities and Social Sciences. Of these 108 units, 27 must be in the humanities (art, history, language, linguistics, literature, music, philosophy) and 27 in the social sciences (anthropology, economics, political science, psychology, social science). The remaining 54 may be drawn from either. They may include work done under the HSS Tutorial Program. They may include (to the limit of 27 units) courses in business economics and management (BEM). They may *not* include reading courses unless granted credit by petition.

Entering freshmen will enroll in a "Freshman Humanities" course (numbered 10 or below in the catalog) and must pass *three* terms thereof, thus satisfying the minimum humanities requirement, unless excused during the year for exceptional performance. The common denominator of freshman humanities courses is 4,000 words of essay writing a term. Successful completion of three terms, or excuse therefrom, is a prerequisite for advanced humanities (numbered 11 and above) but *not* for social sciences. Excuse from freshman humanities does not reduce the 108-unit total requirement or the 27-unit humanities requirement; it simply allows a student to enter advanced humanities sooner.

First Year, All Options
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	Classical Mechanics and Electromagnetism (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)[1]	6 or	6 or	6
	Introductory courses in the humanities and social sciences. A wide choice of alternatives will be available to students; the Registrar will announce the offerings for each term	9	9	9
	Freshman Laboratory Courses[2]	x	x	x
	Additional Electives[3]	x	x	x
PE	Physical Education[4]	3	3	3

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 of more than 58 units requires formal approval of a petition for overload.

[1]This course is offered in each of the three terms.

[2]The additional 9 units of laboratory work must be chosen from APh 9—6 units per term; Bi 1—3 units; Bi 9—3 units; Ch 3 b—5 units; Ch 4 ab—6 units per term; ChE 10—3 units; E 5—6 units; CS/EE 11—6 units; Ge 1—3 units; Ph 3—6 units; Ph 4—6 units.

[3]A partial list of electives particularly recommended for freshmen includes the following: APh 3, APh/MS 4, Ay 1, Bi 1, Bi 2, ChE 10, CS/EE 4, EE 5, Env 1, Ge 1, and CS 10.

[4]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 before graduation.

Applied Mathematics Option

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

Option Requirements

1. Ma 5 abc, AMa 95 abc or Ma 108 abc, and AMa 101 abc
2. One of the following (or an approved combination): AMa 98 abc, AMa 151 abc, AMa 152 abc, AMa 153 abc, AMa 181 abc, or AMa 104 and AMa 105 ab
3. One of the following (or an approved combination): Ma 118 abc, Ma 120 abc, Ma 121 abc, Ma 125 abc, Ma 141 abc, or Ma 137 and Ma 143 ab. Ma 108 abc may be accepted if not used to satisfy 1.
4. Passing grades must be obtained in a total of 483 units, including the courses listed above.

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	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Humanities Electives	9	9	9
	Electives	9	9	9
		45	45	45

Third Year

AMa 95 abc or	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
Ma 108 abc	Advanced Calculus (4-0-8)			
	Humanities Electives	9	9	9
	Electives	27	27	27
		48	48	48

Fourth Year

AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
	Humanities Electives	9	9	9
	Electives[1]	27	27	27
		45	45	45

[1]See items 2 and 3 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 of fields that overlap, a definite dividing line cannot be drawn between them.

Realizing this, the applied physics option draws its faculty from the Divisions of Physics, Mathematics and Astronomy; Engineering and Applied Science; Chemistry and Chemical Engineering; and Geological and Planetary Sciences. This interdivisional aspect of the option allows a flexibility and range in curriculum, appropriate to the student's particular research interests, that may 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 or her 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.

Option Requirements

1. Any three of the following: APh 24, Ph 3, Ph 5, Ph 6, Ph 7
2. APh 50 abc and APh 106 abc or Ph 106 abc
3. AMa 95 abc
4. Either APh 78 abc, or one term of APh 77 and one chosen from the following: APh 77, APh 154, Ph 77, EE 91, Ch 26, Ae/APh 104 bc, ChE 126, CS/EE 121, MS 130, MS 131, MS 132
5. 54 additional units of APh courses numbered over 100, which must include one of the following: APh 101 abc, APh 105 abc, APh 114 abc, APh 156 abc, APh 181 abc, APh 190 abc. None of these courses shall be elected by the student to be taken on a pass/fail basis. Note that APh 100 and APh 200 do not satisfy this requirement.
6. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

Second Year

		Units per term		
		1st	2nd	3rd
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
	Humanities Electives	9	9	9
	Laboratory Electives[1]	6	6	6
APh 17 abc	Thermodynamics (3-0-6)	9	9	9
	Other Electives	9	9	9
		51	51	51

Third Year

		1st	2nd	3rd
APh 50 abc	Applied Physics (3-0-6)	9	9	9
APh 110 abc	Topics in Applied Physics	2	2	2
AMa 95 abc	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
	Humanities Electives	9	9	9
	Other Electives[2]	18	18	18
		50	50	50

[1]See item 1, option requirements.
[2]See item 5, option requirements.

Fourth Year

APh 78 abc	Senior Thesis, Experimental[1]	6	6	6
Ph 106 abc	Topics in Classical Physics	9	9	9
	APh Electives[2]	9	9	9
	Humanities Electives	9	9	9
	Other Electives	18	18	18
		51	51	51

[1]See item 4, option requirements.
[2]See item 5, option requirements.

Suggested Electives

The student may elect any course that is offered in any term provided he or she has the necessary prerequisites for that course. The following subjects are suggested as being especially suitable for a well-rounded course of study. They need not be taken in the year suggested.

Sophomore Year	*Junior Year*	*Senior Year*
APh 23	APh 77	APh 77
APh 24	Ph 77 ab	APh 91 c
Ge 1	EE 91 abc	APh 100
Ge 2	EE 114 abc	Ae/APh 101 abc
Bi 1	Ch 26 ab	APh 105 abc
Ay 1	Ge 154 abc	APh 114 abc
ME 1 ab	APh 100	AMa 101 abc
ME 19 abc		AMa 104
EE 13 abc		AMa 105 ab
EE 14 abc		Ch 125 abc
EE 90 abc		Ph 125 abc
Ma 5 abc		Ph 129 abc
MS 15 abc		Ph 77 ab

More Specialized Courses

APh/MS 126 abc	APh 181 abc	Ch 113 abc
APh 140 abc	APh 190 abc	EE 91 abc
APh 153 abc	APh 195 ab	EE 155 abc
APh 154	AM 135 abc	Ge 104 abc
APh 156 abc	ChE 103 abc	Ge 166
APh 161 abc	ChE 126 abc	

Astronomy Option

The astronomy option is designed to give the student an understanding of the basic facts and concepts of astronomy, to stimulate his or her interest in research, and to provide a basis for graduate work in astronomy. The sophomore-junior sequence (Ay 20, 21, 22, 100, 101, 102) constitutes a solid introduction to modern astronomy. More advanced courses may be taken in the junior and senior years.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed in the Division of Physics, Mathematics and Astronomy may, at the discretion of his or her department, be refused permission to continue the work in this option.

Option Requirements

1. Ay 20, Ay 21 or 102, Ay 101, 14 units of Ay electives excluding Ay 1, Ph 3, Ph 5 or 6, Ph 7, Ph 92 abc, and Ph 106 abc
2. 54 additional units of Ay or Ph courses
3. 27 additional units of science or engineering electives of which 18 must be outside the Division of Physics, Mathematics and Astronomy
4. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

Second Year

		Units per term 1st	2nd	3rd
Ph 2 abc	Waves, Quantum Mechanics and Statistical Physics (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	.	.
Ay 21	Galaxies and Radio Sources (3-0-6)	.	9	.
Ph 3, 5, 6, 7	Physics Laboratory[1]	0-6	0-6	6
	Humanities Electives	9	9	9
	Electives[2]	0-9	3-6	12-15
	Suggested total number of units	44-47	45-48	45-48

Third Year

		1st	2nd	3rd
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	9	9	9
	Electives	18-24	9-12	9-15
	Suggested total number of units	45-51	47-50	45-51

Fourth Year

	1st	2nd	3rd
Astronomy or Physics Electives	18	18	18
Humanities Electives	9	9	9
Electives	18-24	18-24	18-24
Suggested total number of units	45-51	45-51	45-51

Students are encouraged (but not required) to undertake research leading to a senior thesis; credit for this work is provided through Ay 42.

[1]Students are required to take (a) Ph 3 if not already taken, (b) Ph 5 or Ph 6, and (c) Ph 7.

[2]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 a background as possible in other related fields of science and engineering.

Suggested Electives

The student may elect any course that is offered in any division in a given term, provided that he or she has the necessary prerequisites for that course. The following list contains courses useful to work in various fields of astronomy and astrophysics: Bi 1, EE 5, Ge 1, Ge 2, Ma 5 abc, AMa 95 abc[1], AMa 105 ab, Ma 112 ab, EE 13 abc, EE 14 abc, EE 90 abc, Ge 152, Ge 155, Ge 166 a, Ge 166 b, Ph 77 ab, Ph 93 ab[1], Ph 125 abc[1], Ay 22, Ay 100, Ay 110, Ay 131, Ay 132, Ay 133 ab, and Ay 141.

[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

The undergraduate option in biology is designed to build on a solid foundation in mathematics and physical science by providing an introduction to the basic facts, concepts, problems, and methodologies of biological science. The option serves as a basis for graduate study in any field of biology or for admission to the study of medicine. Instruction is offered in the form of participation in the ongoing research programs of the division, as well as in formal course work. Course work emphasizes the more general and fundamental properties of living organisms, and areas of current research interest, rather than the traditional distinct fields within the life sciences.

The division encourages undergraduate participation in its research program and believes that research participation should be a part of each student's program of study at the Institute. Research opportunities may be arranged with individual faculty members or guidance may be obtained from a student's individual faculty adviser in the division or from the Biology Undergraduate Student Adviser.

The requirements listed below for the biology option are minimal requirements. An adequate preparation for graduate work in biology will normally include additional elective research or course work in biology and/or advanced course work in other sciences or mathematics. Flexibility to accommodate varied individual scientific interests, within the broad scope of biology, is achieved through the provision of elective courses, arrangements for individual research (Bi 22), and tutorial instruction (Bi 23). In addition, arrangements may be made to take courses at neighboring institutions in fields of biology that are not represented in our curriculum.

Premedical Program. The undergraduate course for premedical students is essentially the same as that for biology students and is intended as a basis for later careers in research as well as in the practice of medicine. It differs in some respects from premedical curricula of other schools; however, it has been quite generally accepted as satisfying admission requirements of medical schools. 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 advisers: Dr. Marlene Coleman and Professor A. J. Hudspeth.

Option Requirements

1. Specific courses: Bi 1, Bi 7, Bi 9, Bi/Ch 110 abc, Bi 122, Bi 150, and Ch 41 abc.
2. An additional 55 units of Bi courses. At least 10 of these units must be in Bi 22 or laboratory courses (Bi 111, Bi 116, Bi 134, Bi 161).
3. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

Second Year

		Units per term 1st	2nd	3rd
	Humanities Electives	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
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
	Electives	9-15	0-6	0-6
		45-51	45-51	45-51

Third Year

		1st	2nd	3rd
	Humanities Electives	9	9	9
Bi 7	Organismic Biology (3-3-3)	9	.	.
Bi/Ch110abc	Biochemistry (4-0-8)	12	12	12
Bi 122	Genetics (3-3-6)	.	.	12
	Electives[1,2,3]	15-21	24-30	12-18
		45-51	45-51	45-51

Recommended Electives[2]

		1st	2nd	3rd
Ch 21 abc	The Physical Description of Chemical Systems	9	9	9
Ch 24 ab	Introduction to Biophysical Chemistry	.	9	9

Fourth Year

		1st	2nd	3rd
	Humanities Electives	9	9	9
Bi 150	Neurobiology (4-0-6)	10	.	.
	Electives[3]	26-32	36-42	36-42
		45-51	45-51	45-51

[1]Electives must include sufficient units of work in Biology to complete the graduation requirement for 140 units of work in Biology.

[2]Ch 21 or the combination of Ch 21 a, Ch 24 ab is strongly recommended for students interested in chemical biology, as many graduate programs expect entering students to have taken a course in physical chemistry.

[3]The sequence of courses Bi 150, Bi 156, Bi 157, Bi 151, and Bi 152 is designed to provide a comprehensive introduction to the field of neurobiology.

Suggested Electives

Second Year

Second Term: Ch 4 a   Third Term: Ch 4 b

Third Year

First Term: Bi 22, Bi 23, Bi 27, Bi 114, Bi 116, Bi 134, Bi 135, Bi 136, Bi 137, Ch 21 a, L 1 a, L 32 a, L 50 a

Second Term: Bi 22, Bi 23, Bi 27, Bi 106, Bi 111, Bi 155, Ch 21 b, Ch 24 a, L 1 b, L 32 b, L 50 b

Third Term: Bi 22, Bi 23, Bi 27, Bi 156, Bi 157, Bi 158, Ch 21 c, Ch 24 b, Env 144, L 1 c, L 32 c, L 50 c

Fourth Year

In addition to those listed for the third year:

First Term: Bi 209, Bi 216, Bi 217, Bi 220 a, Bi 260, Ch 144 a, Ch 244 a

Second Term: Bi/Ch 132 a, Bi 151, Bi 152, Bi 161, Bi 209, Bi 214, Bi 220 b, Bi 260, Ch 144 b, Ch 244 b, Env 145 a

Third Term: Bi 115, Bi 125, Bi/Ch 132 b, Bi 141, Bi 209, Bi 218, Bi 220 c, Bi 241, Bi 260, Env 145 b, Ge 5

Chemical Engineering Option

Chemical Engineering is one of the broader of the engineering disciplines, involving the application of mathematics, physics, chemistry, and economics to a variety of problems, mainly characterized by chemical change. Study in this option leads, especially when followed by graduate work, to research and development in industry and government laboratories or to research and teaching in universities.

Freshman and sophomore students normally take the fundamental courses in chemistry, physics and mathematics (Ch 1 abc, Ch 41 abc, Ph 1 abc, Ph 2 abc, Ma 1 abc, and Ma 2 abc). Students who show themselves to be qualified may, however, elect to take more advanced courses.

Students interested in an introduction to the breadth of chemical engineering are encouraged to take ChE 10. The open-ended projects in ChE 10 also offer an opportunity to become acquainted with some of the faculty in chemical engineering.

In the second year, students normally take a basic course in chemical engineering thermodynamics, ChE 63 abc. In addition, there are 27 units of elective courses.

Juniors take courses in the physical description of chemical systems, an introduction to the techniques of applied mathematics, and a unified course in transport phenomena involving the study of transfer of momentum, energy, and materials in situations of practical interest. They also take a course in applied chemical kinetics involving the basic study of chemical reactions combined with transport processes in systems of practical interest and a course on the fundamentals of the control of dynamic systems. The work in kinetics and control and other previous chemical engineering courses is used in senior courses in the optimal design and simulation of chemical systems. Seniors may also take the chemical engineering laboratory during the first term and may continue that laboratory or take the laboratory in physical chemistry. There are at least 69 units of elective courses.

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 year such research has resulted in a 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 this option.

Option Requirements

1. Ch 41 abc, ChE 63 abc, ChE 126 a and either ChE 126 b or Ch 26 a, AMa 95 abc, Ch 21 abc, ChE 103 abc, ChE 101, ChE 105, ChE 110 ab, ChE 111, and Ec/SS 11[1]
2. 4 units of laboratory other than AMa and CS, in addition to requirements in (1) above, and not including AMa, CS, or 18 units of chemistry electives

[1]These 9 units partially satisfy the Institute requirements in Humanities and Social Sciences.

3. 18 units of chemistry electives[1]
4. 27 units of science and engineering electives[2]
5. Passing grades must be earned in a total of 516 units, including the courses listed below.

[1]In addition to chemistry courses taught within the Division of Chemistry and Chemical Engineering, other courses such as Bi 110 and Env 142 may be used to satisfy this requirement.

[2]If research units (ChE 80) are to be used to fulfill elective requirements in the chemical engineering option, a written research report approved by the research director must be submitted in duplicate before May 10 of the year of graduation.

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	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	9	9	9
		45	45	45

Third Year

AMa 95 abc	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
Ch 21 abc	The Physical Description of Chemical Systems (3-0-6)	9	9	9
ChE 101	Chemical Kinetics and Reactor Design (3-0-6)	.	.	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
ChE 105	Process Control (3-0-6)	.	9	.
	Electives	18	9	9
		48	48	48

Fourth Year

ChE 110 ab	Optimal Design of Chemical Systems (3-0-6)	9	9	.
ChE 111	Simulation and Design of Chemical Systems (3-0-6)	.	.	9
ChE 126 ab	Chemical Engineering Laboratory (1-6-2)	9	9	.
ChE 161	Advanced Chemical Kinetics and Reactor Design (3-0-6)	9	.	.
	Electives	9	18	33
		36	36	42

Chemistry Option

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.

A first-year general chemistry course is taken by all freshman students. The emphasis is on fundamental principles and their use to systematize descriptive chemistry. Students who show themselves to be qualified and receive the instructor's consent may elect to take an Advanced Placement first-year chemistry course (at least two terms from Ch 2 abc or Ch 41 abc). The one-term required laboratory course (Ch 3 a) presents basic principles and techniques of synthesis and analysis and develops the laboratory skills and precision that are fundamental to experimental chemistry. The laboratory in the following two terms (Ch 4 ab) introduces the student to methods of synthesis, separation, and instrumental analysis used routinely in research.

Beyond the freshman year, each student in the chemistry option, in consultation with his or her adviser, selects a suitable course of study under the supervision of the division. The requirements of the option are listed below. A student wishing to deviate from these requirements should submit with justification an alternate curriculum for consideration by his or her adviser and the Undergraduate Study Committee.

Undergraduates in the option must also take chemistry courses below the 100 level for a letter grade with the exception of Ch 1, Ch 2, Ch 3 a, Ch 4 ab (if taken during the freshman year), and Ch 90, which are only offered on a pass/fail basis. Within the total period of undergraduate study there are additional 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 PE.

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 is less than 1.9 will be admitted to the option for the following year only with the special permission of the Division of Chemistry and Chemical Engineering.

Option Requirements

1. Ch 14, Ch 21 abc (or Ch 21 a, Ch 24 ab), Ch 41 abc, Ch 90.
2. A minimum of five quarters of laboratory work chosen from Ch 4 ab, Ch 5 ab, Ch 15, Ch 26 ab, and Bi 111.
3. A minimum of five terms of advanced chemistry electives from chemistry course offerings at the 100 and 200 level, including cross-listed offerings such as Bi/Ch 110 abc, Bi/Ch 132 ab, and ChE/Ch 164, but excluding Ch 180 and Ch 280.
4. Passing grades must be earned in the courses that constitute the approved program of study, including those listed above.

Typical Course Schedule

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	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ch 5 a	Advanced Techniques of Synthesis and Analysis (1-6-2)	.	9	.
	Electives	15-18	6-9	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 (0-6-4)	10	.	.
Ch 21 abc	The Physical Description of Chemical Systems (3-0-6)	9	9	9
Ch 90	Oral Presentation (1-0-1)	.	2	.
	Electives	18-22	36-40	36-40
		43-47	47-51	45-49

Fourth Year

Ch 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.

Professor of Physical Chemistry Richard Dickerson and graduate student Horace Drew compare an electron density map and a wire model for a small double-helical DNA molecule of sequence: ctyosine—guanine—cytosine—guanine, or simply CGCG.

Suggested Representative Courses of Study for Those Intending To Do Graduate Work in Particular Areas of Chemistry[1,2]

Inorganic Chemistry	*Chemical Physics*	*Organic Chemistry*	*Chemical Biology*
Sophomore Year	Sophomore Year	Sophomore Year	Sophomore Year
Ch 5 ab[3]	Ch 21 abc[7]	Ch 5 ab[3]	Ch 5 a[3]
Ch 41 abc	Ch 26 ab[7]	Ch 41 abc	Ch 41 abc
Ma 2 abc	Ch 14	Ma 2 abc	Ch 14
Ph 2 abc	Ma 2 abc	Ph 2 abc	Ma 2 abc
HSS elective	Ph 2 abc	HSS elective	Ph 2 abc
other elective(s)	HSS elective	other elective(s)	HSS elective
Junior Year	Junior Year	Junior Year	Junior Year
Ch 14	Ch laboratory[8]	Ch 14	Ch laboratory[11]
Ch 21 abc	Ch 41 abc[7]	Ch 21 abc	Ch 21 a
Ch elective(s)[4]	Ch elective(s)[9]	Ch elective(s)[10]	Ch 24 ab (or Ch 21 bc)
Ch laboratory[5]	Ch 80[6]	Ch laboratory[5]	Ch 80[6] (or Bi 22)
Ch 80[6]	Ch 90	Ch 80[6]	Ch 90
Ch 90	HSS elective	Ch 90	Bi/Ch 110 ab
HSS elective	AMa 95 ab	HSS elective	Bi 111
			HSS elective
Senior Year	Senior Year	Senior Year	Senior Year
Ch electives[4,5]	Ch 125 abc	Ch electives[5,10]	Ch (Bi) electives[11,12]
Ch 80[6]	Ch electives[8,9]	Ch 80[6]	Ch 80[6] (or Bi 22)
HSS elective	Ch 80[6]	HSS elective	HSS elective
	HSS elective		

[1]A significant fraction of the chemical literature, especially in organic chemistry, is in German. A reading knowledge of German is therefore useful in research at the doctoral level. Russian is another important language for chemistry; however, the leading Russian periodicals are translated and published in English.

[2]Experience in computer programming and use is now important to all areas of chemistry.

[3]Requires Ch 4 ab; if Ch 4 ab was not taken in the freshman year, it can be taken in the sophomore year, and Ch 5 ab deferred to the junior year.

[4]Ch 112, Ch 117, Ch 120 ab, Ch 122 abc, Ch 135 ab, Ch 144 abc, Ch 154, Ch 212, Ch 213 abc, Ch 242 ab, Ch 247 ab.

[5]Ch 15, Ch 26 ab, Ch 118 ab, Bi 111.

[6]See "Research Opportunities for Undergraduates in Chemistry," which may be obtained from the Chairman of the Undergraduate Studies Committee.

[7]Students without sufficient math preparation may delay Ch 21 abc and Ch 26 ab until their junior year and take Ch 5 ab and Ch 41 abc during their sophomore year.

[8]Ch 5 ab[3], Ch 15, Ch 118 ab, Bi 111.

[9]Ch 119, Ch 120 ab, Ch 127 ab, Ch 130 ab, Ch 135 ab, Ch 144 abc, ChE/Ch 164, Ph 106 abc, AMa 105 ab.

[10]Ch 112, Ch 120 ab, Ch 122 abc, Ch 135 ab, Ch 144 abc, Ch 154, Ch 242 ab, Ch 247 ab.

[11]Ch 5 b, Ch 15, Ch 26 ab, Ch 118 ab.

[12]Ch 122 abc, Ch 131, Bi/Ch 132 ab, Ch 144 abc, Ch 154, Ch 242 ab, Ch 244, Ch 247 ab.

Suggested Elective Courses for the Chemistry Option

1. *Chemical Engineering:* Chemical Engineering Systems (ChE 10), Chemical Engineering Thermodynamics (ChE 63), Undergraduate Research (ChE 80), Chemical Kinetics and Reactor Design (ChE 101), Transport Phenomena (ChE 103), Advanced Polymer Science (ChE 167), Polymer Science Laboratory (ChE 168), Optimal Control Theory (Ae/ChE 172), Advanced Transport Phenomena (ChE 173).

2. *Biology:* Introduction to Biology (Bi 1), Cell Biology (Bi 9), Genetics (Bi 122).
3. *Engineering:* Introductory Methods of Applied Mathematics (AMa 95), Laboratory Research Methods in Engineering and Applied Science (E 5), Introduction to Solid-State Electronics (APh 3), Solid-State Electronics Laboratory (APh 9), Introduction to Linear Electronics (EE 5). Laboratory in Electronics (EE 90), Introduction to Computing (CS 10).
4. *Physics:* Physics Laboratory (Ph 3, Ph 4, Ph 5, Ph 6, Ph 7), Topics in Classical Physics (Ph 106), Quantum Mechanics (Ph 125), Methods of Mathematical Physics (Ph 129), Statistical Physics (Ph 127).
5. *Humanities:* Introduction to Microeconomics (Ec/SS 11), Introduction to Macroeconomics: Principles and Problems (Ec 15), Elementary French (L 102) or Elementary German (L 130) or Elementary Russian (L 141).
6. *Miscellaneous:* Introduction to Astronomy (Ay 1), Introductory Geology (Ge 1), Introduction to Geochemistry (Ge 130), Advanced Calculus (Ma 108).

Economics Option

The principal objectives of the economics option are to provide a useful, working knowledge of the economic system and its most important institutions and to present a rigorous curriculum in the conceptual basis and practical applications of modern economics. The upper division courses in microtheory, macrotheory, and econometrics build upon the methods of analysis provided in the Institute freshman and sophomore science and mathematics requirement, offering students comprehensive, scientific development of the fundamentals of modern economic theory. The remaining courses apply the tools of economic analysis to particular areas of public concern where economics is most relevant. The program provides students with an excellent preparation for graduate study in economics, and for an economics oriented plan of study in a graduate professional school of business or law, as well as a deeper understanding of the economic system and related public affairs.

Option Requirements

1. Ec/SS 11 a, Ec 121 ab, Ec 122, and Ec 126 ab
2. Ma 112 a, or CS/SS 142 a
3. 54 additional units of advanced economics and social science courses (not including Business Economics and Management). Students may take AMa 181 ab in partial fulfillment of this requirement.
4. 45 units of science, mathematics, and engineering courses. This requirement cannot be satisfied by freshman laboratory courses or courses primarily for freshmen, graded on a pass/fail basis, and not serving as prerequisites for more advanced courses.The courses Ay 1, Bi 1, Env 1, and Ge 1 may be taken to satisfy this requirement only if taken after the freshman year. Note: AMa 181 ab may count toward either this requirement or the economics electives requirement, but not toward both.
5. Passing grades must be earned in a total of 516 units, including courses listed above.

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	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ec/SS 11 abc	Social Science Principles and Problems (3-0-6)	9	9	9
Ec 15	Introduction to Macroeconomics: Principles and Problems (3-0-6)	.	9	
	Electives[1]	18	9	18
		45	45	45

[1]See requirements 4 and 5 above.

Third Year

Ec 121 ab	Intermediate Microeconomics (3-0-6)	9	9	.
Ec 122	Econometrics (3-06)	.	9	.
Ec 126 ab	Money, Income, and Growth (3-0-6)	9	9	.
Ma 112 a or	Statistics (3-0-6)	9	.	.
CS/SS 142 a	Computer Modeling and Data Analysis (3-0-6)	9	.	.
	Electives[1]	9	18	45
		45	45	45

Fourth Year

Electives[1]	45	45	45

[1]See requirements 4 and 5 above.

Electrical Engineering Option

The electrical engineering option is designed to provide a broad exposure to the fundamentals of the electrical sciences while allowing some degree of specialization in a particular aspect of modern electrical engineering. Study in this option leads, especially when followed by graduate work, to research and development in industry and government laboratories or to research and teaching in universities.

Students electing this option normally begin their work in electrical engineering with the theory and laboratory practice of electronics in their sophomore year in EE 14 abc and EE 90 abc, although many may have already been introduced to the field through freshman electives. The junior year program features a choice of alternative courses in passive and active circuit design and two one-term courses designed to introduce important areas of modern electrical engineering: energy processing systems, EE 40, and communications systems, EE 60. The digital electronics course CS/EE 4 may also be taken in the junior year if it has not previously been taken. In his or her senior year the student will ordinarily take an advanced course in electricity and magnetism, EE 151 abc, and demonstrate his or her ability to formulate and carry out a research or development project, through either the senior thesis, EE 78 abc, or the senior projects laboratory, EE 91 abc. The senior student may elect advanced courses to continue special interests begun in the required courses or in the electives taken in the sophomore and junior years; alternatively, a senior may select a broader range of topics from EE or other engineering or science courses.

A student whose interests lie in the electrical sciences but who wishes to pursue a broader course of studies than that allowed by the requirements of the electrical engineering option may elect the engineering and applied science option.

Attention is called to the fact that any student who has a grade-point average less than 1.9 at the end of the academic year in the subjects listed under electrical engineering may be refused permission to continue work in this option.

Option Requirements

1. E 10
2. AMa 95 abc
3. EE 14 abc, EE 40, EE 90 abc, EE 151 ab
4. CS/EE 4 or CS 112
5. EE 13 ab or EE 112 abc or EE 114 abc
6. EE 60 or EE 160 abc
7. EE 78 abc or two terms of EE 91 abc

8. In addition to the above courses, 27 units selected from EE or CS/EE courses numbered over 100.
9. Passing grades must be earned in a total of 516 units, including courses listed above.

Typical Course Schedule

Second Year

		Units per term 1st	2nd	3rd
Ph 2 abc	Waves, Quantum Mechanics and Statistical Physics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
	Humanities Electives[1]	9	9	9
EE 14 abc	Introduction to Electronic Engineering (3-0-6)	9	9	9
EE 90 abc	Laboratory in Electronics (0-3-1)	4	4	4
	Electives	9	9	9
		49	49	49

Third Year

		1st	2nd	3rd
AMa 95 abc	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
	Humanities Electives[1]	9	9	9
EE 13 ab[2]	Circuit Theory (3-0-6)	9	9	.
EE 40	Fundamentals of Energy Processing Systems (3-0-6)	9	.	.
EE 60[3]	Communication System Fundamentals (3-0-6)	.	.	9
	Electives	9	18	18
		48	48	48

Fourth Year

		1st	2nd	3rd
	Humanities Electives[1]	9	9	9
E 10	Technical Seminar Presentations (1-0-1)	.	2	.
EE 151 abc	Electromagnetism (3-0-6)	9	9	9
EE 91 abc[4]	Experimental Projects in Electronic Circuits	6	6	.
	Electives	18	18	27
		42	44	45

[1]See Institute requirements for specific rules regarding humanities.
[2]See option requirement 5.
[3]See option requirement 6.
[4]See option requirement 7.

Suggested Electives

First-year students interested in electrical engineering should consider selecting one or two courses per term from APh 3, APh 9, CS/EE 4, CS 10, CS/EE 11, Gr 1, E 5, EE 5, Ph 3.

Suggested elective course sequences for the second, third, and fourth year for various specializations within electrical engineering are given on the next page. Students interested in other areas of specialization or interdisciplinary areas are encouraged to develop their own elective program in consultation with their faculty adviser.

COMMUNICATIONS

Second Year

Selected from APh/ME 17 abc, APh 23, APh 24, CS 112, CS 114, CS 116, CS/EE 121

Third Year

EE 160 abc (Requirement 6), Ma 112 a

Fourth Year

Selected from CS/EE 119 abc, EE 163 abc, EE 165 abc, CS/EE 183 ab, EE 194

COMPUTER ENGINEERING

Second Year

CS 112, CS 114, CS 116

Third Year

Selected from CS/EE 121, CS 137, CS 138, CS 139, CS 140, APh/ME 17 abc

Fourth Year

Selected from CS/EE 121, CS/EE 181, CS 185, EE 114 abc, CS/EE 119 abc, CS/EE 183 abc

QUANTUM ELECTRONICS

Second Year

APh/ME 17 abc, APh 23, APh 24

Third Year

APh 50 abc

Fourth Year

Selected from APh 105 abc, APh 114 abc, APh 153 abc, APh 190 abc, APh 195 abc, EE 155 abc, EE 194, Ph 125 abc

CONTROL

Second Year

E 13; selected from APh/ME 17 abc, E 101

Third Year

E 102 abc, EE 117 ab

Fourth Year

Ae/ChE 172 abc, and selections from EE 112 abc, EE 114 abc, CS/EE 119 abc, EE 160 abc

ELECTRONIC CIRCUITS

Second Year

Selected from APh/ME 17 abc, E 13, E 101

Third Year

EE 114 abc (Requirement 5); selected from CS 112, CS 114, CS 116, CS/EE 121

Fourth Year

Selected from EE 112 abc, EE 117 ab, CS/EE 119 abc, EE 160 abc, EE 182 abc

SOLID-STATE ELECTRONICS

Second Year

APh/ME 17 abc

Third Year

APh 50 abc

Fourth Year

APh 181 abc and selections from APh 105 abc, APh 114 abc

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, energy engineering, the physics of fluids, applied mathematics, earthquake engineering, quantum electronics, aerodynamics, bioinformation systems 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 that permits students to tailor a course of study to their 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 freshmen elective subjects are available as an introduction to various aspects of engineering and applied science. At the end of the first year, students who elect the engineering and applied science option are assigned advisers in their general fields of interest, and, together, they develop programs of study for the next three years. Beyond the Institute-wide requirements of physics, mathematics, and humanities, these programs require one year of applied mathematics and a certain number of units selected from a wide variety of engineering and applied science courses as well as interdivisional options such as applied physics and applied mathematics courses, from which the students and the advisers may build a solid foundation for the kinds of engineering and applied science activities that the students desire to learn. Engineering design (synthesis), as distinct from analysis, is considered an essential part of every engineer's capability. Advisers will expect students to select a sufficient number of courses that place emphasis on design.

Although a special electrical engineering option is available, students whose main interest is in electrical sciences may nevertheless choose the engineering and applied science option if they wish to pursue a broader course of studies.

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 division faculty, be refused permission to continue the work of that option.

Option Requirements

1. E 10
2. AMa 95 abc or Ma 108 abc.
3. 126 additional units in courses in the following: Ae, AM, BIS, CE, ChE, CS, E, EE, ES, Env, Gr, Hy, JP, MS, or ME. Note that the student cannot exercise the pass/fail option on any courses offered to meet this requirement.
4. 9 units[1] of courses taken from the following list: APh 24, APh 77, APh 154, APh 91 abc, Ae/APh 104 bc, AM 155, CE 105, CE 180, CS/EE 121, CS 140, EE 90 abc[2], EE 91 abc, EE 194, Env 116, Env 143, Hy 111, Hy 121, JP 170, MS 90, MS 130, MS 131, MS 132, ME 126
5. 9 units[1] of additional laboratory[3] excluding those for which freshman credit is allowed
6. Passing grades must be earned in a total of 516 units, including courses listed above.

[1]These units will partially satisfy requirement 3 when in appropriate subjects.
[2]Only 6 units of this course can be used to fulfill items 4 and 5.
[3]These electives must be complete laboratory courses and not the laboratory portion of a course. They may be selected from the list in 4 above or from laboratory courses offered by other options.

Typical Course Schedule

Second Year

	Units per term		
	1st	2nd	3rd
Ma 2 abc	9	9	9
Ph 2 abc	9	9	9
Humanities Electives	9	9	9
Electives	18	18	18
	45	45	45

Third Year

	1st	2nd	3rd
AMa 95 abc or Ma 108 abc	12	12	12
Humanities Electives	9	9	9
Electives	24	24	24
	45	45	45

Fourth Year

	1st	2nd	3rd
E 10		2	
Humanities Electives	9	9	9
Electives	33	33	33
	42	44	42

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 above.

Suggested Electives

AERONAUTICS

First Year

One course per term selected from ChE 10, E 5, CS/EE 4, CS 10

Second Year

APh/ME 17 abc; one course per term selected from: ME 1 ab, MS 15 abc, Ay 1, EE 5, APh 3

Third Year

AM 97 abc, ME 19 abc; one course per term selected from: APh 50 abc, AM 96 abc, EE 90 abc, ME 5 abc, MS 5 abc, E 101

Fourth Year

Ae/APh 101 abc, or Hy 101 abc, or Ae/AM 102 abc, and three courses per term selected from: Ae 103 abc, Ae/APh 104 abc, AMa 101 abc, AM 155, Hy 111, ME 126, JP 121 abc, APh 101, MS 120, MS 121, MS 122

APPLIED MECHANICS

First Year

One course per term selected from: E 5, Ge 1, CS/EE 4, CS 10, CS/EE 11

Second Year

One course per term selected from: APh/ME 17 abc, MS 15 abc, Ge 1, Bi 1, AM 96 abc, Ma 31, E 13

Third 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, APh 50 abc; MS 5 abc

Fourth 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, AM 96 abc, AM 135 abc, AM 141 abc, Hy 101 abc, Ph 106 abc, AMa 104, AMa 105 ab

COMPUTER SCIENCE

First Year

One or two courses per term selected from: CS/EE 4, CS 10, CS/EE 11, EE 5

Second Year

CS 137, CS 138, CS 139, Ma 5 abc

Third Year

CS 112, CS 114, CS 116, CS 121, Ma 116 abc; one course per term selected from: Ma 121 abc, Lin 101, Lin 102, Lin 103, Bi/BIS 121, CS 141

Fourth Year

CS 130, Ma 121 abc, AMa 104, AMa 105 ab, CS 140 ab, CS/EE 119 abc, CS/EE 181 abc

ENERGY ENGINEERING

First Year

One course per term selected from: APh 3, APh/MS 4, APh 9, ChE 10, E 5, CS/EE 4, CS/EE 11, Env 1, Gr 1, CS 10

Second Year

APh/ME 17 abc or ChE 63 abc; one course per term selected from: Env 20, EE 5, E 13, EE 14 abc, Ec/SS 11 ab, Ge 1, Ge 5, ME 1 ab, MS 15 abc

Third Year

ME 19 abc; one course per term selected from: APh 50 abc, AM 96 abc, Ch 21 abc; EE 90, ME 5 abc, ME 126, Ph 106 abc

Fourth Year

Me 102 abc, JP 131 and APh 161 ab or ChE 101 ab; one or two courses selected from: Ae/APh 101 abc, Ae 103 abc, Ae 105 abc, AM 97 abc, APh 105 abc, ChE/Env 157, Hy 101 abc, ME 22 abc, ME 118 abc, ME 126, MS 5 abc, Env/Ge 103 abc, ChE 101 abc, ChE 103 abc

NOTE: Humanities electives particularly appropriate to energy studies are Ec 115, Ec 116, Ec 118, SS 130 abc, SS 150 abc.

ENVIRONMENTAL ENGINEERING SCIENCE

First Year

Env 1; one course per term selected from: ChE 10, Bi 1, Bi 9, Ch 3 bc, E 5, Ge 1, CS 10

Second Year

APh/ME 17 abc or ChE 63 abc, Ec/SS 11; one course per term selected from: Env 144, Ch 14, Ch 15, Ch 41 abc, CS/EE 4, CS/EE 11, E 13, Ge 5, MS 15 abc

Third Year

Env 20, ME 19 abc or ChE 103 abc, Ch 21, AMa 95 abc, Ec 118

Fourth Year

Those interested in air quality should take ChE/Env 157 ab, and Env 116. Those interested in water quality should choose from: Env 112 abc, Env/Ge 103 ab, Env 142 ab, Env 145 ab.

FLUIDS AND THERMAL ENGINEERING

First Year

One course per term selected from: Gr 1, E 5, CS 10

Second Year

APh/ME 17 abc, APh 3, Env 20, CS/EE 4, APh/MS 4, EE 5, ME 1 ab, ChE 63 abc

Third Year

ME 19 abc, AM 96 abc; one course per term selected from: MS 15 abc, E 13, EE 13 ab

Fourth Year

ME 118 abc, JP 121 abc; one course per term selected from: Hy 101 abc, AM 97 abc, ME 22 abc, ME 102 abc, Hy 111, ME 126, JP 170, E 101, ME 5 abc

HYDRAULICS AND WATER RESOURCES

First Year

One course per term selected from: Gr 1, CS 10, E 5, Ge 1, Ge 2, Env 1

Second Year

One course per term selected from: APh/ME 17 abc, Ph 3, Ph 4, CS/EE 4, CS/EE 11, ME 15 abc, Gr 1, E 13, AM 96 abc

Third Year

AM 97 abc, ME 19 abc, Ec/SS 11 a, Ec 11 b

Fourth Year

CE 10 abc, CE 115 ab and CE 150, Hy 103 ab, Hy 111 or ME 126, Hy 113 ab, Env 112 abc, or Env 117 or Env 146 abc

MATERIALS SCIENCE

First Year

One course per term selected from: E 5, CS/EE 4, CS 10, ChE 10, APh 3, APh 9, APh/MS 4

Second Year

APh/ME 17 abc; one course per term selected from: ME 1 ab, EE 5, Gr 1

Third Year

AM 97 abc, MS 5 abc, APh 50 abc, MS 15 abc, MS 90

Fourth Year

MS 105, MS 120, MS 121, MS 126 abc

MECHANICAL DESIGN

First Year

One course per term selected from: Gr 1, E 5, EE 5

Second Year

ME 1 ab, APh/ME 17 abc, MS 15 abc

Third Year

ME 19 ab, AM 97 abc; one course per term selected from: ME 5 abc, ME 126, CS 10, EE 90, AM 96 abc

Fourth Year

AM 151 abc, MS 5 ab; two courses per term selected from: Ae 107 abc, AM 155, E 13, E 101 or EE 13 a and EE 13 bc

STRUCTURAL AND SOIL MECHANICS

First Year

One course per term selected from: Gr 1, CS 10, E 5, Ge 1, Ge 2

Second Year

One course per term selected from: APh/ME 17 abc, Ph 3, Ph 4, CS/EE 4, CS/EE 11, MS 15 abc, Gr 1, AM 96 abc

Third Year

AM 97 abc, ME 19 abc

Fourth Year

CE 10 abc, CE 115 ab and CE 105, AM 151 abc, CE 180, CE 181, and CE 182 or Hy 113 ab and Hy 111, Env 112 abc or Env 146

STRUCTURE AND PROPERTIES OF ALLOYS

First Year

One course per term selected from: E 5, CS 10, Gr 1, ChE 10, CS/EE 4, APh 3, APh 9, APh/MS 4

Second Year

APh/ME 17 abc; one course per term selected from: ME 1 ab, MS 15 abc, EE 5

Third Year

AM 97 abc, MS 5 abc, APh 105 abc, Ch 21 abc, APh 50 abc

Fourth Year

APh 114 abc, MS 90, MS 120, MS 121 MS 125, MS 126 abc, Ph 125 abc, MS 130, MS 131, MS 132

Geology, Geochemistry, Geophysics, and Planetary Science Options

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. Field work is emphasized because it provides firsthand experience with geological phenomena that can never be satisfactorily grasped or understood solely from classroom or laboratory treatment. Options are offered in geology (including paleontology and paleoecology), geophysics, planetary science, and geochemistry. Electives permit students to follow lines of special interest in related scientific and engineering fields. Those who do well in the basic sciences and at the same time have a compelling curiosity about the earth and 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 science and mathematics courses is less than 1.9 at the end of an academic year may be refused permission to register in the geological sciences options.

Option Requirements and Typical Course Schedules

Institute Requirements		YEAR 1	2	3	S	4
Ma 1 abc	Freshman Mathematics	27				
Ph 1 abc	Freshman Physics	27				
Ch 1 abc	General and Quantitative Chemistry	18				
Ch 3 a	Experimental Chemical Science	6				
	Freshman Laboratory	9				
HSS	Humanities and Social Science Electives	27	27	27		27
PE 1 abc	Physical Education	9				
	Freshman Electives	3				
Ma 2 abc	Sophomore Mathematics		27			
Ph 2 abc	Sophomore Physics		27			
	Sophomore Science and Engineering Electives[1]		27			
	Total required courses	126	108	27		27

[1]These 27 units of sophomore electives should be used to broaden the students' backgrounds in science and engineering and to help them select an option. None of the introductory courses in the division, including Ge 1, Ge 2, Ge 4, and Ge 5, is specifically required of majors, but the election of one or more of these is highly recommended in the second year. The division recommends that an additional 9 units taken of physics, chemistry and/or engineering laboratory courses be completed in the second year. The units may be selected from the first-year physics, chemistry, and engineering courses, e.g., Ph 5, Ph 6, Ph 7, and Ch 15.

		YEAR 1	2	3	S	4
Division Requirements						
Ge 100	Geology Club recommended			1		1
Ge 102	Oral Presentation					2
Ge 104 abc	Advanced General Geology			27		
Ge 105 ab	Geologic Field Training and Problems			18		
	Language Elective[1]					30
	Total required courses[2]	126	108	73		60

[1]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. These units may be used as part of the 108 units of humanities and social sciences. Two years of language are highly recommended for students planning to do graduate work.

[2]The division requires that passing grades be earned in a total of 516 units including the courses listed above under Institute requirements and below under option requirements.

		YEAR 1	2	3	S	4
Geochemistry Option Requirements						
Ge 114	Optical and X-Ray Mineralogy					12
Ge 115 ac	Petrology and Petrography					24
Ge 123	Summer Field Geology				30	
Ch 21 abc	The Physical Description of Chemical Systems[1]			27		
Ch 14	Chemical Equilibrium and Analysis					6
Ch 15	Chemical Equilibrium and Analysis Laboratory					10
	Total required courses	126	108	100	30	112
Geology Option Requirements						
Ge 107	Structural Geology			9		
Ge 114	Optical and X-Ray Mineralogy					12
Ge 115 ac	Petrology and Petrography					24
Ge 123	Summer Field Geology				30	
Ge 121 abc	Advanced Field and Structural Geology					36
Ch 21 abc	The Physical Description of Chemical Systems[1]			27		
	Geology Electives[2]			27		
	Total required courses	126	108	136	30	132
Geophysics and Planetary Science Option Requirements						
Ph 106 abc	Topics in Classical Physics			27		
AMa 95abc	Introductory Methods of Applied Mathematics			36		
	Option Electives[3]					54
	Total required courses	126	108	136		114

[1]Ch 41 abc or other chemistry courses may be substituted with prior consent of adviser and option representative.

[2]These 27 units may include Ge electives taken in other years and are taken in the fourth year if French, German, or Russian is taken in the third year. The student should particularly note the opportunity for undergraduate research provided by Ge 40 and Ge 41.

[3]These courses may include most mathematics, science, engineering, geophysics, or planetary science courses pertinent to the student's interest, but must be chosen with the advice and consent of the student's adviser.

History Option

History majors must take not less than 99 units of H courses during their four years as undergraduates. Of these, not less than 45 *must* be in junior and senior tutorial (H 97 ab and H 99 abc), and another 18 *may* be in H 98 ab if a student wishes and his or her instructors agree.

The courses and tutorials in the history option cover four areas: medieval Europe to 1500, modern Europe, the United States, and Asia. Each history major will concentrate in one of these areas and write a research paper in it; each student must also take at least 36 units of history in other areas as approved by the adviser or the history option.

A student considering the history option when he or she comes to Caltech will be well advised to take H 1, 2, 6 or 8. In the sophomore year the student should take middle or upper level history courses, but this is also a good time to pursue the study of literature or philosophy, to begin or continue a foreign language (particularly desirable if the area of concentration is to be Europe), and to do introductory work in the social sciences. A student will normally make a commitment to an area of concentration early in the junior year, exploring this area through regular course work supplemented, the second and third terms, by tutorial study in H 97 ab. At the beginning of the senior year a history major will enroll in H 99 abc and be assigned to a faculty member in his or her chosen area. After a period of preparation that may consume part or all of the first term, a student will embark on serious research, the end result of which will be a substantial research paper.

Since statistics can be a useful tool in historical analysis, the option recommends that two of the science and math courses which a history major takes beyond the sophomore year (to satisfy the 54-unit Institute requirement) be Ma 112 a and 112 b. Students who wish to write their senior research papers in the history of science are encouraged to use the rest of the 54 units to advance their understanding of one or two particular scientific disciplines.

Option Requirements

1. H 97 ab, H 99 abc
2. 54 additional units of H courses (including, if appropriate, H 98 ab), of which 36 must be in an area or areas other than the area of concentration.
3. 54 additional units of science and engineering courses. This requirement cannot be satisfied by freshman laboratory courses or courses primarily for freshmen, graded on a pass/fail basis, and not serving as prerequisites for more advanced courses. The courses Ay 1, Bi 1, Env 1, and Ge 1 may be taken to satisfy this requirement only if taken after the freshman year.
4. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

A suggested program follows. Requirements are underlined; courses in parentheses are recommended.

Second Year

	Units per term 1st	2nd	3rd
Ma 2 abc (4-0-5)	9	9	9
Ph 2 abc (4-0-5)	9	9	9
Middle- or Upper-Level History, Literature, Philosophy, or Language	9	9	9
Introductory Social Science	9 (Ec/SS 11 a)	9 (Ec/SS 11 b)	9 (Ec/SS 11 c)
Electives	9	9	9
	45	45	45

Third Year

H 97 ab (2-0-7)		9	9
Science or Math	9	9	9 (Ma 112 a)
History electives	9	9	9
Other electives	27	18	18
	45	45	45

Fourth Year

H 99 abc (1-0-8)	9	9	9
Science or Math	9	9	9
History electives	9 (H 98 a)	9 (H 98 b)	9
Other electives	18	18	18
	45	45	45

Independent Studies Program

The Independent Studies Program (ISP) is an undergraduate option that allows the student to create his or her own scholastic requirements, under faculty supervision, and to pursue positive educational goals that cannot be achieved with a normal option. A student's program may consist of normal Caltech courses, research courses, courses at other schools, and independent study courses (item 5 below). In scope and depth the program must be comparable to a normal undergraduate program, but it need not include the specific courses or groups of courses listed in the formulated Institute requirements for undergraduates.

The ISP Committee, a standing committee of the faculty, has overall responsibility for the program. In addition, each student has his or her own committee of three advisers, two of whom must be professorial faculty. The Registrar keeps records and transcripts of all ISP students, and has application materials for admission into ISP.

Administrative Procedures and Guidelines

1. The student submits a written proposal describing his or her goals, reasons for applying and plan of study for at least the next year. The student must also recruit three faculty members, representing at least two divisions of the Institute, who approve of his or her plans and agree to act as an advisory "committee of three."

2. The committee of three forms the heart of the program and bears the chief responsibility for overseeing the student's progress. The chairman and one other member must be on the professorial staff. The third member may be any qualified individual such as a postdoctoral fellow, graduate student or faculty member of another institution.

3. The ISP committee considers each proposed program in consultation with the prospective members of the committee of three. If the program seems suitable, a three-party written contract is drawn up among the ISP committee, the committee of three, and the student. This contract includes the agreed-upon content of the student's program and the methods for ascertaining satisfactory progress for those parts of the student's program that are not standard Institute courses. Copies of the student's contract, along with all ISP records for each student and his or her transcript, are kept in permanent files in the Registrar's Office.

4. The progress of each student in the ISP is 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 are the responsibility of the ISP committee. When the ISP committee is satisfied that the terms of the contract have been fulfilled by the student, it recommends the student to the faculty for graduation.

5. A plan of study may include special ISP courses to accommodate individual programs of study or special research that falls outside ordinary course offerings. The student and the instructor first prepare a written course contract specifying the work to be accomplished and the time schedule for reports on progress and for work completed. The units of credit and form of grading are decided by mutual agreement between the instructor, the student, and his or her committee of three. ISP courses are recorded on the student's transcript in the same manner as are other Caltech courses.

Literature Option

Students majoring in literature are offered a wide range of courses that enable them to concentrate on either English or American literature. In addition a number of courses in literature in translation enrich the curriculum. All majors are assigned an adviser who will help them select the courses best suited to their needs. Majors preparing for graduate work will be well advised to go beyond the minimum requirements listed below. All literature courses must be taken for grades. It is recommended that literature majors take electives in such related fields as the arts, languages, history, philosophy, and psychology.

Option Requirements

1. 108 units in the Lit 100-180 group of courses. Within these 108 units, the following are required:
   a. 18 units (two terms) of Shakespeare, Lit 114a and b.
   b. 27 units (three terms) selected from the following group of courses in pre-twentieth-century English literature: Lit 106 a, Lit 112 a or b, Lit 116, Lit 120, Lit 122 a or b, Lit 125 a and b, Lit 126
   c. 27 units (three terms) selected from the following courses in American Literature: Lit 132, Lit 134, Lit 136, Lit 138, Lit 140, Lit 142 a or b or c, Lit 146 a
2. L 102 abc or L 130 abc or L 141 abc or the equivalent
3. 54 units of science, mathematics, and engineering courses. This requirement cannot be satisfied by freshman laboratory courses or courses primarily for freshmen, graded on a pass/fail basis, and not serving as prerequisites for more advanced courses. The courses Ay 1, Bi 1, Env 1, and Ge 1 may be taken to satisfy this requirement only if taken after the freshman year.
4. Passing grades must be earned in a total of 516 units, including the courses listed above.

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	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
	Electives[1]	24	24	24
		42	42	42

Third Year

Electives	45	45	45

Fourth Year

Electives	45	45	45

[1]81 of these units partially fulfill the Institute requirement in humanities and social science.

Mathematics Option

The four-year undergraduate program in mathematics leads to the degree of Bachelor of Science. The purpose of the undergraduate option is to give students an understanding of the broad outlines of modern mathematics, to stimulate their interest in research, and to prepare them for later work, either in pure mathematics or allied sciences. Unless students have done exceptionally well in their freshman and sophomore years, they should not contemplate specializing in mathematics. An average of at least "B" in mathematics courses is expected of students in order to major in mathematics.

Since the more interesting academic and industrial positions open to mathematicians require training beyond a bachelor's degree, students who intend to make mathematics their profession must normally plan to continue with graduate study. Some students use their background in mathematics as an entry to other fields such as physics, economics, computer science, business, or law. Students expecting to pursue a Ph.D. degree in mathematics should realize that many mathematics departments require a reading knowledge of one or two foreign languages.

The schedule of courses in the undergraduate mathematics option is flexible. It enables students to adapt their programs to their needs and mathematical interests and gives them the opportunity of becoming familiar with creative mathematics early in their careers. Each term during 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. Sophomores who have not taken Ma 5 must take this course as juniors. Overloads in course work are strongly discouraged; students are advised instead to deepen and supplement their course work by independent reading.

Attention is called to the fact that students whose grade-point averages are less than 1.9 at the end of the academic year in the subjects under mathematics and applied mathematics may, at the option of the department, be refused permission to continue the work of the mathematics option.

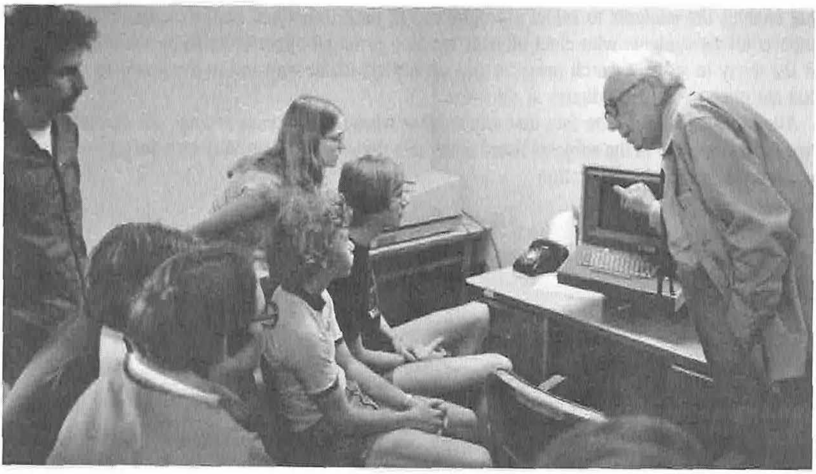
Option Requirements

1. Ma 5 abc, Ma 108 abc
2. One of the following one-year courses: Ma 102 abc, Ma 116 abc, Ma 118 abc, Ma 120 abc, Ma 121 abc, Ma 122 abc, Ma 123 abc, Ma 125 abc, Ma 137 a followed by Ma 143 ab, Ma 144 abc, Ma 150 abc, Ma 151 abc, Ma 152 abc, Ma 160 abc
3. 27 additional units in Ma or AMa
4. Passing grades must be earned in a total of 483 units, including the courses listed above.

Typical Course Schedule

Second Year

		Units per term		
		1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (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	9	9	9
		45	45	45



Professor Emeritus H. F. Bohnenblust is involved in an undergraduate mathematics class that uses the computer as an investigative tool in the formulation of mathematical principles.

Third Year

Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
	Selected courses in Mathematics, minimum	9	9	9
	Humanities Electives	18	18	18
	Electives in Science, Engineering, or Humanities	9	9	9
		48	48	48

Fourth Year

Selected course in Mathematics	9	9	9
Humanities Electives	18	18	18
Electives in Mathematics, Science, Engineering or Humanities	18	18	18
	45	45	45

Physics Option

The distinctive feature of the undergraduate work in physics at the California Institute is the creative atmosphere in which students at once find themselves. 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 electromagnetism as they apply to the dynamics of particles. More complex problems, including quantum mechanics, atomic structure, and statistical mechanics, will be treated in the second year. Those who want to major in physics may choose a more intensive course in their second year. Junior and senior courses 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 that enables the students to select a program to fit their 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 that are always under way and in the graduate seminars that 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.

Option Requirements

1. Ph 3 and Ph 4
2. Ph 5 or Ph 6[1]
3. Ph 7
4. Ph 106 or APh 106
5. Ph 92 or Ph 98 or Ph 125
6. Ph 77 and/or APh 91 in any two-term combination or Ph 78 abc
7. 54 additional units of any of the following: Ph 79, Ph 103 abc, Ph 127 abc, Ph 129 abc, Ph 135 abc, APh 105 abc, APh 114 abc, APh 156 abc or any physics graduate course numbered 200 or greater. Note that the student cannot exercise a pass/fail option on any courses offered to meet this requirement.
8. 27 units of science and engineering courses outside of Ph, APh, Ma, and AMa.
9. Passing grades must be earned in a total of 516 units, including courses listed above but with no more than 9 units per term of Ph 171, Ph 172, or Ph 173.

Typical Course Schedule

Second Year

Ph 2 abc or Ph 12 abc	9	9	9
Ma 2 abc	9	9	9
Humanities	9	9	9
Physics Laboratory[2]	0	6	6
Electives	12	9	9
	39	42	42

Third Year

Ph 106	9	9	9
AMa 95 or Ma 108	12	12	12
Ph 98[3]	9	9	9
Humanities	9	9	9
Electives	9	9	9
	48	48	48

Fourth Year

Ph 77	6	6	0
Physics Electives	18	18	18
Humanities	9	9	9
Electives	18	18	18
	51	51	45

[1]Several lower-division laboratory courses from other options (APh 24, EE 90, etc.) have considerable physics content, and students wishing to substitute such a course for the requirement of Ph 5 or Ph 6 may petition the Physics Undergraduate Committee to do so.

[2]See Option Requirements 1, 2 and 3.

[3]Students who took Ph 2 in their second year may take Ph 125 or an elective.

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[1]	6 units
Ph 7	6 units
	18 units

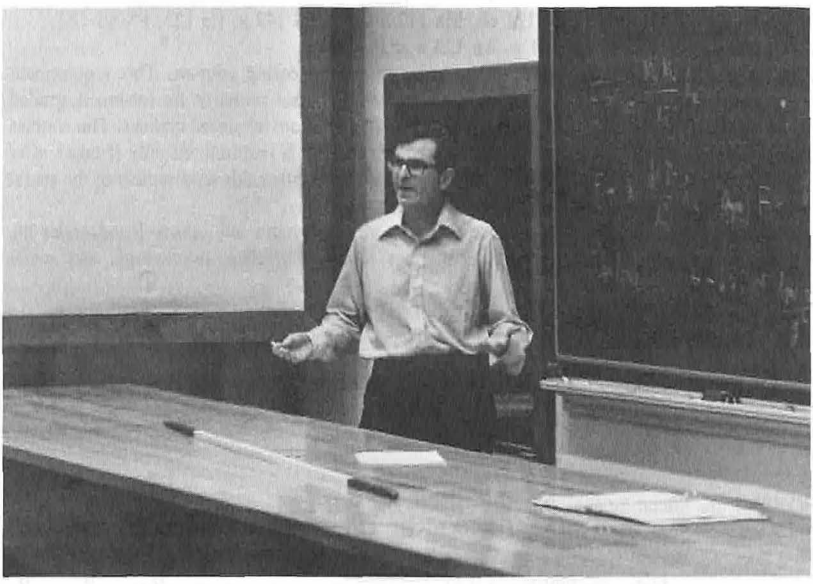
Ph 3	Physics Laboratory	6	6	6
Ph 4	Physics Laboratory	.	.	6
Ph 5	Physics Laboratory	6	.	.
Ph 6	Physics Laboratory	.	6	.
Ph 7	Physics Laboratory	.	.	6

[1]Several lower-division laboratory courses from other options (APh 24, EE 90, etc) have considerable physics content, and students wishing to substitute such a course for the requirement of Ph 5 or Ph 6 may petition the Physics Undergraduate Committee to do so.

Suggested Electives

Sophomore Year

Ma 5 abc	Ay 21	EE 5
Ge 1	Ay 22	EE 13 abc
Ge 4	ME 1 ab	EE 14 abc
Bi 1	ME 3	Ch 41 abc
Ay 20	APh/ME 17 abc	L 130 abc
	EE 4	



Professor David Goodstein, who teaches the Physics 1 class required of all freshmen, offers common lectures to all students. Recitation sections are adapted to the needs of individual students.

Junior Year

Ph 77 ab	Ge 101 abc	EE 13 abc
Ph 171	Ge 166	EE 14 abc
Ph 172	Bi 9	EE 90 abc
AMa 95 abc	Ay 100	Ch 21 abc
Ma 108 abc	Ay 101	L 102 abc
	Ay 102	L 141 abc

Senior Year

Ph 78 abc	Ph 129 abc	APh 105 abc
Ph 79 abc	Ph 135 abc	APh 114 abc
Ph 103 abc	Ph 136 abc	APh 140 abc
Ph 127 abc	APh 91 ab	APh 156 abc

Social Science Option

The social science program is designed to provide undergraduates with a multidisciplinary training in social science. The program focuses on the processes of social, political and economic change and the analytical methods used by social scientists to describe and predict them. The program is designed to be sufficiently flexible to provide an excellent preparation for students intending to attend graduate school in any social science discipline, law or business.

Option Requirements

1. Ec/SS 11 a, Ec/SS 11 b, Ec 121 ab, Ma 112 a or CS/SS 142 a, Ec 122, PS/SS 122
2. One of the following: An 101 a, An 123 a or Psy 13
3. 45 additional units of science, mathematics, and engineering courses. This requirement cannot be satisfied by freshman laboratory courses or courses primarily for freshmen, graded on a pass/fail basis, and not serving as prerequisites for more advanced courses. The courses Ay 1, Bi 1, Env 1, and Ge 1 may be taken to satisfy this requirement only if taken after the freshman year. Note: AMa 181 ab may count toward either this requirement or the social science electives requirement, but not toward both.
4. 45 additional units of social science courses, which includes any course listed under the following headings: anthropology, economics, political science, psychology, and social science
5. Passing grades must be earned in a total of 516 units, including courses listed above.

Typical Course Schedule

Second Year

		Units per term 1st	2nd	3rd
EC/SS 11 abc	Social Science Principles and Problems	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
	Electives	18	18	18
		45	45	45

Third Year

Ma 112 a or	Statistics (3-0-6)	9	.	.
CS/SS 142 a	Computing Modeling and Data Analysis (3-0-6)	9	.	.
Ec 121 ab	Intermediate Microeconomics (3-0-6)	.	9	9
Ec 122	Econometrics (3-0-6)	.	9	.
PS/SS 122	Noncooperative Games in Social Science (3-0-6)	.	.	9
An 101 a or	Selected Topics in Anthropology (3-0-6)	9	.	.
An 123 a or	Anthropology of Development (3-0-6)	.	9	.
Psy 13	Introduction to Social Psychology (3-0-6)	.	.	9
	Electives	9	18	27
		45	45	45

Fourth Year

Electives[1]	45	45	45
	45	45	45

[1]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, 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, which are supervised by those professors whose interests and research are closely related to the area of the option, within the administrative jurisdiction of one or more of the divisions. The graduate student working for an advanced degree in one of the graduate options is associated with an informal group of those professors who govern the option, other faculty including research associates and fellows, and other graduate students working for similar degrees.

A faculty member from each area of graduate study is available for consultation on problems concerning academic programs, degree requirements, financial aid, etc. The representatives for 1980–81 are as follows:

Aeronautics:	Prof. L. Lees
Applied Mathematics:	Prof. H. B. Keller
Applied Mechanics:	Prof. F. S. Buffington
Applied Physics:	Prof. D. L. Smith
Astronomy:	Prof. K. Y. Lo
Biology:	Prof. C. J. Brokaw
Chemical Engineering:	Prof. G. R. Gavalas
Chemistry:	Prof. P. B. Dervan
Civil Engineering:	Prof. F. S. Buffington
Computer Science:	Prof. C. A. Mead
Electrical Engineering:	Prof. R. D. Middlebrook
Engineering Science:	Prof. F. S. Buffington
Environmental Engineering Science:	Prof. F. S. Buffington
Geological and Planetary Sciences:	Prof. D. S. Burnett
Materials Science:	Prof. F. S. Buffington
Mathematics:	Prof. R. P. Dilworth
Mechanical Engineering:	Prof. F. S. Buffington
Physics:	Prof. S. C. Frautschi
Social Sciences:	Prof. L. E. Davis

GENERAL REGULATIONS

Admission to Graduate Standing

Apply to the Dean of Graduate Studies, California Institute of Technology, 204-40, Pasadena, California 91125, for an application form for admission to graduate studies. Admission will be granted *only to a limited number of students of superior ability*, and application should be made as early as possible. 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 wishing to apply for assistantships or fellowships may do so in the appropriate section of the application for admission. The completed application is due in the Graduate Office no later than February 15.

Although the application form permits the applicant to state his or her intended major field of study and special interests, the application may actually be considered by two or more divisions or interdisciplinary programs.

To be admitted to graduate standing an applicant must in general have received a bachelor's degree representing the completion of an undergraduate course in science or engineering substantially equivalent to one of the options offered by the Institute. He or she must, moreover, have attained such a scholastic record and present such recommendations as to indicate that he or she 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 or she 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.

Admission to graduate standing does not of itself admit the student 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 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 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 Graduate Office. Special no-credit classes in English are sometimes offered at Pasadena City College for those students who need to improve their command of the language or who wish to perfect it. Information regarding these classes can be obtained from the Chairman of the Faculty Committee on Foreign Students and Scholars or from the International Desk. It is strongly recommended, however, that students who achieve a low TOEFL score make arrangements for remedial work during the summer preceding their registration.

Special students, not working for degrees, are admitted only under exceptional circumstances.

Graduate Residence

One term of residence shall consist of one term's work of not fewer than 36 units of advanced work in which a passing grade is recorded. If fewer than 36 units are successfully carried, the residence will be regarded as shortened in the same ratio; but the completion of a greater 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 three terms (one academic year) of graduate work; Aeronautical Engineer, Civil Engineer, Electrical Engineer, and Mechanical Engineer, after a minimum of six terms (two academic years) of graduate work; and Doctor of Philosophy, after a minimum of nine terms (three academic years) of graduate work.

Advanced work is defined as study or research in courses whose designated course 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 or campus facility.

Before registering, students should consult with members of the department in which they are taking their major work to determine the studies that they 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.

Students will not receive credit for courses unless they are properly registered. *The students themselves are charged with the responsibility of making certain that all grades to which they are entitled have been recorded.*

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 residency requirements, the student must file a registration card for such summer work in the Office of the Registrar in May. 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 or her department's consent, the approval of the Dean of Graduate Studies.

In registering for research, students should indicate on their program card the name of the instructor in charge, and should consult with him or her to determine the number of units to which the proposed work corresponds. At the end of the term the instructor in charge may decrease the number of units for which credit is given in case he or she 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, an assistantship, 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 option representative 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. Registration for 10 units may be granted for the term in which the Ph.D. examination is taken.

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 or her major work.

Part-Time Programs

Part-time graduate study programs at the Institute are subject to the following rules:

a. Applicants for the part-time program must submit a regular application form.
b. Any research work done for academic credit shall be supervised by a Caltech faculty member.
c. 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.
d. Part-time studies in the program will be limited to the first two years of academic residence for each student. Beyond the initial period, students continuing their graduate work must do so on a full-time basis.
e. 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.
f. Any option at the Institute retains the right not to participate in the program or to accept it under more stringent conditions.

Caltech Graduate Students Working at Special Laboratories

a. 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 or she 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.
b. A student's request to carry out thesis work at the Special Laboratories should be formally endorsed by the appropriate committee of his or her 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 their commitment of special equipment or any other resources required for the thesis work. Approval of the Special Laboratories should also indicate that the thesis topic is a sensible one from their point of view, but that the subject is not likely to be preempted from the student.
c. 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 award (almost always awarded in conjunction with a GRA) and be on the same basis as a campus thesis student.
d. Employment by the Special Laboratories of a graduate student for work not connected with his or her 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, Pass-Fail grading may also be used.

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, arrangements may be made for the student to be temporarily in full-time residence at SIO.

Thesis research done partly at SIO may be arranged directly by the student's 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 or her Caltech thesis adviser and will enroll for Caltech research units.

DEGREE REGULATIONS

Degree of Master of Science

The Master of Science degree is a professional degree 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.

A student who enters the Institute holding a master's degree from another institution will not normally be awarded a master's degree in the same field from the Institute unless the initial admission to Caltech graduate standing indicated that the student was to be a master's candidate. A student may not normally be awarded two master's degrees from the Institute.

Special regulations for the master's degree are listed under each graduate option.

Residence and Units of Graduate Work Required. At least one academic year of residence at the Institute and 135 units of graduate work subsequent to the baccalaureate degree are required for the master's degree. Included in these units are at least 27 units of free electives or of required studies in the humanities. Courses used to fulfill requirements for the bachelor's degree may not be counted as graduate residence.

To qualify for a master's degree, a student must complete the work indicated in the section on special regulations for his or her option with a grade-point average for the approved M.S. candidacy courses of at least 1.9, considering for this purpose only 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 before 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.

Registration. Continuity of registration must be maintained until all requirements for the master's degree have been completed, with the exception of summer terms and authorized leaves of absence.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree, he or she must file in the Office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. On the candidacy form, the student will submit a proposed plan of study, which must have the approval of his or her 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 department representative.

All changes in registration must be reported on drop or add cards to the Registrar's Office.

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. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a new petition to continue graduate work toward the desired degree. Students who have received an engineer's degree will not in general be admitted for the doctor's degree.

Residence. At least six terms of graduate residence subsequent to a baccalaureate degree equivalent to that given by the 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 on graduate work.

To qualify for an engineer's degree a student must complete the work prescribed by his or her supervising committee with a grade-point average of at least 1.9, 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 or her department when establishing his or her program.

Registration. Continuity of registration must be maintained until all requirements for the engineer's degree have been completed, with the exception of summer terms and authorized leaves of absence.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree, he or she must file in the Office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. Upon receipt of this application, the Dean, 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 or her work as approved by the committee shall be entered on the application form and shall then constitute a requirement for the degree. Changes in the schedule will not be recognized unless initialed by the proper authority. No course that appears on the approved schedule and for which the applicant is registered may be removed after the last date for dropping courses as listed in the catalog.

The student will be admitted to candidacy for the degree when the supervising committee certifies: (a) that all the special requirements for the desired degree have been met, with the exception that certain courses of not more than two terms in length may be taken after admission to candidacy; (b) that the thesis research has been satisfactorily started and 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 or her thesis in accordance with the regulations that govern the preparation of doctoral dissertations, which may be obtained from the Graduate Office. The candidate must obtain written approval of the thesis by the chairman of the division and the members of the supervising committee, on a form obtained from the Office of the Dean of Graduate Studies.

The use of "classified" research as thesis material for any degree will not be permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Examination. At the discretion of the option in which the degree is desired, a final examination may be required. This examination would be conducted by a committee appointed by the candidate's supervising committee.

Degree of Doctor of Philosophy

The degree of Doctor of Philosophy is conferred by the Institute primarily in recognition of breadth of 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 clear and forceful self-expression in both oral and 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 or she has chosen the major subject. Each student should consult his or her department concerning special divisional and departmental requirements.

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; however, these degrees are not general prerequisites for the doctor's degree. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a request to continue graduate work toward the desired degree. Students who have received an engineer's degree will not, in general, be admitted for the doctor's degree.

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, the admission for the engineer's degree will be cancelled.

A student who holds a Ph.D. degree from another institution will not normally be admitted to graduate standing at Caltech to pursue a second Ph.D. degree. A student will not normally be awarded two Ph.D. degrees from the Institute.

Minor Programs of Study. The Institute has no required minor program for the degree of Doctor of Philosophy, but individual options may have minor requirements at their discretion and on the approval of the Graduate Study Committee. Those students enrolled in a doctoral program prior to October 1, 1974, will have the choice of completing their work under this new policy or under the minor policy in effect at the time they were first enrolled. For the earlier policy, reference may be made to copies of catalogs on file in the Graduate Office or in divisional offices.

A student who has satisfied the requirements for a minor program of study will be given recognition by explicit mention of the minor field on the Ph.D. diploma.

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.

A student whose undergraduate work has been insufficient in amount or too narrowly specialized, or whose preparation in his or her special field is inadequate, must count upon spending increased time in work for the degree.

Registration. Continuity of registration must be maintained until all requirements for the doctor's degree have been completed, with the exception of summer terms and authorized leaves of absence.

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 the student has been admitted to work toward the doctor's degree and has been in residence at least one term thereafter; has initiated a program of study approved by the major department and, if needed, by the minor department; has satisfied the several departments concerned by written or oral examination or otherwise that he or she has a comprehensive grasp of the 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 entries under the graduate options. 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 is responsible for seeing that admission is secured at the proper time.* A student not admitted to candidacy before the beginning of the fourth academic year of graduate work at the Institute must petition through his or her division to the Dean of Graduate Studies for permission to register for further work.

Foreign Languages. The Institute believes in the importance of the knowledge of foreign languages and encourages their study as early as possible, preferably before admission to graduate standing. Although there is no Institute-wide foreign language requirement for the degree of Doctor of Philosophy, graduate students should check for possible specific requirements set by their division or smaller academic unit. Previous work is recognized, and further study as a graduate student is possible.

Examination. Each doctoral candidate shall be examined broadly and orally on the major subject, the scope of the thesis, and its significance in relation to the major subject. The examination, subject to the approval of the 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 Graduate Office, not less than two weeks before the date of the examination. Ordinarily more than two weeks are needed for the necessary arrangements. *The date of the examination and the composition of the examining committee will not be approved by the Dean of Graduate Studies until the thesis is submitted in final form*—i.e., ready for review by the Dean, the members of the examining committee, and the Graduate Office proofreader. (See *Thesis* below.)

Thesis. The candidate is to provide a copy of his or her completed thesis to the members of the examining committee at least two weeks before the final oral examination. The date of the examination and the composition of the examining committee will not be approved by the Dean of Graduate Studies until the thesis is submitted in completed form, i.e., ready for review by the Dean, the members of the examining committee, and the Graduate Office proofreader. A petition for 10 units registration may be granted if these arrangements are approved before the end of the third week of the term in which the thesis will be submitted.

The last date for submission of the final, corrected thesis to the Dean of Graduate Studies is two weeks before the degree is to be conferred. Two copies of the thesis are to be submitted in accordance with the regulations governing the preparation of doctoral dissertations, obtainable from the Graduate Office. For special departmental regulations concerning theses, see specific graduate options.

Before submitting the final, corrected thesis to the Dean of Graduate Studies, the candidate must obtain approval of the thesis by the chairman of his or her division and the members of the examining committee, on a form that can be obtained at the Office of the Dean.

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 or her own 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.

GRADUATE EXPENSES

The tuition charge for all students registering for graduate work is currently $5,229 per academic year, payable in three installments at the beginning of each term. Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Students desiring permission to register for fewer than 36 units should therefore petition on a form obtained from the Registrar. If reduced registration is permitted, the tuition for each term is at the rate of $48 a unit for fewer than 36 units with a minimum of $480 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 that are not part of the normal educational facilities of the Institute.

The payment of tuition by graduate students is required (a) without reference to the character of the work by the student, which may consist of the performance of research, of independent reading, or of the writing of a thesis or other dissertation, as well as attendance at regular classes; (b) without reference to the number of terms in which the student has already been in residence; and (c) without reference to the status of the student as an appointee of the Institute, except that members of the academic staff of rank of Instructor or higher are not required to pay tuition.

Students who register for summer work, and who have not paid full tuition at the Institute during the preceding academic year, may be subject to a summer health fee of $36.

Each graduate student is required to make a general deposit of $25 to cover loss of, or damage to, Institute property used in connection with work in regular courses of study. Upon completion of graduate work, or upon withdrawal from the Institute, any remaining balance of the deposit will be refunded.

Unpaid Bills. All bills owed the Institute must be paid when due. Any student whose bills are past due may be refused registration for the term following that in which the past due charges were incurred. Transcripts will not be released until all bills due have been paid or satisfactory arrangements for payment have been made with the Office of Student Accounts.

Information regarding fellowships, scholarships, and assistantships is discussed on the following pages. Students of high scholastic attainment may be awarded special tuition awards covering all or a part of the tuition fee. Loans also may be arranged by making an application to the Faculty Committee on Scholarships and Financial Aid.

Expense Summary 1980-81

General:

General Deposit	$ 25.00[1]
Tuition	5,229.00
Graduate Student Council Dues	6.00
	$5,260.00

Other:

Books and Supplies (approx.)	$450.00

Graduate House Living Expenses
Room—$945.00 to $1,035.00 per academic year[2]
(Room rates are subject to change.)
Meals—Available at Chandler Dining Hall or the Athenaeum (members only)

The following is a list of graduate fees at the California Institute of Technology for the Academic Year 1980–81, together with the dates on which these charges are due. Fees are subject to change at the discretion of the Institute.

	First Term	*Fee*
September 29, 1980	General Deposit	$ 25.00
	Tuition	1,743.00
	Graduate Student Council Dues	6.00
	Second Term	
January 5, 1981	Tuition	1,743.00
	Third Term	
March 30, 1981	Tuition	1,743.00

Tuition fees for fewer than normal number of units:

Over 35 units	Full Tuition
Per unit per term	48.00
Minimum per term	480.00

Audit Fee, $48.00 per lecture hour, per term.

Fees for Late Registration. Registration is not complete until the student has personally turned in the necessary registration forms for a program approved by his or her adviser and has paid tuition and other fees. A penalty fee of $10 is assessed for failure to register within five days of the scheduled dates.

ASCIT Dues. Graduate students are eligible for membership in the Associated Students of the California Institute of Technology, Inc., or ASCIT, pursuant to by-laws thereof. Dues are $45 annually.

Room Deposit. A $50 deposit must accompany each room application and will be refunded upon termination of the contract. (This deposit should not be confused with the General Deposit of $25.)

[1]This charge is made only once during residence at the Institute.
[2]Room rent is billed one month in advance and is payable upon receipt of the monthly statement.

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 $6 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 are entitled to a partial refund of tuition based on the period of attendance. The schedule for the specific percentage of tuition to be refunded for specific days of attendance may be obtained in the Office of Student Accounts. The days in attendance are the number of days counted from the first day of the term to the date that the petition for *withdrawal, leave of absence,* or *reduction of units* (to fewer than 36) is approved by the Dean of Graduate Studies.

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 Foundation, 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, Pasadena, CA 91125.

The Institute owns a limited number of apartments and houses for rental to married Caltech students. Contact the Housing Office upon arrival for information.

The Off-Campus Housing Office maintains a current file of available rooms, apartments, and houses in the Pasadena area. The listings are available for use upon arrival at Caltech. Please note: The Institute cannot make negotiations for individual housing off campus.

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 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. Health services available to graduate students are explained in Section II.

The International Desk. The International Desk, 14 Dabney Hall, 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 under 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, tuition scholarships, and graduate assistantships. In general, tuition scholarships may be for full or partial tuition charges; assistantships provide cash stipends; and fellowships often provide both tuition scholarship awards and stipends. Graduate assistants are eligible to be considered for Special Tuition Awards.

A request for financial assistance is included on the application for admission to graduate standing. These applications should reach the 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. Application should be made to the Graduate Office.

Graduate Assistantships

Graduate assistants help with teaching, laboratory work, or research of a character that affords them useful experience. Teaching assistantships are for 12 or 15 hours per week during the academic year devoted to preparation, grading, and consulting with students. Laboratory assistantships and research assistantships usually are for 15 hours per week, sometimes up to 20 hours per week, during the academic year and 30 hours per week during the summer. Combined teaching and research assistantships are possible. Assistantships ordinarily permit carrying a full graduate residence schedule also.

Graduate Scholarships, Fellowships, and Research Funds

The Institute offers a number of endowed fellowships and scholarships for tuition and/or stipend to graduate students of exceptional ability who wish to pursue advanced study and research. Funds have been endowed by the following gifts.

Earle C. Anthony Fellowships
Meridan Hunt Bennett Fellowships
Robert Roe and Nellie Canfield Blacker Fellowships
Norman Bridge Fellowship
Edith Newell Brown Scholarships
Theodore S. Brown Scholarships
Elmer West Clark Fellowships
Lucy Mason Clark Fellowship
Samuel H. and Dorothy Breed Clinedinst Scholarship
Ray G. Coates Scholarship
Francis J. Cole Fellowships
Continental Oil Company Fellowship
Albert and Kate Page Crutcher Fellowship
Caroline W. Dobbins Scholarships and Fellowships
Donald Wills Douglas Prize Fellowships
Alexander M. and Florence W. Drake Fellowship
Richard P. Feynman Fellowships
J. S. Fluor Graduate Fellowship
Henry Ford II Scholar Award
GALCIT Wind Tunnel Fellowships
Daniel and Florence Guggenheim Foundation Fellowships
Gulf Fellowship in Engineering and Applied Science
Beno Gutenberg Fellowships
Haagen-Smit/Tyler Environmental Fellowships
Robert H. Halpenny Memorial Fund
Clarence J. Hicks Memorial Fellowship
Albert Hall Hughey Scholarship
Saul Kaplun Fellowship

William N. Lacey Fellowship in Chemical Engineering
provided by the Union Oil Company Foundation
Henry Laws Scholarships and Fellowships
Smith and Louise Lee Memorial Fellowships
Robert L. Leonard Scholarship
Li Ming Memorial Scholarship
Howard J. Lucas Fellowship
Joseph F. Manildi Scholarship
The Helen G. and Arthur McCallum Fund
Clark B. Millikan Scholarships
Robert A. Millikan Fellowships
Blanche A. Mowrer Memorial Fund
David Lindley Murray Educational Fund
May McManus Oberholtz Scholarship
William G. Reed Graduate Fellowship
Frederick Roeser Loan, Scholarship and Research Fund
William E. Ross Memorial Scholarships
Eben G. Rutherford Fund
Bruce H. Sage Fellowship in Chemical Engineering
provided by the Union Oil Company Foundation
Virginia Steele Scott Fellowship
Evelyn Sharp Fellowship
Royal W. Sorensen Fellowship
Keith Spalding Memorial Scholarships
John Stager Stemple Memorial Fund
Van Maanen Fellowship
Laszlo Zechmeister Scholarship

Special Fellowships and Research Funds

In addition to the National Science Foundation, the Department of Health, Education, and Welfare, the Department of Energy, and the California State Graduate Fellowship program, gifts are received from the following donors to support graduate study.

American Vacuum Society
ARCS Foundation, Inc., Los Angeles Chapter
R. C. Baker Foundation
Borg-Warner Corporation
C F Braun & Co
California Foundation for Biochemical Research
California Institute Research Foundation
Corning Glass Works Foundation
Dean's Student Aid Fund
Josephine de Karman Trust
Eastman Kodak Company
Exxon Education Foundation
The General Electric Foundation
Lawrence A. Hanson Foundation
The John Randolph Haynes and Dora Haynes Foundation
Fannie and John Hertz Foundation
Hughes Aircraft Company
International Business Machines Corporation

William F. Marlar Memorial Foundation
Merck Company Foundation
Monsanto Company
Northrop Corporation
Jessie Smith Noyes Foundation, Inc.
Pickering-Link Foundation
Rockwell International
Gordon Ross Medical Foundation
Schlumberger Foundation
Jack J. Schoustra
Shell Companies Foundation
The Spencer Foundation
Standard Oil Company of California
Stauffer Chemical Company
John and Beverly Stauffer Foundation
The Upjohn Company
Thomas J. Watson Foundation
Weyerhaeuser Company Foundation
Xerox Corporation

A number of governmental units, industrial organizations, educational foundations, and private individuals have contributed funds for the support of fundamental research related to their interests and activities. These funds offer financial assistance to selected graduate students in the form of graduate research assistantships.

Bohnenblust Travel Grants in Mathematics

Special grants may be awarded to outstanding graduate students in mathematics to enable them to travel here or abroad to further their mathematical education. The Mathematics Department established these awards in 1978 to honor H. F. Bohnenblust, who served Caltech as Professor of Mathematics, Executive Officer for Mathematics, and Dean of Graduate Studies. Application forms and further details are available in the Mathematics Office, 253 Sloan.

The W. P. Carey & Co., Inc., Prize in Applied Mathematics

A prize of $500 will be awarded by a faculty committee in applied mathematics for an outstanding doctoral dissertation. All applied mathematics Ph.D. theses submitted during each 12-month period beginning June 1 will be considered, but the prize will not necessarily be given every year. This award has been made possible by gifts from William Polk Carey and from W. P. Carey & Co., Inc.

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 as well as making application for graduate study at the Institute. Those wishing to be considered for the JPL program should consult JPL and their option. In general such programs require some part-time employment during the academic year, as well as full-time work during the summer.

Loans

There are four sources of loans available to graduate students: Federal loans under the National Direct Student Loan (NDSL) program, loans under the Federal Insured Student Loan (FISL) program, loans from special funds of the California Institute of Technology, and UCB Tuition Loans. The amount of loans available from the programs of the federal government is limited by the appropriate government regulations. NDSL borrowers are subject to the same repayment terms and qualification requirements as outlined for undergraduate students on page 182. Loans from Institute funds normally may not exceed $2,500 per year. These loan funds are listed on page 182. Repayment terms, including interest rates, may be obtained from the Office of Student Accounts.

The terms and conditions of UCB Tuition Loans are outlined on page 183.

SPECIAL REGULATIONS OF THE GRADUATE OPTIONS

Aeronautics

Aims and Scope of Graduate Study in Aeronautics

The Institute offers graduate programs in aeronautics leading to the degrees of Master of Science, Aeronautical Engineer, or Doctor of Philosophy. The programs are designed to provide intense training in the foundations of the aeronautical sciences with emphasis on research and the experimental method. Entering graduate students should have a thorough background in undergraduate mathematics, physics, and engineering science. Applicants for graduate study should submit Graduate Record Examination scores with their applications.

Physics of Fluids	Aeronautical Engineering and Propulsion
Technical Fluid Mechanics	Aero Acoustics
Structural Mechanics	
Mechanics of Fracture	

While research and course work in aeronautics at the Institute cover a very broad range of subjects, a choice of one of the above fields allows students to specialize in their own interests while still taking advantage of the flexibility offered by the breadth of interests of the aeronautics group. A student with an interest in energy-related subjects will find many courses and research projects of particular use. Subjects of major importance in the efficient use of energy in transportation and power production, such as turbulent mixing, drag reduction, and lightweight structures, have historically been the focus of research activity in the aeronautics option.

A student and his or her adviser may design a program of study in one of the above fields consisting of the fundamental courses prescribed in the regulations for the separate degrees listed below and of electives selected from the list of aeronautics courses. Special attention is called to the list of one-term courses, numbered Ae 210 or higher, that are offered each year to interested students.

Degree of Master of Science in Aeronautics

Admission. Students with a baccalaureate degree equivalent to that given by the Institute are eligible for admission to work toward the Master's Degree in Aeronautics.

Course Requirements. 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 a proposed program approved by his or her adviser prior to registration for the first term of work toward the degree.

Degree of Aeronautical Engineer

The degree of Aeronautical Engineer is considered to be a terminal degree for the student who desires advanced training more highly specialized and with less emphasis on academic research than is appropriate to the degree of Ph.D.

Admission. Students with a baccalaureate degree equivalent to that given by the Institute or with a Master of Science degree are eligible for admission to work for the Engineer's degree.

Program Requirements. The degree of Aeronautical Engineer is awarded after satisfactory completion of at least 135 units of graduate work equivalent to the Master of Science program described above, plus at least 135 additional units of advanced graduate work. This latter program of study and research must consist of:

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 six terms of graduate residence beyond the baccalaureate degree (not counting summer registrations) except by permission after petition to the aeronautics faculty.

Degree of Doctor of Philosophy in Aeronautics

Admission. Students with a baccalaureate degree equivalent to that given by the Institute or with a Master of Science degree are eligible for admission to work for the Ph.D. degree.

Qualifying Examination. Before completing six terms of graduate residence after the baccalaureate degree (not counting summer registrations) and after completing at least 40 units of research in his or her chosen field, the student must satisfactorily pass a qualifying exam to determine whether he or she is qualified to pursue problems typical of Ph.D. work. Emphasis in the qualifying exam can be directed at a) establishing the student's ability to formulate research plans, b) determining the extent of the student's knowledge in his or her field of interest and c) determining the extent of the student's ability to use mathematical and physical principles for original work in the chosen discipline.

Candidacy. To be recommended for candidacy for the Ph.D. in aeronautics the applicant must have satisfactorily completed at least 135 units of graduate work equivalent to the above Master of Science program and, in addition, must pass with a grade of C or better:

a. 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

b. at least 45 units of aeronautics courses numbered Ae 200 or higher, excluding research and seminars
c. at least 54 units of courses outside of the applicant's chosen discipline, approved by the aeronautics faculty.

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.

Foreign Languages. The student is encouraged to discuss with his or her adviser the desirability of studying foreign languages.

Thesis and Final Examination. 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 the supervising committee. Not less than two weeks after the submission of the thesis rough drafts, the candidate is expected to give a seminar covering the results of his or her research, and this seminar will be followed by a thesis examination by the supervising committee. The seminar should be given as early as possible, but not later than two months before the degree is to be conferred.

Subject Minor in Aeronautics

A student majoring in a field other than aeronautics may, with the approval of the aeronautics faculty, elect aeronautics as a subject minor. A minimum of 54 units in subjects acceptable to the aeronautics faculty is required, and the student must be examined orally by a representative of the aeronautics faculty.

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 interest 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 or her in mapping out a course of study. The work of the student during the first year will usually include some independent reading and/or research.

Categories of Courses

Courses that are expected to form a large part of the student's program are divided into three categories as follows:

Group A. Courses in mathematics and mathematical methods. Examples of these would include: AMa 101, AMa 104, AMa 105, AMa 201, AMa 204, Ma 109, Ma 125, Ma 137, Ma 141, Ma 143, Ma 144.

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, AMa 151, AMa 152, AMa 153, AMa 181, AMa 220, AMa 251, AMa 260.

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 normally admitted for the Ph.D. program. The master's degree may be awarded in exceptional cases. Of the 135 units of graduate work required by Institute regulations, at least 81 units of advanced graduate work should be in applied mathematics.

Degree of Doctor of Philosophy in Applied Mathematics

The Oral Candidacy Examination. In order to be recommended for candidacy the student must, in addition to satisfying the general Institute requirements, pass an oral candidacy examination. 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 any independent study carried out by the student during his or her first graduate year.

Further Requirements. In order to be recommended for the Ph.D. in applied mathematics, the student must do satisfactory work in a program containing at least 45 units of work in courses of the type indicated in Group A, and at least 45 units of courses chosen from Groups B and C. This is intended to prevent undue specialization in either the more mathematical or the more engineering type of courses.

Submission of Thesis. On or before the first Monday in April of the year in which the degree is to be conferred, a candidate for the degree of Ph.D. in applied mathematics must deliver a typewritten or printed copy of the completed thesis to his or her research supervisor.

Final Examination. The final oral examination 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. However, 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 of graduate-level courses (numbers 100 and above) must be selected from courses in AM, AMa, Ae, Hy, JP, CE and ME 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 108 units of advanced courses arranged by the student in conference with his or her adviser and approved by the faculty in applied mechanics. If the student chooses to take a subject minor, the units thereof may be included in the total of 108, subject to the approval of 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 a minor;
d. pass an oral examination on the major subject, and, if the student has a minor, examination on the subject of that program may be included at the request of the discipline offering the minor.

Language Requirements. The student is encouraged to discuss with his or her adviser the desirability of taking foreign languages, which may be included in a minor with 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 or her specialized field of research.

Subject Minor in Applied Mechanics

A student majoring in another branch of engineering, or another division of the Institute, may elect applied mechanics as a subject minor, with the approval of the faculty in applied mechanics and the faculty in his or her major field. The group of courses shall differ markedly from the major subject of study or research, and shall consist of at least 54 units of advanced work. The student shall be examined orally and separately from the examination in the student's major.

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 or her in a technological context. Graduate study in applied physics should therefore cover considerable ground with the least possible loss of depth. Independent and original research is essential, but not for the purpose of acquiring advanced knowledge in a narrow specialty. In the rapidly changing technology of today an applied physicist should not expect to remain precisely within the field of thesis research; instead through research he or she 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

Of the 135 units required for this degree, at least 54 units must be selected from APh 114, Ch 125 or Ph 125, APh 105, Ae/APh 101, and APh 156. Topics in Applied Physics, APh 110 abc, is required. The remaining portion of the 135 units is to be made up from electives approved by the option representative.

Suggested electives include: APh 105, APh 114, Ae/APh 101, APh/MS 126, APh 140, APh 153, APh 156, APh 161, APh 181, APh 190, APh 200, Ph 125, Ph 129, AMa 101, AMa 104, AMa 105, AM 135, ChE 103, ChE 165, Ch 113, Ch 120, Ch 125, Ge 104, Ge 154, Ge 166. As a result of consultation with his or her adviser, a student may be required to take AM 113 abc, depending on his or her previous experience.

Degree of Doctor of Philosophy in Applied Physics

Candidacy. To be recommended for candidacy for the doctor's degree the applicant must satisfy the requirements listed below:

a. Competence must be demonstrated in the following subjects, at the levels indicated.
1. Classical Physics: Mechanics and Electromagnetism
   course level: Ph 106 or APh 106
2. Quantum Mechanics
   course level: 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, Ae/APh 101, or APh 156

Competence in *each* of these subjects must be demonstrated either by successfully completing an appropriate Caltech course with a grade no lower than C or, with the exception of number 3, by taking an oral examination over the subject matter. Separate examinations will be given on each area.

b. Oral candidacy examination. The student will prepare a brief presentation on a topic agreed upon by the student and the student's proposed thesis research adviser, normally the projected research topic. The candidacy examination will be based upon the student's background in applied physics and its relation to this presentation.

The oral examination will be given only after the student has demonstrated competence in the five areas and must be completed before the close of the student's second year of residency.

c. Competence in research must be demonstrated as follows: The student must have a doctoral thesis adviser and must have completed 18 units of research with this adviser no later than the beginning of the student's third year of residence.

The Minor. By its nature, applied physics spans a variety of disciplines and the major requirement reflects this. A minor is *not* required of students majoring in applied physics. They are, however, encouraged to take advanced courses appropriate to their particular interests.

Thesis and Final Examination. The candidate is required to take a final oral examination covering his or her doctoral thesis, its significance and relation to his or her major field. This final examination will be given not less than two weeks after the doctoral thesis has been presented in final form, and prior to its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted.

Subject Minor in Applied Physics

Graduate students electing a subject minor in applied physics must complete 54 units of graduate courses in applied physics. The courses may be selected from any of the applied physics courses with numbers *greater than* 100, excluding APh 110 and APh 200.

The student's proposed program must be approved by the Applied Physics Graduate Studies Committee. The committee will examine the course program to determine which of the following areas of interest in applied physics it includes:

Group A: Ae/APh 101, APh 156, APh 161.
Group B: APh 105, APh 114, APh 140, APh 181, APh 214.
Group C: APh 153, APh 190, APh 195.

It is recommended that the program include courses from more than one of the above areas.

The Applied Physics Graduate Studies Committee may recommend an oral examination based upon its evaluation of the course program. When the program includes more than one of the above areas of interest, then an oral examination may not be required.

Astronomy

Admission

All applicants for admission to graduate study in astronomy, including those from foreign countries, are required to 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 Examination in physics (see Placement Examinations, page 265) 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 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 programs. Students in planetary physics may substitute appropriate advanced courses in geophysics and geochemistry. All the above courses must be passed with a grade of C or better.

The Minor: It is recommended that students take a subject minor in physics. Other fields in which subject minors are taken include geology or engineering, depending on the student's field of specialization.

Language Requirement: To be admitted to candidacy for the Ph.D. degree in astronomy, the student must demonstrate a knowledge of Russian, German, Spanish, or French sufficient for the reading of technical material in his or her 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 a written examination (see below);
d. pass an oral examination (see below);
e. fulfill the language requirement (see above); and
f. be accepted for thesis research by a staff member.

Students in radio astronomy may omit Ay 131. Theoretical astrophysics students may omit Ay 133 a; 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 written examination will be given in October of the second year. It will cover the material from the required astronomy courses and will consist of two three-hour papers. The oral examination must be taken before the end of the first term of the third year. It will cover matters related to the subject of the candidate's proposed thesis. Special permission will be required for further registration if the candidacy course requirements and the written and oral examinations are not satisfactorily completed by the end of the third year of graduate work.

Final Examination: A final draft of the thesis must be submitted at least six weeks before the commencement at which the degree is to be conferred. At least two weeks after submission of the thesis, the student will be examined orally on the scope of his or her thesis and its relation to current research in astronomy.

Subject Minor in Astronomy

The program for a subject minor in astronomy must be approved by the department before admission to candidacy. In addition to general Institute requirements, the student must complete satisfactorily, with a grade of C or better, 45 units in advanced courses in astronomy.

Biology

Aims and Scope of Graduate Study in Biology

Graduate students in biology come with very diverse undergraduate preparation—majors in physics, chemistry, mathematics, or psychology, as well as in biology and its various branches. The aims of the graduate program are to provide, for each student, individual depth of experience and competence in a particular chosen major specialty; perception of the nature and logic of biology as a whole; sufficient strength in basic science to allow continued self-education after formal training has been completed and thus to keep in the forefront of changing fields; and the motivation to serve his or her field productively through a long career. In accordance with these aims, the graduate study program in biology includes the following parts: (a) the major program, which is to provide the student with early and intense original research experience in a self-selected subject of biology, supplemented with advanced course work and independent study in this subject; (b) an optional minor program, usually designed to provide the student with professional insight into a subject outside the 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 designed to provide a well-rounded and integrated training in biology and the appropriate basic sciences, and adjusted to special interests and needs. (b) and (c) may include supervised, independent study. An individual program will be recommended to each student in a meeting with the student's advisory committee (see below). A student majoring in psychobiology may arrange to do one or more terms on another campus to obtain relevant course work in psychology and medicine not offered at the Institute. The Division of Biology does not encourage applications from students who have pursued undergraduate study in biology at the Institute, because the broader perspective to be gained from graduate study in a different setting is considered to be essential for the full development of each student's potential. Exceptions to this policy may be considered by the faculty of the division if there are circumstances, such as completion of an advanced degree at another institution, which indicate that it would be in the best interests of a student to pursue graduate study at the Institute.

Admission

Applicants are expected to meet the following minimal requirements: mathematics through calculus, general physics, organic chemistry, physical chemistry (or the equivalent), and elementary biology. Students with deficient preparation in one or more of these categories may be admitted but required to remedy their deficiencies in the first years of graduate training, 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.

When feasible, visits to the campus for personal interviews will be arranged before a final decision for admission is made. Graduate Record Examinations (verbal, quantitative, and an advanced test in *any* science) are required of applicants for graduate admission intending to major in biology. Applicants are encouraged to take these examinations and request that the scores be transmitted to Caltech, in November or earlier, to ensure unhurried consideration of their applications.

Advisory Committees

An advisory committee will be constituted for each student, to provide consultation and advice throughout the period of study until admission to candidacy. Each advisory committee will consist of three or four faculty members, including a student's current research supervisor and at least one member of the Graduate Admissions Committee who will serve as chairman of the advisory committee. The composition of the committee will be adjusted as necessary if the student changes research supervisors or areas of interest. Each student meets with his or her advisory committee at the time of beginning work in the division to formulate a plan of study, again in the third term of the first year of study to discuss progress and subsequent plans, and at other times when problems arise or advice is needed.

Teaching Requirements for Graduate Students

All students must acquire teaching experience.

Master's Degree in Biology

The Biology Division does not admit students for work toward the M.S. degree. In special circumstances the M.S. degree may be awarded, provided Institute requirements are met. In general the degree is not conferred until the end of the second year of residence. The degree does not designate any of the disciplines of the division, but is an M.S. in Biology.

Degree of Doctor of Philosophy in Biology

Major Subjects of Specialization. A student may pursue major work leading to the doctoral degree in any of the following subjects:

Biophysics	Immunology
Cell Biology	Molecular Biology
Developmental Biology	Neurobiology
Genetics	Psychobiology

At graduation, a student may choose if the degree is to be awarded in biology or in the selected subject. If the award is to be in biology, a minor will be designated only if it is from another division of the Institute.

Minor Subjects. The Division of Biology does not have a requirement for a minor, but encourages students to undertake work outside of their major subject. Recognition of such work on a student's diploma requires completion of a formal minor program, which usually consists of 45 units of advanced course work or research, either in another division of the Institute in accordance with the regulations of that division, or in one of the major subjects of specialization in biology that is not closely related to a student's major field. Students should consult with their advisory committee in planning such a program.

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 an ability to carry out original research and have passed, with a grade of B or better, the candidacy examination in the major.

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 the major 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 minor (if any). The thesis committee will meet with the student soon after admission to candidacy and at intervals thereafter to review the progress of the thesis program. This committee will, with the approval of the Dean of Graduate Studies, also serve as the thesis examination committee (see below).

Thesis and Final Examination. Two weeks after copies of the thesis are provided to the examination committee, the candidate collects the copies and comments for correction. At this time, the date for the final examination is set at the discretion of the major professor and the division 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 for the Institute library. A third copy is required for the division library.

Minor in Biology

A student majoring in another division of the Institute may, with the approval of the Biology Division, elect a subject minor in any of the subjects listed above under major subjects of specialization. Requirements for such a minor are determined by the faculty committee designated for each subject. A minor program in biology is also available to students of other divisions. Such a program shall consist of 45 units of upper division course work in the Biology Division, each course passed with a grade of "C" or better. Approval of each program must be obtained from the Biology Graduate Advisory Committee. A student majoring in another division who elects a subject minor in biology may if desired arrange to have the minor designated as biology, rather than with the name of the specific minor subject.

Chemical Engineering

Aims and Scope of Graduate Study in Chemical Engineering

The Institute was one of the earliest schools to emphasize instruction on basic subjects rather than on specialized material relating primarily to particular industries or processes. 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, the division may prescribe additional work in these subjects before recommending him or her 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 engineering mathematics, AM 113 abc, if an equivalent course has not been taken previously. The M.S. requirements also include 36 units of advanced courses in chemical engineering, which should ordinarily constitute a coherent program of study, for example including ChE 173 ab, or ChE 164, 165, or ChE 161, 162. Other courses may be substituted upon approval by the chemical engineering faculty. In addition to the required courses, there are 45 units of electives, 18 units of which must be in science and engineering subjects and 27 units of which may include science and engineering subjects, humanities and social science subjects, or research. Finally, the M.S. requirements include at least 18 units of research, ChE 280, which represent two terms of research under the supervision of a chemical engineering faculty member or a two-term industrial research or development project performed with a member of the faculty in cooperation with professional staff at a local industrial laboratory. A research report must be submitted on the work performed under ChE 280 at least three weeks before the end of the final term of residence to a designated member of the faculty, who will ask that it be read and approved by three members of the faculty. A copy of each approved M.S. report will be kept in the chemical engineering library.

Degree of Doctor of Philosophy in Chemical Engineering

The work leading to the Ph.D. degree prepares students for careers in universities and in the research laboratories of industry and government, although Ph.D. graduates are also well qualified for the areas listed for the master's degree. Usually the first year of graduate work is principally devoted to course work in chemical engineering and related subjects. Time is also devoted during this period to the choice of a research project and to its initiation. During the second year the student is expected to spend at least half time on research, and to complete the course work and candidacy requirements. Some time is available for elective courses. It is expected that the research project will occupy full time during the third and subsequent years. If summers are spent on research and other academic pursuits, the Ph.D. requirements could 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.

Course Requirements. Although there are no formal chemical engineering course requirements, all Ph.D. students must take a selected number of courses outside of chemical engineering to provide both a broadening experience and an opportunity for obtaining further depth in the general thesis area. This requirement may be satisfied by completion of a subject minor in another option, or by completion of an integrated program of study, which normally consists of a total of 54 units (the equivalent of two one-year courses), and must be approved in advance by the Graduate Study Committee in chemical engineering. Generally, AM 113 will not be allowed, nor will research units from other options. A grade of C or better is required in any course that is to be included in the program.

Candidacy Requirements. To be recommended for candidacy the student must demonstrate proficiency at the graduate level in chemical engineering. This will be done by way of chemical engineering courses, an oral subject examination, which is to be taken at 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 or her research, to be submitted before the end of the third 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 or her second year of graduate residence at the Institute will not be allowed to register in a subsequent academic year except by special permission of the Division of Chemistry and Chemical Engineering.

Thesis and Final Examination. See page 226 for regulations concerning theses and final examinations. A copy of the corrected thesis is to be submitted to the chemical engineering graduate secretary for the chemical engineering library.

The final examination will be concerned with the candidate's oral presentation and defense of a brief resume of his or her research.

Subject Minor in Chemical Engineering

Graduate students electing a subject minor in chemical engineering must complete 45 units of graduate courses in chemical engineering that are approved by the chemical engineering faculty. In general, this program of courses should include ChE 173/174 or ChE 101/161/162 or ChE 164/165/169 or ChE 110/111. A grade of C or better is required for each course included in the program. In order to satisfy the requirements for a subject minor, the candidate must pass a short oral examination given by the department.

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 research problem that interests you, and begin research upon it early in the first year. You can elect to do research that crosses the boundaries of traditionally separate areas of chemistry, for in this relatively compact division, you are encouraged to go where your scientific curiosity drives you; you are not confined to a biochemical or physical or organic laboratory. A thesis that involves more than one adviser is not uncommon, and interdisciplinary programs with biology, physics, 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 chemical physics, organic chemistry, inorganic and electrochemistry, organometallic chemistry, and chemical biology. Graduate students are encouraged also to attend seminars in other divisions.

Placement Examination

During the week preceding registration for the first term of graduate study, students admitted to work for advanced degrees will be required to take a written placement examination in the fields of inorganic, organic, and physical chemistry and in chemical equilibrium. 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.

In the event that you fail to show satisfactory performance in any area of the placement examination, you will be required to complete satisfactorily a prescribed course, or courses, in order to correct the deficiency.

Course Program

For an advanced degree, no graduate courses in your principal area of research are 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.

Degree of Doctor of Philosophy in Chemistry

Candidacy. There is no formal course work required in your *major* field of interest (for minor requirements, see below). However, 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 before the examination.

The result of the candidacy examination may be either (a) pass, (b) fail, or (c) conditional. Conditional status is granted when the committee decides that deficiencies in a student's research report, propositions, or overall progress can be remedied in a specific and relatively brief period of time. In order to change conditional to pass status, you will have to correct the indicated 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 (nor can financial assistance be continued) past the end of the sixth term of residence without being admitted to candidacy, except by petitioning the division for special permission. This permission, to be requested by a petition submitted to the divisional graduate studies committee stating a proposed timetable for correction of deficiencies, must be submitted before registration for each subsequent term (including the summer following the sixth term of residence) until admission to candidacy is achieved.

Language 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* foreign language: French, German, or Russian. This demonstration can be by test, by good performance in a course at Caltech, or by sufficient undergraduate course work in the language.

The Minor. In order to provide breadth in your graduate experience, you are required either to (a) complete a subject minor in another option (the requirements being set by that option) or (b) complete an approved program of course work outside your principal area of research. This program consists of at least 36 units of course work (the equivalent of approximately four standard one-term courses) outside the scientific area in which your dissertation research is performed (exclusive of courses taken in fulfillment of the chemistry language requirement). These courses may be either inside or outside the chemistry option. Courses for the minor shall be taken on a letter grade basis unless the course is offered with only a pass/fail option. A grade of C or better is required for credit toward the minor. Your adviser has the responsibility of determining which courses fulfill the requirement in your particular case, subject to final approval by the chemistry graduate studies committee.

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 before 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 in other options taking chemistry as a subject minor will be assigned a faculty adviser in chemistry by the chemistry graduate studies committee. In consultation with this adviser, the student will work out an integrated program of courses, including at least 45 units of formal course work at the 100 level or above. This program must be approved by the chemistry graduate studies committee, and a grade of C or better in each course in the approved program will be required.

Civil Engineering

Aims and Scope of Graduate Study in Civil Engineering

Students who have not specialized in civil engineering as undergraduates, as well as those who have, may be admitted for graduate study. As preparation for advanced study and research, a good four-year undergraduate program in mathematics and the sciences may be substituted for a four-year undergraduate engineering course with the approval of the faculty. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his or her program in consultation with a member of the faculty. In some cases the student may be required to make up deficiencies in engineering science courses at the undergraduate level. However, in every case the student will be urged to take some courses that will broaden an understanding of the overall field of civil engineering, as well as courses in his or her specialty. Most graduate students are also required to take further work in 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 and 108 units (minimum) of graduate level courses (numbers 100 and above) from at least three of the five general subject areas of structures and solid mechanics, soil mechanics, hydraulics and water resources, environmental engineering science, and mathematics. Students who have not had AMa 95 abc or its equivalent will be required to include AM 113 abc in their program. The faculty encourages students to take 27 units in the humanities and social sciences.

Degree of Civil Engineer

Greater specialization is provided by work for the engineer's degree than for the master's. The candidate for this degree is allowed wide latitude in selecting his or her program of study, and is encouraged to elect related course work of advanced nature in the basic sciences. The degree of Civil Engineer is considered to be a terminal degree for the student who desires advanced training more highly specialized and with less emphasis on research than is appropriate to the degree of Doctor of Philosophy. However, research leading to a thesis is required for both degrees. The student should refer to Institute requirements for the engineer's degree.

Degree of Doctor of Philosophy in Civil Engineering

Upon admission to work toward the Ph.D. degree in civil engineering, a counseling committee of three members of the faculty is appointed to advise the student on his or her 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.

Course Requirements. A student must complete at least 108 units of advanced courses, arranged in conference with his or her adviser and approved by the faculty in civil engineering. Students are expected to take not less than 45 units of work in subjects, other than the required mathematics, not closely related to their thesis research. If a student elects to take a subject minor, the units so taken may be included in the total 108, and shall be subject to the approval of the faculty in civil engineering.

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 in consultation with his or her advisory committee, and approved by the faculty in 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 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 graduate residence in which he or she will be expected to demonstrate an understanding of the major field of interest;

b. a discussion of a brief research report describing accomplishments to date, including reading, study, and plans for future research. The student must present the report to the examining committee at least ten days before the examination.

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; 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.

Subject Minor in Civil Engineering

A student majoring in another branch of engineering, or in another division of the Institute, may, with the approval of the faculty in civil engineering, elect civil engineering as a subject minor. At least 54 units of approved courses must be taken, and an oral examination must be passed.

Computer Science

Master's Degree in Computer Science

There are five general requirements to fulfill for an M.S. in computer science.

1. *Units outside immediate area of interest.* Of the 135 units of advanced work (courses numbered 100 or greater) required for the M.S., 27 must be outside the student's major area of interest. Neither computer science (CS) courses nor courses in closely related fields in other departments can be counted.
2. *B.S. equivalent preparation.* As part of the degree requirements, M.S. students should demonstrate competence in four of the following areas: (a) theory, (b) hardware, (c) systems, (d) software, and (e) applications. Competence can be demonstrated by passing the appropriate course offered at Caltech or by suitable undergraduate preparation.
3. *Advanced work in computer science.* M.S. students must pass at least 54 units of advanced CS courses in addition to units earned for reading, research, project, and the M.S. thesis.
4. *Hardware course work.* Of the 54 units mentioned above, at least 9 must be in hardware-related courses, including CS 181, CS 286, CS/EE 11 or related courses offered by the electrical engineering or applied physics faculties.
5. *M.S. thesis.* Completion of an M.S. thesis, acceptable to the computer science faculty, is required for the M.S. degree.

Completion of a total of 135 units is required for the M.S. degree; a typical course is 9 units per term, and a typical program of 45 units/term is outlined below.

First term	*Second and third terms*
CS courses: 27 units	CS courses; 18 units
Elective: 9 units	Elective: 9 units
M.S. thesis project: 9 units	M.S. thesis project: 18 units

Degree of Doctor of Philosophy in Computer Science

All first year Ph.D. students are required to complete the M.S. program, or its equivalent.

Candidacy. To be admitted to candidacy, a student must have completed the M.S. program or its equivalent, have entered upon a course of research approved by his or her thesis adviser, and have passed a candidacy oral examination on his or her major subject.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his or her specialized fields of research.

Subject Minor in Computer Science

A subject minor is not required for the Ph.D. degree in computer science; however, students majoring in other fields may take a subject minor in computer science provided the program consists of 45 units sufficiently removed from their major program of study.

Electrical Engineering

Aims and Scope of Graduate Study in Electrical Engineering

The Bachelor of Science degree may be followed by graduate study leading either to the Master of Science degree in Electrical Engineering, usually completed in one year, or the more advanced degrees of Electrical Engineer or Doctor of Philosophy, usually completed in three to five years. The doctoral candidate may first obtain the Master of Science degree or may enter directly into studies for the degree of Doctor of Philosophy. In judging admission for the Ph.D. degree, the EE faculty places particular emphasis on any evidence of future research potential. The graduate curriculum is flexible. Students participate in graduate seminars and in research projects.

Placement Examination

Students admitted to work toward any advanced degree 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 abc, for which graduate credit will be received. Notices of the placement examination are sent well in advance of the examination date.

Master's Degree in Electrical Engineering

Of the 135 units required for this degree, a minimum of 99 units are required from the following list of courses: CS/EE 121, EE 112, EE 114, EE 116, EE 117, CS/EE 119, EE 151, EE 155, EE 160, EE 163, EE 165, CS/EE 181, EE 182, CS/EE 183, EE 194, EE 291[1], APh 105, APh 114, APh 140, APh 153, APh 156, APh 181, APh 190, APh 195, APh 214, APh 281, Ph 125, Ph 209, AM 125, CS 112, CS 114, CS 116, CS 137, CS 138, CS 139, BIS 240, AMa 101, AMa 104, AMa 105, AMa 153, AMa 181, Ch 125.

Other electives may be substituted upon approval of the electrical engineering faculty. E 150 abc, Engineering Seminar, is required. Students are urged to consider including a humanities course in the remaining free electives.

The attention of students interested in energy-related studies is drawn to EE 114 abc, Electronic Circuit Design; EE 117, Power Electronics; EE 291, Advanced Work in Electrical Engineering (in the Power Electronics Laboratory); ME 102 abc, Principles of Energy Conversion and Distribution; and to additional courses listed under other engineering options.

[1]Not more than 21 units may be used toward the total of 99 units.

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. A student may apply for admission to work directly for the degree of Doctor of Philosophy, or he or she may first enroll in study for the Master of Science degree and later apply for admission. This application will be judged in part on the academic performance during B.S. or M.S. studies, but great weight will be given to his or her future research potential. New Ph.D. students, and M.S. students who wish to transfer to Ph.D. studies, are required to make an oral presentation to a faculty committee at the beginning of the second term.

Candidacy. To be recommended for candidacy for the doctor's degree the applicant must satisfy the following requirements:

a. Complete 18 units of research in his or her field of interest.
b. Obtain approval of a course of study consisting of at least 189 units of advanced courses in electrical engineering or the related subjects listed under the Master's Degree, except that units in research (e.g., EE 191 and 291) may not be counted in this total. The course taken to satisfy requirement (c) may be included in this total. Courses taken to fulfill the requirements for the Master of Science degree may be included also.
c. Pass one of the following subjects with no grade lower than C: AMa 101 abc, AM 125 abc, Ma 108 abc, Ph 129 abc. An applicant may also satisfy any of the above course requirements by taking an examination in the subject with the instructor in charge. This examination will cover the whole of the course specified, and the student may not take it either in parts or more than twice.
d. Pass a qualifying oral examination covering broadly his or her major field and minor program of study. This examination is normally taken near the end of the second year of graduate study.

Thesis and Final Examination. The candidate is required to take a final oral examination covering the doctoral thesis and its significance in and its relation to his or her major field. This final examination will be given not less than two weeks after the doctoral thesis has been presented in final form, and before its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted.

Subject Minor in Electrical Engineering

A student majoring in another option at the Institute may elect a subject minor in electrical engineering. He or she must obtain approval from the electrical engineering faculty of a course of study containing at least 45 units of advanced courses with an EE listing (excluding EE 191 and 291). In addition, an oral examination is required, normally taken following completion of the course of study.

Engineering Science

Aims and Scope of Graduate Study in Engineering Science

The Engineering Science option at Caltech is designed for students of subjects that form the core of the new "interdisciplinary" sciences. These branches of science provide the basis for modern technology. Students may choose physics and applied mathematics as their minor subjects and choose a thesis adviser within the Division of Engineering and Applied Science.

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 bioinformation systems 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 of Applied Mathematics I; AM 125 abc, Engineering Mathematical Principles; or Ph 129 abc, Methods of Mathematical Physics. Students emphasizing bioinformation systems should refer to different requirements given below.

A minimum of 54 units of courses must have the approval of the student's adviser and the faculty in engineering science.

Degree of Doctor of Philosophy in Engineering Science

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 or her 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. This requirement shall be in addition to requirement (b) above, and shall not be counted toward any minor requirements. Students emphasizing bioinformation systems should refer to different requirements given below.

Language Requirements. Students are encouraged to discuss with their advisers the desirability of taking foreign languages. Foreign languages are not required.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidates' knowledge in their specialized fields of research.

Subject Minor in Engineering Science

A subject minor is not required for the Ph.D. degree in engineering science; however, students majoring in other fields may take a subject minor in engineering science provided the program consists of 45 units sufficiently far removed from their major program of study and is approved by the appropriate faculty group and by the option representative.

Master's Degree in Engineering Science with Emphasis on Bioinformation Systems

See description on page 138. M.S. degrees are given in this area under the option of Engineering Science. A minimum of 54 units must be selected from applied mathematics, computer science, and biology courses, as approved by the faculty in bioinformation systems.

Degree of Doctor of Philosophy in Engineering Science with Emphasis on Bioinformation Systems

See description on page 138. Ph.D. degrees are given in this area under the option of Engineering Science.

Course Requirements. To be recommended for candidacy for the Ph.D. degree in engineering science with emphasis on bioinformation systems, 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 or her adviser and approved by the faculty in bioinformation systems;
c. students in bioinformation systems are required to take at least an additional 27 units of advanced mathematics as approved by the faculty in bioinformation systems.

Other requirements are the same as listed under Engineering Science above.

Environmental Engineering Science

Aims and Scope of Graduate Study in Environmental Engineering Science

Environmental problems cut across many disciplines. Graduate study in environmental engineering science emphasizes environmental problem areas and the application of information from several fields in achieving solutions. Opportunities for interactions among several branches of engineering, science, and social science are numerous.

In selecting courses and research topics, each student is advised to plan for both breadth of study of the environment and depth of understanding in a particular subject area. The curriculum has been developed primarily for students pursuing the Ph.D. degree. The purpose of the Ph.D. program is to prepare students for careers of specialized research, advanced engineering, planning, and management in various aspects of the environment including, for example, environment-energy relationships. The M.S. degree is also offered for students who plan careers in engineering, planning, or management in some aspect of environmental engineering. Although all graduate students are encouraged to develop a wide awareness of the range of environmental problems, the environmental engineering science program is not designed to train environmental generalists.

Admission

Students with a bachelor's degree in engineering, science, or mathematics may apply for admission to work for either the M.S. or Ph.D. degree. Programs of study are arranged individually by each student in consultation with a faculty adviser. In some instances a student may need to take additional undergraduate courses in preparation for graduate work in this field.

Master's Degree in Environmental Engineering Science

For the M.S. degree a minimum of 135 units of work in advanced courses is required. Each student selects a program with the approval of a faculty adviser. The program should be well balanced, with courses in several areas of concentration to avoid too narrow specialization.

The program must contain at least 63 units of electives chosen from *Group A* below, including 3 units of Seminar (Env 150 abc), plus at least 45 units chosen from *Group B*. The remaining units are for free electives of any graduate courses at the Institute. Students who have not had AMa 95 abc or its equivalent are required to include AM 113 abc as part of their *Group B* or free elective units.

Group A. Env/Ge 103, Env 112 abc, Env 116, Env 142 ab, Env 143, Env 144, Env 145 ab, Env 146 ab, Env 150 abc, ChE/Env 157 abc.

Group B. Env 100, Env 200, Env/Ge 203 abc, Env 206, Env 214 abc, Env 250, Env 300, AMa 101 abc, AMa 104, AMa 105ab, AMa 181 abc, AM 113 abc, AM 125 abc, Bi/Ch 110 ab, Bi/Ch 132 abc, Bi 111, Ch 117, Ch 118 ab, ChE 101 ab, ChE 103 abc, ChE 162, ChE/Ch 164, ChE 165 ab, Ae/ChE 172 abc, ChE 173 ab, CE 115 ab, Ec 115, Ec 118, Ec 122 ab, Ec 128 abc, Ge 111 ab, Ge 130, Ge 137 ab, Ge 244 ab, Hy 101 abc, Hy 103 ab, Hy 111, Hy 113 ab, Hy 121, Hy 213, CS/SS 142 abc, SS 130 abc, SS 132, SS 150 abc, SS 222 ab.

Degree of Doctor of Philosophy in Environmental Engineering Science

Upon admission to work toward the Ph.D. degree in environmental engineering science, a faculty adviser is appointed to assist the student in the design of an academic program. The faculty adviser will act as chairman of the three-member counseling committee appointed for each student. The student chooses a thesis adviser at a time when his or her major research interest has become clearly defined.

The program of courses for the Ph.D. should be designed to meet the student's need in preparation for research, to provide depth in the major area, and to give breadth of outlook. Each Ph.D. program must receive the approval of the environmental engineering science faculty, upon the recommendation of the faculty adviser and the counseling committee. Students should submit their schedule of courses for the Ph.D. to the faculty for approval early in the first year of enrollment.

Major Areas of Specialization. Students may do major study in the following areas: air pollution control, aerosol physics and chemistry, water quality control, aquatic chemistry, marine ecology, environmental fluid mechanics, water resources, environmental health engineering, hydraulic engineering, coastal engineering, environmental economics, and systems analysis.

Course Requirements. A student is expected to complete at least 135 units of advanced courses in addition to the units required to satisfy the minor program requirement and the advanced mathematics requirement. At least 45 of these units should represent work in science or engineering beyond that encountered in introductory courses in the student's immediate area of specialization.

Minor Program Requirements. The purpose of the minor program is to broaden the student's outlook by acquaintance with subject matter outside the major field. Each student is expected to elect a *subject minor* of at least 45 units. The subject minor requires the approval of the minor option and of the EES faculty. Under exceptional circumstances, the EES faculty may approve an alternative minor program of 45 or more units comprising two or three closely related courses offered by two divisions or options, provided that the program has coherence.

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 the program of advanced courses as arranged in consultation with the 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 a candidacy examination on the major subject.

The candidacy examination will be in two parts. Part A must be passed before registration day of the *spring* quarter of the *second* year of graduate study, except that for students entering with an M.S. (or equivalent) the time limit is registration day of the *spring* quarter of the *first* year of their graduate study at Caltech. Part A of the examination will take the form of a review of the student's scholastic record, and may require the student to provide an oral defense of his or her preparation to be admitted to candidacy for the Ph.D.

Part B of the examination must be passed before registration day of the *winter* quarter of the *third* year of graduate study, except that for students entering with an M.S. (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 discussion of a brief written research report provided by the student to the examining committee at least ten days before the examination. The report will describe accomplishments to date, including reading, study, and plans for future research.

Thesis and Final Examination. Copies of the completed thesis must be provided to the examining committee two weeks before the examination. The final oral examination covers principally the work of the thesis and, according to Institute regulations, must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate, one of which is deposited in the Institute library and one 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 a proposed minor program to the option representative for approval. The proposed program must consist of 45 or more units in EES courses or in closely related courses of other options. Upon completion of these courses the student must pass an oral examination.

Geological and Planetary Sciences

Aims and Scope of Graduate Study

Graduate students in the Division of Geological and Planetary Sciences enter with very diverse undergraduate preparation—majors in 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 students a depth of competence and experience in their major field, sufficient strength in the basic sciences to allow them to continue self-education after their formal training has been completed, and the motivation and training to keep them in the forefront of their field through a long and productive career.

Graduate Record Examination Test Scores

All North American applicants for admission to graduate study in the Division of 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 very 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 the first term of graduate work, students will be required to take placement examinations covering basic aspects of the earth sciences and including elementary physics, mathematics, and chemistry. These examinations will be used to determine the students' understanding of basic scientific principles and ability to apply these principles to specific problems. It is not expected that they possess detailed informational knowledge, but it is expected that they demonstrate a degree of proficiency comparable to that attained by undergraduate students at Caltech. Students who have demonstrated proficiency in earlier residence at the Institute may be excused from these examinations. The past record and performance in the placement examinations will be used to determine whether the student 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 a particular field. All graduate students will be notified, prior to arrival, who their advisers will be, and prior to registration day they should seek the counsel of their advisers in planning a program for each term. Students can and should consult with other staff members concerning this program of study and research. It is the responsibility of the advisers to see that students register at the earliest possible time for the proper courses to fulfill the division requirements and to correct any deficiencies indicated by the placement exam. It is the responsibility of the students to seek and consider their advisers' advice. If students elect to do a Ph.D. thesis under their academic adviser, another staff member will then be appointed as their academic adviser, as distinct from the 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 Caltech undergraduate curriculum. 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. Students in geophysics or planetary science may petition the Academic Officer for permission to satisfy the basic division requirement for the Ph.D. program in place of the undergraduate petrology and field geology requirement. The Institute requires a year of residence and a total of 135 graduate units for a Master's degree. These 135 units of courses numbered over 100 may include as many as 27 units of courses required in the appropriate undergraduate option and may include as many as 27 units of humanities or other 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 that will be termed the "major subject" of the candidate. The division will accept as major subjects the disciplines listed herewith.

Geology and Geobiology	Geophysics
Geochemistry	Planetary Science

Admission to Candidacy. Students may be admitted to candidacy for the Ph.D. degree by vote of the division staff upon meeting the following requirements.

a. Pass the qualifying examination.
b. Satisfy minimum course requirements in their major and minor subjects.
c. Satisfy the language and oral presentation requirements.
d. Satisfy their academic and thesis advisers that their course work has prepared them to undertake research in their major subject.
e. Be accepted for thesis research by a division staff member.

Students 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. Subsequent to completion of the preliminary qualifying examination, the Ph.D. program of each student will be monitored by the faculty of one of the four major subjects within the division. All students must choose one of these options during their second year. The faculty of each option will formally review each year the progress of the students in the option; students may be asked to present to the faculty their research work and other evidences of progress. For students in their sixth year of graduate residence (or fifth year beyond the M.S.) such a presentation and review is specifically required before the faculty may vote to continue to award financial aid, for at most one additional year. The option representatives have the responsibility to organize these reviews and to make recommendations to the full division faculty, which may deny permission to continue in the Ph.D. program for any student showing inadequate progress. For a student who has passed the Ph.D. preliminary qualifying examination, permission to continue toward the Ph.D. degree may be withdrawn only upon action of the division as a whole.

Qualifying Examination. This examination will consist of the oral defense of three propositions, 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. Students have the privilege of consultation and discussion with various staff members concerning their 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 the student's background in the earth sciences and allied fields, and his or her capabilities in applying scientific principles to the solution of specific problems. The ideal candidate will display originality and imagination as well as scholarship.

All first-year students must submit to the Core Committee by May 15 a preliminary status report of their choice of proposition topics. The statement should be as specific as possible, and should preferably give the specific titles of propositions already formulated. The Core Committee will review the preliminary status report for the required breadth, scope, and substance and will make appropriate recommendations. Final propositions must be submitted to the division office at least one week before registration day of the fourth 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 the 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 101 abc is specifically required and should be taken during the first year. Ge 104 abc, Ge 105 ab, and Ge 160 are especially recommended as part of these courses. Students may be exempted from one or more quarters of Ge 101 by the instructor and the Academic Officer on the basis of previous work taken. Where appropriate these 45 units may be counted 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. Throughout their graduate work students are expected to participate in departmental seminars and in seminar courses led by distinguished visitors.

Geology and Geobiology: In addition to the general Institute and basic division requirements, candidates 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 their major field, but excluding languages, research and reading courses, and certain courses constituting basic preparation in their field as follows: Ma 1, Ma 2, Ph 1, Ph 2, Ch 1, Ge 104, Ge 105, Ge 107, Ge 114, Ge 115, Ge 123. 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; Ch 21 abc may be included as part of these units. 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.

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. 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 division; Ch 21 abc may be included as part of these units. 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 90 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, AMa/EE 161, EE 255. A minimum proficiency in basic mathematical methods at the level of Ph 129 or AMa 101 is required.

Group B. Courses in physics, applied physics, and chemical physics: Ph 106, Ph 125, AM 131, AM 141, APh 114, APh 214, Ph 127, Ph 205, Ph 236, MS 205, Ch 21, Ch 125. 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.

The recommended courses in these three categories are only representative of the required level, and substitutions may 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 90 unit requirement. Research and reading courses cannot be used to satisfy these requirements but are highly recommended as preparation for the oral qualifying examination.

Planetary Science: In addition to general Institute and basic division requirements, the candidate for a Ph.D. degree in planetary science shall acquire at least a minimum graduate background in each of three categories of course work: (1) The Earth Sciences, (2) Physics, Mathematics, Chemistry, and Astronomy, and (3) Planetary Science.

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 coincide with the basic division requirement. Reading and research courses may not be used, although students are expected to take such courses and to devote each summer to research in planetary science. Planetary Science Seminar (Ge 225 abc) is required each year for all planetary science students.

Students shall demonstrate professional competence in a second scientific field distinct from their specialization within planetary science. This may be accomplished either by: (1) satisfactory completion of a subject minor or (2) submission of publications that demonstrate an equivalent competence. 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, students are expected to meet the following schedule unless specific written waivers are obtained by them from the Academic Officer or planetary science option representative.

End of second 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 third 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 fourth academic year: completion of Ph.D. thesis.

Fifth academic year or beyond: satisfactory thesis progress required each quarter.

Minor Requirement. A minor is required in the planetary science option 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. A minor must be comprehensive enough to give students a fundamental knowledge of the field, and their diplomas and degrees will indicate both the major and minor fields. The division prefers that students take a subject minor in other divisions of the Institute, but students may take a subject minor within the division in a different field from their major.

Students taking a minor within the division must then demonstrate a competency in the minor field markedly exceeding that normally expected by their major fields and markedly exceeding the undergraduate requirements in the field. Such a minor will include at least 45 units, normally including one or more 200-level courses as well as the 100-level supporting courses.

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 sixth term of residence. Final approval will be given only after completion of all courses.

Assistant Professor of Geology Kerry Sieh studies the alluvial deposits near Palmdale, where he has discovered evidence for the history of movement of the San Andreas fault over the last 2000 years.

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 the 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.

Oral presentation (Ge 102) is required of all candidates for degrees in the division.

Thesis and Paper for Publication. Doctoral candidates must complete a thesis in their 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.

Candidates are expected to publish the major results of their 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 at least 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.

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 minor in any one of the major subjects listed above. Such a subject minor will include at least 45 units normally, including one or more 200-level courses as well as the 100-level supporting courses. Normally, a member of the division faculty will participate in the oral thesis defense.

History

The program for a subject minor in history must be approved by the department before the admission to candidacy. In addition to general Institute requirements, the student must complete satisfactorily, with a grade of C or better, 45 units in advanced courses in history.

Materials Science

Aims and Scope of Graduate Study in Materials Science

Students may enter the graduate program in materials science with undergraduate preparation in physics, chemistry, or engineering, as well as materials science. The program is designed to give the students a thorough grounding in areas fundamental to an understanding of materials properties, with strong emphasis on research in the areas of ongoing faculty work. This work includes studies of defects in crystals and the structure and properties of amorphous materials. Energy-related studies include radiation damage problems relevant to fast breeder and controlled thermonuclear reactor systems, and studies of amorphous and crystalline silicon relevant to solar cell technology.

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 or her 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 120	Kinetics of Crystal Imperfections (3-0-6)	9	.	.
MS 121	Solid-State Diffusion (3-0-6)	.	9	.
APh/MS 126 abc	The Electronic Structure of Metals and Alloys (3-0-6)	9	9	9
MS 130	Metallography and Pyrometry (0-6-3)	9	.	.
MS 131	Crystal Defects (1-6-2)	.	9	.
MS 132	X-Ray Metallography Laboratory (0-6-3)	.	.	9
	Electives (see below)	Minimum 60 for year		
	Total	Minimum 135 for year		

Electives

Students who have not had the equivalent of AMa 95 abc are required to take AM 113 abc in place of 36 of the elective units. They are encouraged to include a course in humanities or social sciences in their electives.

Technical electives that are particularly encouraged are additional courses in materials science: MS 105, and MS 205 ab; courses in mathematics, applied mathematics and applied mechanics: Ma 112 ab, AMa 101 abc, AMa 105 abc, AM 125 abc, AM 141 abc, AM 151 abc, AM 155; courses in applied physics: APh 105 abc, APh 114 abc, APh 153 abc, APh 161 abc, APh 181 abc; courses in physics: Ph 106 abc, Ph 125 abc, Ph 129 abc; courses in aeronautics: Ae/AM 102 abc, Ae 213, Ae 221; courses in mechanical engineering: ME 101 abc, ME 118 abc; a course in chemical engineering: ChE 167 ab.

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 counseling committee of three members of the faculty is appointed to advise the student on his or her 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 108 units of advanced courses arranged by the student in conference with his or her adviser and approved by the counseling committee and the faculty in materials science. If the student chooses to take a subject minor, the units thereof may be included in the total of 108, subject to the approval of 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 a minor;
d. pass an oral examination on the major subject, and if the student has chosen 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 examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his or her specialized field of research.

Subject Minor in 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 or her major field, elect materials science as a subject minor. The group of courses shall differ markedly from the major subject of study or research, and consist of at least 54 units of advanced work. The student shall be examined orally and separately from the examination in the student's major.

Mathematics

Aims and Scope of Graduate Study in Mathematics

The principal aim of the graduate program is to equip the student to do original research in mathematics. Independent and critical thinking is encouraged by participation in seminars and by direct contact with faculty members; an indication of the current research interests of the faculty is found on page 145. In order to enable each student to acquire a broad background in mathematics, individual programs of study and courses are mapped out in consultation with faculty advisers. The normal course of study leads to the Ph.D. degree.

Admission

Each new graduate student admitted to work for an advanced degree in mathematics will be given an interview on Thursday or Friday of the week preceding the beginning of instruction in the fall term. The purpose of this interview is to ascertain the preparation of the student and assist him or her to map 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 that are offered are listed in Section V. They are divided into 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 have been 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. The seminar Ma 190 is 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. In addition to Ma 190, the first year graduate program normally consists of two or three 100-series courses.

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.

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

Bohnenblust Travel Grants in Mathematics

Special grants may be awarded to outstanding graduate students in mathematics to enable them to travel here or abroad to further their mathematical education. The Mathematics Department established these awards in 1978 to honor H. F. Bohnenblust, who served Caltech as Professor of Mathematics, Executive Officer for Mathematics, and Dean of Graduate Studies. Application forms and further details are available in the Mathematics Office, 253 Sloan.

Master's Degree in Mathematics

Entering graduate students are normally admitted directly to the Ph.D. program, since the Institute does not offer a regular program in mathematics leading to the master's degree. This degree may be awarded in exceptional circumstances either as a terminal degree or as a degree preliminary to the Ph.D. degree. Sufficiently advanced undergraduates may be admitted to graduate standing to pursue a master's degree simultaneously with the bachelor's program.

The recipient of a master's degree will be expected to have acquired, in the course of studies as an undergraduate or graduate student, a comprehensive knowledge of the main fields of mathematics comparable to 180 units of work in mathematics at the Institute with course numbers greater than 90.

The general Institute requirements specify that the recipient of a master's degree must have taken at least 135 units of graduate work as a graduate student at the Institute, including at least 81 units of advanced graduate work in mathematics. This advanced work is interpreted as work with a course number greater than 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 have acquired an understanding of the main fields of modern mathematics and to have demonstrated an ability to do competent research in a particular field.

The first graduate year is usually spent in acquiring basic background knowledge in the several fields of mathematics. In order to determine as early as possible the candidate's progress toward this objective, written candidacy examinations will be given toward the end 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 emphasize the ability to apply basic mathematical ideas and theorems to specific cases. 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. The results of this evaluation will be reported to the student and will be used in consultation with the student to plan a subsequent academic program. At this time each student is expected to arrange with a member of the faculty to act as a research adviser.

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, candidates for the degree of Doctor of Philosophy must deliver typewritten or reproduced copies of their theses to their supervisors. These copies must be complete and in the exact form in which they will be presented to the members of the examining committees. Candidates are also responsible for supplying the members of their examining committees, at the same time or shortly thereafter, with reproduced copies of their theses. The department will assign to the candidates, immediately after the submission of their theses, a topic of study outside their fields of specialization. During the next four weeks the candidates are 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 theses have been handed in. It will cover the theses and fields related to them and the assigned topics of study.

Subject Minor in Mathematics

Students majoring in other fields may take a subject minor in mathematics. Minor programs must include 54 units of advanced work approved by a representative of the mathematics department who will insure that the work represents a concentrated study in one or more of the main fields of mathematics. A special oral examination in the subject minor will be given soon after completion of the minor program.

Mechanical Engineering

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. The program is intended to be completed within the nine months of the academic year, even by students who hold assistantships. 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 a 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:

Mechanical Engineering

		Units per term		
E 150 abc	Seminar (1-0-0)	1	1	1
	Approved electives[1]	Minimum	81 per year	
	Free electives[2]	Minimum	51 per year	
	Total	Minimum	135 per year	

Approved electives: Courses from AM, AMa, ME, JP, MS, and Hy with numbers of 100 and above will generally meet the conditions for the approved electives.

Program Suggested for Propulsion

E 150 abc	Seminar (1-0-0)	1	1	1
JP 121 abc	Jet Propulsion Systems and Trajectories (3-0-6)	9	9	9
	Approved electives[1]	Minimum	98 for year	
	Free electives[2]	Minimum	27 for year	
	Total	Minimum	135 for year	

Approved electives: Ae/AM 102, Ae 104, AM 151, Hy 101, JP 131, JP 170, ME 102, ME 118, ME 126.

Program Suggested for Energy

E 150 abc	Seminar (1-0-0)	1	1	1
ME 102 abc	Principles of Energy Conversion and Distribution (3-0-6)	9	9	9
	Approved electives[1]	Minimum	98 for year	
	Free electives[2]	Minimum	27 for year	
	Total	Minimum	135 for year	

Approved electives: Ae 103, APh 140, APh 161, ChE 101, ChE 157, EE 151, Env 103, Hy 101, JP 131, ME 118, Ph 106.

[1]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 approved electives. Substitution for approved electives may be made with the approval of the student's adviser and the faculty in mechanical engineering.

[2]Students are urged to consider including a humanities course in the free electives.

Degree of Mechanical Engineer

Work toward the degree of Mechanical Engineer requires a minimum of two years following completion of the bachelor's degree or the equivalent. Upon a student's admission to work toward the M.E. degree, an advisory committee of three members of the faculty is appointed. The 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 should meet with the committee before registration for the purpose of planning his or her work.

Not less than 55 units of work shall be for research and thesis; the exact number shall be determined by a supervising committee, appointed by the Dean of Graduate Studies, which succeeds the counseling committee. Courses should be closely related to mechanical engineering. The specific courses (to be taken and passed with a grade of C or better by the candidate) will be planned with the counseling 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 AMa 101 abc, that is acceptable to the faculty in mechanical engineering. A suitable course program may usually be organized from the more advanced courses listed under AM, AMa, Hy, JP, ME, MS, and Ae.

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 counseling committee of three members of the faculty is appointed to advise the student on his or her program. The 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 108 units of advanced courses arranged by the student in conference with his or her adviser and approved by the counseling committee and the faculty in mechanical engineering. If the student chooses to take a subject minor, the units thereof may be included in the total of 108, subject to the approval of 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, 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 a minor;
d. pass an oral examination on the major subject, and if the student has chosen a subject minor, an examination on the subject of that program may be included at the request of the discipline offering 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 the specialized field of research.

Subject Minor in Mechanical Engineering

A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in mechanical engineering and the faculty in his or her major field, elect mechanical engineering as a subject minor. The group of courses shall differ markedly from the major subject of study or research, and consist of at least 54 units of advanced work. The student shall be examined orally and separately from the examination in the student's major.

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 prepares students for careers in scientific research or research combined with teaching, so that independent research is an essential part of the graduate program. Courses are offered that will help a beginning graduate student prepare for research and will provide a broad, sound knowledge of physics. These courses are not required; each student takes only those courses that are needed. Instead of formal course requirements, each student must pass a candidacy examination that seeks to determine his or her readiness to undertake original research and his or her basic knowledge of physics.

To broaden the student's experience beyond the narrow limits of his or her 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.

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 or she 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 91125, and submitted as early as convenient. While late applications will be considered, applications should whenever possible reach the Graduate Office by February 15, 1981. Special inquiries will be welcomed by the chairman of the Physics Graduate Admissions Committee. Applicants must take the Graduate Record Aptitude Test and Advanced Physics Test, by mid-December 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 or her first term of graduate study, a student admitted to work for an advanced degree in physics is required to take placement examinations to be used as a guide in selecting the proper course of study. These examinations will cover material in mechanics and electromagnetism, quantum mechanics, and mathematical physics, approximately as covered in Ph 106, Ph 125, and Ph 129. In general, they will be designed to test whether the student possesses an understanding of general principles and the ability to apply these to concrete problems, rather than detailed informational knowledge. In cases in which there is a clear basis for ascertaining the status of the entering graduate student, the placement examinations may be waived.

Master's Degree in Physics

A student is not normally admitted to work toward the M.S. degree in physics unless he or she 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 118 abc, Ph 127 abc, Ph 129 abc, Ph 135, Ph 136, Ph 203 ab, Ph 205 abc, Ph 209 abc, Ph 213 ab, Ph 221, Ph 224 abc, Ph 229, Ph 230 abc, Ph 231 abc, Ph 236 abc, Ph 237 abc.
Other electives ....27 units
These must be graduate courses from physics or any other option, including humanities.

With the approval of the department 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 that describes the results of independent research; and passing a final oral examination based on this thesis and research.

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 125, Ph 129, 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 in the following list: Ph 127, Ph 135, Ph 136, Ph 203, Ph 205, Ph 213, Ph 221, Ph 224, Ph 229, Ph 230, Ph 231, Ph 234, Ph 236, Ph 237, APh 140, APh 156, APh 190, APh 214, Ay 131 or Ay 132, Ay 133, Ay 138, Ay 218. The purpose of course requirements is to broaden the student's knowledge of physics and acquaintance with material outside his or her own field of specialization; for this reason, no more than 18 units of any given course in the above list may be counted toward these requirements. In addition to these course requirements, the student will normally take other advanced courses, particularly in the field of specialization. In general a student will find it desirable to continue 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 course. If he or she obtains grades below C in courses, or an unsatisfactory grade on the written or oral candidacy examination, the Physics Graduate Committee will review the student's entire record, and if it is unsatisfactory will refuse permission to continue work for the Ph.D.

Candidacy Examinations. A written candidacy examination, in several sections and requiring a total of about fifteen hours, must be passed as one of the requirements for the Ph.D. degree. This examination covers that body of knowledge felt to be essential no matter what the candidate's ultimate field of specialization may be. The examination will be offered at frequent intervals and the separate sections may be taken at different times. At least two sections must be attempted before the end of the first year and all must be passed before the end of the third year. Further guidelines concerning the expected rate of progress in passing parts of the examination are available in the Physics Graduate Office. The flexible scheduling of the written candidacy examination allows students to prepare for the separate sections while simultaneously learning about research areas through either advanced courses or reading and research courses.

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 or her chosen field. The candidate must have passed at least 15 units of Ph 171, Ph 172, or Ph 173 before taking the 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 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.

Research Requirements. There is no specific research requirement but in general a substantial effort is required to master the techniques in a given field and carry out a significant piece of original research. Each student is strongly advised to start research as soon as possible and carry it on in parallel with course work. Attendance at the physics seminar course, Ph 242, helps students become acquainted with the work done by research groups at Caltech.

The Minor. A minor is not required, but a student may elect to pursue a minor in another option.

Language Requirements. There are no language requirements for a Ph.D. in physics, 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 is responsible for completing the 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

Students desiring a subject minor in physics should discuss their proposed program with the chairman of the Physics Graduate Committee. 45 units are required for approval of a subject minor in physics. Physics courses with numbers over 100 will be allowed for the subject minor, but those that count at reduced credit for physics graduate students will count at the same reduced credit toward the minor. At least 18 of the 45 units must be chosen from the Physics Electives List, (see list under "Master's Degree in Physics") excluding Ph 129 and any specific courses in physics required for the student's major program. 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

In recent years, industry, academia, and government have placed increasing value on the work of analysts who have a thorough technical training in the theories and modeling methods of several social scientific disciplines, and who also have a strong background and interest in applying these techniques to the real decision-making problems that face organizations in both public and private sectors. The graduate program in social science produces scholars who can meet this need.

The problems faced by contemporary business and government are complex, and often require basic research in the theories and methods of several disciplines if they are to be solved successfully. The course of instruction in the graduate social science program enables students to do this work.

The first-year curriculum focuses on microeconomic theory, game theory, formal political theory, quantitative methods, and the analytical techniques of policy research. The course of instruction gives students the basic scientific tools that will serve as a technical foundation for more specialized and applied work in subsequent years. It also gives students time enough to acquire additional skills in mathematics.

The second-year curriculum allows students to develop specialties that will enable them to work in the vanguard of research in these fields. Advanced course work is offered in microeconomic theory, political science, several fields of public policy, econometrics, field research methods of anthropology, experimental methods in social science, and quantitative social scientific history. In addition, students can participate in research workshops in policy analysis that introduce them to the techniques of applied social scientific research. In developing research projects, students are encouraged to work with faculty members in law, in the physical sciences, and in engineering. Second-year research activities give students experience in the art of formulating and executing complicated, policy-relevant projects.

Graduates of the program, depending on their fields of specialization, are qualified to take positions in university departments of economics or political science, schools of public policy, or in decision science or managerial economics departments in schools of business. They are also prepared to take positions in economic analysis, program evaluation, and planning offices in government agencies. In addition, a special program has been developed to enable students to obtain joint degrees in social science from Caltech and law from cooperating schools of law. Graduates of this program are qualified for teaching positions in schools of law and for legal practice as well as for other positions in academia and government.

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 Ma 112 a. 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, students will, in consultation with the option committee and their research adviser, develop a program that will allow them to prove their competence in three major areas.

a. *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 students with a substantial knowledge of existing theory that is relevant to those problems and to introduce them to the revisions that must be effected if they are to work across disciplines. The areas of competence must include microeconomics and analytical political science.
b. *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.

c. *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 that all graduate students will be expected to attend.

Master's Degree in Social Science

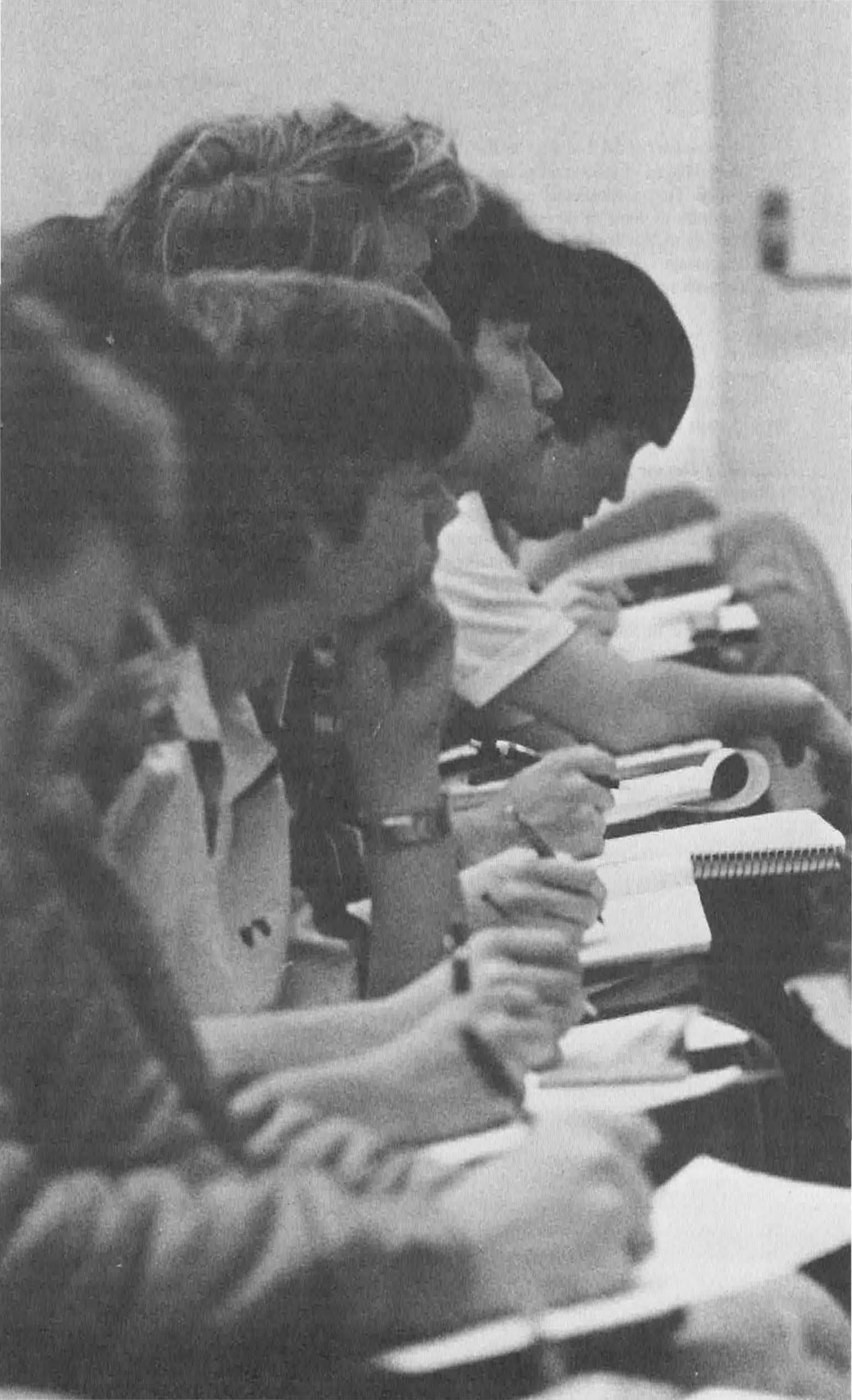
Entering graduate students are admitted for the Ph.D. program. The M.S. degree is awarded in exceptional cases. Of the 135 units of graduate work required by Institute regulations, at least 81 units of advanced work should be in social science.

Degree of Doctor of Philosophy in Social Science

Requirements for the Ph.D. include passing a written 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 that 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.

Subject Minor in Social Science

Graduate students taking social science as a subject minor shall complete a program of not less than 45 units in social science approved by the option committee.



Section V

SUBJECTS OF INSTRUCTION

Courses numbered below 100 are taken primarily by undergraduate students. Those numbered from 100 to 199 are taken by both undergraduates and graduates, and those numbered 200 and above are taken primarily by graduate students.

The school year is divided into three terms. The number of units assigned in any term to any subject represents the number of hours spent in class, in laboratory, and estimated to be spent in preparation per week. In the following schedules, figures in parentheses denote hours in class (first figure), hours in laboratory (second figure), and hours of outside preparation (third figure). 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.

At the end of the seventh week of each term, a list of courses to be offered the following term is published by the Registrar's Office. On the day of registration (see Academic Calendar), an updated and revised course schedule is published announcing the courses, class hours, and room assignments for the term.

AERONAUTICS

Advanced Courses

Ae/APh 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms.* The course begins with the study of one-dimensional flows and then moves to consideration of flows with progressively more complex dimensionality. During the third term viscous flows are treated. Topics to be discussed include: thermodynamics of fluid flow, equations of motion; one-dimensional compressible flow, shock waves, nonsteady flow; acoustics, thin airfoil theory; potential flow; kinematics of fluid flow, stress, vorticity; vortex flows; dynamics of real fluids, viscous flow, boundary layer theory. Instructor: Brown.

Ae/AM 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 97 abc or equivalent.* Static and dynamic stress analysis. Two- and three-dimensional theory of stressed elastic solids. Analysis of structural elements with applications in a variety of fields. Variational theorems and approximate solutions, finite elements. A variety of special topics will be discussed in the third term. Instructor: Housner.

Ae 103 abc. Vehicle Performance and Dynamics. *9 units (3-0-6); first, second, third terms. 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, 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. Instructor: Culick.

Ae/APh 104 abc. Experimental Methods. *9 units (3-0-6 first term; 1-3-5 second and third terms). Prerequisites: AMa 95 abc or equivalent (may be taken concurrently), Ae/APh 101 abc (may be taken concurrently).* Lectures on experiment design and implementation. Measurement methods, transducer fundamentals, instrumentation, optical systems, signal processing, noise theory, analog and digital electronic fundamentals, data acquisition and processing systems. Experiments (second and third terms) in solid and fluid mechanics with emphasis on current research methods, on low-speed and high-speed aerodynamics, laser Doppler velocimetry, signal noise. Instructor: Sturtevant.

Ae 107 abc. Case Studies in Engineering. *9 units (3-0-6); first, second, third terms.* Each term, the case history of a major engineering project will be treated in detail. Cases will include aerospace projects and other current engineering programs. Lecturers will, in general, be specialists in their fields from industrial or research organizations. Starting with the economic, political, and technological environment in which the concept originated, the course will proceed to the project initiation, detailed engineering and design, manufacturing operations, and future growth potential. Both project successes and difficulties will be discussed. Instructor: Dimotakis.

Ae/AM 108 abc. Finite Element Methods. *9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission.* A course on finite elements covering fundamental concepts, computer implementation, and mathematical analysis of the method. Techniques for general classes of linear and nonlinear elliptic, parabolic, hyperbolic, and eigenvalue problems. Survey and evaluation of important finite elements. Error estimates and computer code architecture for typical problem classes. Implicit and explicit algorithms in transient analysis. Emphasis on problems from structural and solid mechanics, and special topics of interest to the class, e.g., algorithms for viscoelasticity, viscoplasticity, nonlinear heat conduction, Navier-Stokes equations, contact-impact problems, etc. Instructor: Hughes.

Ae 109 ab. Energy and Environmental Problems in Aeronautics. *9 units (3-0-6); first and second terms.* Historical and projected energy requirements of commercial, private, and military aviation, and relation to the total energy problem. Examination of major factors affecting aircraft energy consumption in taxiing, takeoff and climb, cruise, and landing modes. Problems and prospects for new fuels and advances in aerodynamic and power plant design. Environmental problems of noise and air pollution, including effects of power plant exhaust emissions on the troposphere (subsonic aircraft) and the stratosphere (supersonic aircraft). Methods of reducing pollutant emissions by analysis and experiments on combustion and mixing processes in aircraft power plants. Not offered in 1980–81.

Ae 150 abc. Aeronautical Seminar. *1 unit (1-0-0); first, second, third terms.* Speakers from campus and outside research and manufacturing organizations discuss current problems and advances in aeronautics. Graded pass/fail only. Instructor: Lees.

Ae/ChE 172 abc. Optimal Control Theory. *9 units (3-0-6); first, second, third terms.* Parameter optimization problems. Optimization problems for dynamical systems with terminal and path constraints (calculus of variations). Linear-quadratic approach to feedback controller design. Numerical methods for solving two-point boundary value problems. Selected topics in mathematical system theory. Optimal estimation, prediction, and smoothing for linear systems with additive Gaussian noise. Optimal control in the presence of uncertainty. Instructors: Staff.

Ae 200. Research in Aeronautics. *Units to be arranged.* Properly qualified graduate students are directed in research by the staff.

Ae 201 abc. Advanced Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101 or Hy 101; AM 125 or AMa 101 (may be taken concurrently).* Foundations of the mechanics of real fluids. Basic concepts will be emphasized. Subjects covered (not necessarily in the order listed) include: physical properties of real gases; the equations of motion of viscous and inviscid fluids; the dynamical significance of vorticity; exact solutions; motion at high Reynolds number emphasizing boundary layer concepts and their mathematical treatment; inviscid compressible flow theory; shock waves; similarity for subsonic, transonic, supersonic and hypersonic flows. In addition, topics will be selected from the following subjects: low Reynolds number approximate solutions; hypersonic aerodynamics; acoustics; flow of mixtures with chemical changes and energy transfer; stability and turbulence; rotating and stratified fluids. Instructor: Saffman.

Ae 202 abc. Advanced Solid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ae/AM 102 or equivalent.* Deformation of elastic/plastic solids. Solution methods in linear elasticity. Application of integral transform and complex variable methods. Introduction to wave mechanics. Variational methods. Finite element methods, structural dynamics and stability. Not offered in 1980–81.

Ae 203 abc. Applied Aerodynamics and Flight Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae 103 or equivalent.* Several problems in flight mechanics of aircraft and rockets, especially those in which standard methods are inadequate, are treated. These include the effects of variations of air speed and density, gyroscopic effects, atmospheric perturbations of orbital motions, and entry dynamics and heating. Related topics in wing theory are developed and applied. Not offered in 1980–81.

Ae 204 abc. Technical Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101, Hy 101 or equivalent.* External and internal flow problems encountered in engineering for which only empirical methods exist. Turbulent shear flow, separation, transition, three-dimensional and nonsteady effects. Basis of engineering practice in design of devices such as mixers, ejectors, diffusers, control valves. Studies of flow-induced oscillations, wind effects on structures, vehicle aerodynamics. Instructors: Coles, Roshko.

Ae 208 abc. Fluid Mechanics Seminar. *1 unit (1-0-0); first, second, third terms.* A seminar course in fluid mechanics. Weekly lectures on current developments are presented by staff members, graduate students, and visiting scientists and engineers. Instructor: Liepmann.

Ae 209 abc. Seminar in Solid Mechanics. *1 unit (1-0-0); first, second, third terms.* A seminar for staff and students of all divisions whose interests lie in the general field of solid mechanics. Reports on current research by staff and students on the campus are intermixed with seminars given by invited lecturers from companies and other research institutions. Instructors: Staff.

Note: The following courses, with numbers greater than Ae 210, are one-term courses offered each year to interested students. Depending on conditions, some of the courses may be taught as tutorials or reading courses, while others may be conducted more formally.

Ae 212. Shell Theory. *9 units (3-0-6); first term. Prerequisite: instructor's permission.* General mathematical formulation of the theory of thin elastic shells. Membrane and bending stresses in shells. Elastic stability. Surveys of recent advances in the nonlinear theories of stressing and buckling of shells. Not offered in 1980–81.

Ae 213. The Mechanics of Fracture. *9 units (3-0-6); second term. Prerequisites: Ae 202 or equivalent and instructor's permission.* An advanced course stressing the analysis of fracture in metallic and nonmetallic solids, designed to give the student an appreciation of the approximations made in analytically modeling the physics of the fracture process. Several fracture criteria as based on energy balance, cohesion modulus, and crack opening displacement are discussed in the light of their applicability to brittle, ductile, and viscoelastic solids for quasi-static and fast running cracks. Not offered in 1980–81.

Ae 217. Aero- and Hydroelasticity. *9 units (3-0-6). Prerequisite: instructor's permission.* 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 in 1980–81.

Ae 221. Theory of Viscoelasticity. *9 units (3-0-6); second term. Prerequisites: Ae 202 or equivalent and instructor's permission.* Material characterization and thermodynamic foundation of the stress-strain laws. Correspondence rule for viscoelastic and associated elastic solutions and integral formulation for quasi-static boundary value problems. Treatment of time-varying boundary conditions such as moving boundaries and moving loads. Stress waves. Approximate methods of viscoelastic stress analysis. Not offered in 1980–81.

Ae 225. Special Topics in Solid Mechanics. *9 units (3-0-6); first, second, third terms.* Subject matter will change from term to term depending upon staff and student interest but may include such topics as structural dynamics; aeroelasticity; thermal stress; mechanics of inelastic materials; and nonlinear problems. Not offered in 1980–81.

Ae 231. Wing Theory. *9 units (3-0-6); second term. Prerequisites: Ae/APh 101, AM 113 or equivalent and instructor's permission.* Application of potential flow theories and boundary layer theories to flows around airfoils and wings. Topics are selected from two-dimensional airfoils, three-dimensional wings at subsonic, transonic, and supersonic Mach numbers. Not offered in 1980–81.

Ae 232 ab. Numerical Methods in Fluid Mechanics. *9 units (3-0-6); second, third terms. Prerequisites: Ae/APh 101, AM 113 or equivalents and instructor's permission.* Problem-oriented review of numerical methods in fluid mechanics. Topics are selected from: boundary layers, shock-wave structure, one-dimensional flow with chemical reactions, nonsteady one-dimensional flow, two-dimensional inviscid and viscous flows. Not offered in 1980–81.

Ae 234. Hypersonic Aerodynamics. *9 units (3-0-6). Prerequisites: Ae/APh 101, AM 125 or instructor's permission.* An advanced course dealing with aerodynamic problems of flight at hypersonic speeds. Topics are selected from: hypersonic small-disturbance theory, blunt body theory, boundary layers and shock waves in real gases, heat and mass transfer, testing facilities and experiment. Not offered in 1980–81.

Ae 235. Acoustical Problems in Fluid Mechanics. *9 units (3-0-6); first term. Prerequisite: instructor's permission.* Fundamental principles. Geometrical acoustics. Standing waves. Cavities. Diffraction. Sound in moving media. Aerodynamic noise. Nonlinear acoustics. Focusing. Shock diffraction. Instructor: Kubota.

Ae 237 ab. Non-Steady Gasdynamics. *9 units (3-0-6); second, third terms. Prerequisites: Ae/APh 101 or equivalent.* Review of shock waves, simple expansion waves. Real gas effects. Basic shock-tube performance. Wave interactions and geometrical effects. Non-ideal behavior in shock tubes. Shock-tube techniques and applications. Blast and detonation waves. Shock Hugoniots in various media. Instructors: Sturtevant, Roshko.

Ae 239. Turbulent Shear Flows. *9 units (3-0-6); third term.* Similarity arguments for classical shear flows; jet, wake, plume, mixing layer, boundary layer. Survey of current research on large coherent structures. Role of such structures in mixing, entrainment, and transport. Not offered in 1980–81.

Ae 240. Special Topics in Fluid Mechanics. *9 units (3-0-6); first, second, third terms.* Subject matter will change from term to term depending upon staff and student interest. Instructors: Staff.

ANTHROPOLOGY

An 101 abc. Selected Topics in Anthropology. *9 units (3-0-6).* Not offered in 1980–81.

An 123 ab. The Anthropology of Development. *9 units (3-0-6); first, second 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 of the social organization of selected societies in Latin America, Europe, Africa and elsewhere over the past half century. Instructor: Scudder.

An 124. The Evolution and Current Status of Small-Scale Human Societies. *9 units (3-0-6); third term. Prerequisite: An 123 a.* Lectures deal with human and cultural evolution prior to the rise of the pre-industrial city; reading and student projects deal with the implications of the contemporary world for small-scale human societies, and for the Navajo in particular. Instructor: Scudder.

APPLIED MATHEMATICS

Undergraduate Courses

AMa 95 abc. Introductory Methods of Applied Mathematics. *12 units (4-0-8); first, second, third terms. Prerequisites: Ma 1 abc, Ma 2 abc, or equivalent.* The topics studied include introductions to the following: functions of complex variables; linear ordinary differential equations; special functions; eigenfunction expansions; integral transforms; linear partial differential equations and boundary value problems. Instructors: Cohen, List.

AMa 98 a,b,c. Topics in Applied Mathematics. *9 units (3-2-4), (3-0-6), (3-0-6). Three independent quarters.*

a. **Topics in Digital Computing.** *Prerequisite: some knowledge of Fortran.* The course gives Fortran users an introduction to computer graphics, assembler language programming, and compilers on the IBM System 370. A formula manipulation system is also discussed. Instructor: Tadmore.
b. **Ordinary Differential Equations.** *Prerequisite: Ma 2.* Qualitative theory of linear and nonlinear differential equations, phase-plane, Poincaré-Bendixson theory, stability. Applications. Instructors: Staff.
c. **Applications of Differential Geometry.** *Prerequisites: Ma 2, Ph 2.* Basic concepts of differential geometry such as frame fields, Frenet formulas, connection forms, differential manifolds, tangent vectors, differential forms and their integrals, geodesics, curvature, Riemannian geometry, and covariant derivatives are explained mainly with the aid of curves and surfaces in three-dimensional Euclidean space. The concepts are applied to particle dynamics, fluid dynamics, and electromagnetic theory. Text: Barrett O'Neill, *Elementary Differential Geometry*. Instructors: Staff.

Advanced Courses

AMa 101 abc. Methods of Applied Mathematics I. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or Ma 108.* Review of basic complex variable analysis; asymptotic expansions; ordinary linear differential equations; Sturm-Liouville theory; eigenfunction expansions; integral transforms; special functions; integral equations; introduction to partial differential equations; elementary theory of nonlinear differential equations. Instructors: Fornberg, Whitham.

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: Keller.

AMa 105 ab. Introduction to Numerical Analysis. *11 units (3-2-6); second, third terms. Prerequisites: AMa 95 and 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 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. Several large computing problems are assigned each quarter. Instructor: Tadmore.

AMa 106 ab. Numerical Linear Algebra. *9 units (3-0-6); second, third terms. Prerequisite: some familiarity with elementary matrix theory.* Computational methods for problems in linear algebra such as linear transformations, eigenvectors-eigenvalues, direct and iterative methods for simultaneous equations, overdetermined systems, linear programming, etc. Coding principles, computational efficiency, stability and error analysis are stressed. Not offered in 1980–81.

AMa 110. Introduction to the Calculus of Variations. *9 units (3-0-6); first term. Prerequisite: AMa 95 or 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. Not offered in 1980–81.

AMa 151 abc. Perturbation Methods. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 101 or equivalent; may be taken concurrently with instructor's permission.* The course discusses uniformly valid approximations in various physical problems. Generalized boundary layer technique. Coordinate straining techniques; Poincaré's method. Problems with several time scales; averaging techniques; method of Krylov Bogoliubov. Eigenvalue problems. Examples taken from various fields of science. Instructor: Lagerstrom.

AMa 152 abc. Linear and Nonlinear Wave Propagation. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 101 or equivalent; may be taken concurrently with instructor's permission.* Mathematical formulation, hyperbolic equations, characteristics, shocks. Combined effect of nonlinearity and diffusion. Wave propagation with relaxation effects. Dispersive waves, group velocity, geometry of waves, nonlinear dispersive waves. Diffraction theory. The emphasis is on solving physical problems and the mathematical theory is developed through a wide variety of problems in gasdynamics, water waves, plasma physics, electromagnetism. Not offered in 1980–81.

AMa 153 abc. Stochastic Processes. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or Ma 108.* Basic probability and probabilistic approximations; applications to stochastic population theories and stochastic epidemics. Markov chains, random walks and discrete potentials, Brownian motion. Correlations, power spectra, and application to filtering and prediction of stationary processes. Stochastic differential equations, use of Fokker-Planck and Kolmogorov equations. Markov Process methods. Instructor: Franklin.

AMa 181 ab. Mathematical Programming and Game Theory. *9 units (3-0-6); second, third terms. Prerequisite: some knowledge of linear algebra.* Theory of linear and nonlinear programming. Simplex algorithm. Integer programming and network flows. Zerosum, two-person games. Linear models of exchange and production. Kakutani fixed-point theorem. Theory of n-person games. Applications to engineering and economics. Not offered in 1980–81.

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). Prerequisite: AMa 101 or equivalent.* First order partial differential equations; classification and theory of linear and nonlinear higher order partial differential equations; well-posed problems; maximum principles; fundamental solutions and Green's functions; spectral theory; integral operators; special techniques. Not offered in 1980–81.

AMa 204 abc. Numerical Solution of Differential and Integral Equations. *9 units (3-0-6). Prerequisite: some familiarity with elementary numerical methods.* Theoretical and practical study of methods for approximate solution of various linear and nonlinear ordinary and partial differential and integral equations with the use of digital computers. Not offered in 1980–81.

AMa 205 abc. Numerical Fluid Mechanics. *9 units (3-0-6). Prerequisite: familiarity with elementary numerical methods and linear algebra.* Survey of the relevant theory of partial differential equations. Well-posed problems, different time scales, propagation of singularities. Numerical treatment of model equations. Methods for solving problems in gasdynamics, in particular treatment of shocks and discontinuities. Shallow water equations with applications to meteorology and oceanography. Navier-Stokes equations. Use of vorticity and stream function, large Reynolds number problems, treatment of boundary layers. MHD difficulties compared with fluid dynamics. The role of simulation. Instructor: Kreiss.

AMa 220 ab. Bifurcation Theory and Nonlinear Boundary Value Problems. *9 units (3-0-6); second, third terms. Prerequisite: some knowledge of differential equations.* Theory and applications of bifurcation and nonlinear boundary value problems in mechanics, fluid dynamics and nonlinear diffusion processes. Lyapounov-Schmidt theory. Multiple bifurcations and Newton's polygons. Extension of bifurcated branches, secondary bifurcation, perturbed bifurcation and imperfection sensitivity. Hopf bifurcation of periodic solutions. Catastrophe theory. Nonlinear boundary value and eigenvalue problems. Monotonicity methods. Stability theory. Degree theory. Instructor: Keller.

AMa 251 ab. Applications of Group Theory. *9 units (3-0-6); first, second terms. Prerequisite: some knowledge of linear algebra.* Applications of group theory to differential equations and to physics 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 some classical Lie groups. Not offered in 1980–81.

AMa 260 abc. Special Topics in Continuum Mechanics. *9 units (3-0-6). Prerequisites: AMa 101 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.

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, Ma 141, Ma 143, Ma 144, Ma 205, AM 135, AM 136, AM 175, ES 131, Ph 125, and Ph 209.

APPLIED MECHANICS

Undergraduate Courses

AM 96 abc. Applied Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc.* Basic principles and applications of classical mechanics. Analytical description of motion. Force-acceleration, energy, and momentum principles. Variational principles, generalized coordinates, and Lagrange's equations. Rigid body dynamics. Response of mechanical systems to periodic and transient excitations. Free and forced vibrations of discrete and continuous systems. Introduction to random vibrations, non-linear mechanics, self-excited vibrations, and stability problems. Applications to such problems as orbital mechanics, gyroscopic motions, vibration isolation, dynamic instrumentation, design for shock and vibration environments, critical speeds of rotating equipment, etc. Instructor: Hudson.

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.* Introduction to the theory of stress and strain in solid bodies. Applications to beams, columns, plates and shells, torsion, inelastic behavior, numerical and experimental stress analysis, wave propagation, energy methods of analysis. Instructor: Knauss.

Advanced Courses

Ae/AM 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 97 abc or equivalent.* Static and dynamic stress analysis. Two- and three-dimensional theory of stressed elastic solids. Analysis of structural elements with applications in a variety of fields. Variational theorems and approximate solutions, finite elements. A variety of special topics will be discussed in the third term. Instructor: Housner.

Ae/AM 108 abc. Finite Element Methods. *9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission.* A course on finite elements covering fundamental concepts, computer implementation, and mathematical analysis of the method. Techniques for general classes of linear and nonlinear elliptic, parabolic, hyperbolic, and eigenvalue problems. Survey and evaluation of important finite elements. Error estimates and computer code architecture for typical problem classes. Implicit and explicit algorithms in transient analysis. Emphasis on problems from structural and solid mechanics, and special topics of interest to the class, e.g., algorithms for viscoelasticity, viscoplasticity, nonlinear heat conduction, Navier-Stokes equations, contact-impact problems. Instructor: Hughes.

AM 113 abc. Engineering Mathematics. *12 units (4-0-8); first, second, third terms. A course for graduate students who have not had the equivalent of AMa 95 abc. Prerequisite: Ma 1 abc, Ma 2 abc, or equivalent.* Linear differential equations, including power series solutions and special functions. Introduction to complex variable theory with applications. Linear differential equations and special functions in the complex domain. Fourier series and orthogonal functions. Solution of boundary value problems for partial-differential equations by conformal mapping, separation of variables and integral transforms. Instructors: Sternberg, Yates.

AM 125 abc. Engineering Mathematical Principles. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or AM 113 abc.* Topics include: linear spaces, operators and matrices, integral equations, variational principles, differential equations, stability, perturbation theory. Applications to problems in engineering and science are stressed. Instructor: Caughey.

AM 135 abc. Mathematical Elasticity Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission.* Cartesian tensors. Kinematics and kinetics of continuous media, constitutive relations for elastic solids. Fundamental problems and related theorems of linearized elastostatics and elastodynamics. Integration theory and applications to specific problems of engineering interest. Instructor: Knowles.

AM 136 abc. Advanced Mathematical Elasticity Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 135 abc or equivalent.* Topics drawn from the more advanced linear theory and nonlinear theory. Specific content varies according to interests of students and instructor. Instructors: Knowles, Sternberg.

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. Introduction to linear elastodynamics. Waves in the infinite elastic medium. Reflection and refraction of time harmonic waves at an interface. Time harmonic waves in elastic waveguides (rods, plates, layers); wave dispersion. Transient waves in an elastic half space and a waveguide. Transient wave scattering and diffraction. Boundary value problems. Introduction to theory of waves in viscoelastic and plastic media. Instructor: Miklowitz.

AM 151 abc. Dynamics and Vibrations. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc, or instructor's permission.* Variational principles and Lagrange's equations. Response of mechanical systems to periodic, transient, and random excitation. Free and forced response of discrete and continuous systems. Approximate analysis methods. Introduction to nonlinear oscillation theory and stability. Instructor: Iwan.

AM 155. Dynamic Measurements Laboratory. *9 units (1-6-2); first term.* Theory and practice of dynamic instrumentation. Dynamic tests of mechanical systems including steady-state and transient excitation. Analog techniques applied to random load problems. Not offered in 1980–81.

AM 175 abc. Advanced Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: AM 125 abc and AM 151 abc or equivalents.* Topics 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. Not offered in 1980–81.

AM 200. Special Problems in Advanced Mechanics. By arrangement with members of the staff, properly qualified graduate students are directed in independent studies in mechanics. 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 physical principles governing 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: Wilts.

APh/MS 4. Introduction to Materials Science. *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 term. Prerequisite: APh 3. Six units credit allowed toward freshman laboratory requirement.* An introductory nonstructured project laboratory designed to provide an opportunity for projects related to the course APh 3. 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 fabricate a few simple devices, including a MOSFET. In addition, projects may be undertaken as an extension of the APh 3 demonstrations. Typical devices possible with facilities available: light emitting diode, solar cell, Schottky barrier diode, junction FET, bipolar transistor. Graded pass/fail. Instructor: McCaldin.

APh/Me 17 abc. Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Introduction to the use of thermodynamics and statistical mechanics in physics and engineering. Entropy, temperature, and the principal laws of thermodynamics. The thermodynamic identity for open and closed systems. Canonical equations of state. Applications to cycles, engines, phase and chemical equilibria. Probability and stochastic processes. Kinetic theory of perfect gases. Statistical mechanics. Applications to gases, gas degeneration, equilibrium radiation, and simple solids. Instructor: Liepmann.

APh 23. Demonstration Lectures in Optics. *6 units (2-0-4); first term. Prerequisites: Ma 1 abc, Ph 1 abc.* Nine demonstration lectures, covering the fundamentals of optics with an emphasis on modern optical applications, are intended to exhibit basic optical phenomena including refraction, dispersion, birefringence, diffraction, and laser oscillation, and the applications of these phenomena in optical systems: two-beam and multiple-beam interferometry, Fourier-transform spectroscopy, Fourier-transform image processing, holography, electro-optic and acousto-optic modulation, optical detection and heterodyning, optical fibers and integrated optical systems, optical communications and radar, adaptive optical systems. Instructor: Bridges.

APh 24. Introductory Modern Optics Laboratory. *6 units; second term. Prerequisite: APh 23.* Laboratory experiments to acquaint students with the contemporary aspects of modern optical research and technology. Experiments encompass many of the topics and concepts covered in APh 23. Instructor: Bridges.

APh 50 abc. Applied Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc, Ma 2 abc, or equivalents.* Quantum mechanics and applications to problems of the three states of matter: solids, gases, and liquids. Topics include discussion of bound and free particles, the electromagnetic field, diatomic molecules, quantum systems in thermal equilibrium, and perturbation theory. 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: Johnson.

APh 77. Laboratory in Applied Physics. *9 units.* Selected experiments in applied physics that are chosen so as to familiarize the student with laboratory equipment and procedures in differing areas of applied physics such as cryogenics, magnetism, plasmas, fluids, semiconductors, optics, and materials properties. Instructor: Bellan.

APh 78 abc. Senior Thesis, Experimental. *9 units; first, second, third terms. Prerequisite: instructor's permission.* This course is intended to provide supervised experimental research experience, and is open only to senior applied physics majors. Requirements will be set by individual faculty members, but will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Applied Physics Undergraduate Committee. Students desiring additional units should register in APh 100. Not offered on a pass/fail basis. Instructors: Culick and the applied physics faculty.

APh 79 abc. Senior Thesis, Theoretical. *9 units; first, second, third terms. Prerequisite: instructor's permission.* This course is intended to provide supervised theoretical research experience, and is open only to senior applied physics majors. Requirements will be set by individual faculty members, but will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Applied Physics Undergraduate Committee. Not offered on pass/fail basis. This course cannot be used to satisfy the laboratory requirement in APh. Instructors: Culick and the applied physics faculty.

APh 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 only 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. Not offered in 1980-81.

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.

Ae/APh 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms.* The course begins with the study of one-dimensional flows and then moves to consideration of flows with progressively more complex dimensionality. During the third term viscous flows will be treated. Topics to be discussed include: thermodynamics of fluid flow, equations of motion; one-dimensional compressible flow, shock waves, nonsteady flow; acoustics, thin airfoil theory; potential flow; kinematics of fluid flow, stress, vorticity; vortex flows; dynamics of real fluids, viscous flow, boundary layer theory. Instructor: Brown.

Ae/APh 104 abc. Experimental Methods. *9 units (3-0-6 first term; 1-3-5 second and third terms). Prerequisites: AMa 95 abc or equivalent (may be taken concurrently), Ae/APh 101 abc (may be taken concurrently).* Lectures on experiment design and implementation. Measurement methods, transducer fundamentals, instrumentation, optical systems, signal processing, noise theory, analog and digital electronic fundamentals, data acquisition and processing systems. Experiments (second and third terms) in solid and fluid mechanics, with emphasis on current research methods, on low-speed and high-speed aerodynamics, laser Doppler velocimetry, signal noise. Instructor: Sturtevant.

APh 105 abc. States of Matter. *9 units (3-0-6); first, second, third terms. Prerequisite: APh/ME 17 or equivalent.* 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: Smith.

APh 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, mechanics of fluids and elastic materials, boundary value problems, multipole expansions, and various applications of electromagnetic theory. Note: The basic content of this course will be similar to Ph 106, but the selection of applications and some topics may be different. Not offered in 1980–81.

APh 110. Topics in Applied Physics. *2 units (2-0-0); first, second, third terms.* A seminar course designed to acquaint juniors and first-year graduate students with the various research areas represented in the option. Lecture each week given by a different faculty member of the option, reviewing, in general terms, his or her field of research. Graded pass/fail. Instructors: Bellan and applied physics faculty.

APh 114 abc. Solid State Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 50 or Ph 92 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, symmetries in solids, lattice vibrations, electronic states in solids, transport phenomena, semiconductors, superconductivity, magnetism, ferroelectricity, defects, and optical phenomena in solids. Instructor: McGill.

APh/MS 126 abc. The Electronic Structure of Metals and Alloys. *9 units (3-0-6); first, second, third terms. Prerequisite: an introductory course in quantum mechanics.* The basic principles of quantum mechanics and thermodynamics applied to understanding electronic band structure, metallic cohesion, structural stability, phase equilibrium and the kinetics of phase transitions, metastable states, lattice dynamics and elastic behavior, transport properties, superconductivity, magnetism, and the physics of metallic surfaces and thin metals films. Comparison of theory with experimental data and phenomenological concepts will be offered with some discussion of current technological areas of application including superconducting devices and high field magnets, magnetic memory devices, radiation damage to metals, and corrosion resistance. Instructor: Johnson.

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 experiments, cryogenic techniques, and macroscopic quantum devices. Not offered in 1980–81.

APh 153 abc. Modern Optics. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc.* The emphasis is on fundamental principles of modern optics and on understanding of contemporary optical systems. Geometrical optics, ray matrices, and the Hamiltonian analogy will introduce the wave equation and its solutions. Topics include: Fresnel and Fraunhofer diffraction, Fermat's principle, the analysis of systems based on e.m. theory, Gaussian beam propagation, interferometry, holography, speckle, van der Lugt filters, pattern recognition, fiber optics, light modulation, diffraction by sound, radiometry, detectors, sources. Instructors: Staff.

APh 156 abc. Plasma Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* An introduction to the principles of plasma physics. 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. Instructors: Corngold and staff.

APh 161 abc. Nuclear Energy. *9 units (3-0-6); first, second, third terms. Prerequisites: AMa 95 abc and Ph 106 abc or equivalent.* Fission and fusion reactors, underlying nuclear physics, particle diffusion, static and dynamic phenomena, effects of radiation on matter, reactor types, economics of nuclear energy. Not offered in 1980–81.

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. Traditional and novel methods of device fabrication. Applications will be made to a wide variety of devices and attention given to feasible schemes for device construction. Instructor: Nicolet.

APh 190 abc. Quantum Electronics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125, or equivalent.* This course covers 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 continues with laser oscillation, important laser media, Gaussian beam modes, the electro-optic effect, nonlinear-optics theory, second harmonic generation, parametric oscillation, stimulated Brillouin and Raman scattering. Other topics include: Light modulation, diffraction of light by sound, integrated optics, phase conjugate optics, and quantum noise theory. Text: *Quantum Electronics* by Yariv. Instructor: Yariv.

APh 195 abc. Molecular Gas Lasers. *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. Not offered in 1980–81.

APh 200. Applied Physics Research. *Units in accordance with work accomplished.* Offered to graduate students in applied physics for research or reading. Students should consult their advisers before registering for the course. Graded pass/fail.

APh 214 abc. Advanced Solid-State Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 114 abc and Ch 125 abc or Ph 125 abc.* 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. Not offered in 1980–81.

APh 250. Advanced Topics in Applied Physics. *Units and term to be arranged.* 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 faculty may present portions of this course from time to time. Instructors: Staff.

APh 300. Thesis Research in Applied Physics. *Units in accordance with work accomplished.* APh 300 is elected in place of APh 200 when the student has progressed to the point where his or her research leads directly toward a thesis for the degree of Doctor of Philosophy. Approval of the student's research supervisor and of his or her department adviser or registration representative must be obtained before registering. Graded pass/fail.

ART

Art 101. Topics in Art. *9 units (3-0-6).* Instructors: Staff.

Art 102. British Art of the Georgian Period. *9 units (3-0-6); third term.* An introduction to the visual arts and the vocabularies of analysis for the study of painting through an in-depth study of the British art of the Georgian period in the collection of the Huntington Art Gallery. Instructor: Wark.

Art 103. Ancient Art. *9 units (3-0-6).* An introductory course to art of the Western tradition from ancient times to the year 800 A.D. Important works of architecture, sculpture, painting, and allied arts (city planning, mosaics, book illumination) will be studied in the historical and cultural context in which they were produced: Paleolithic, Neolithic, Egyptian, Mesopotamian, Mediterranean, Greek, Roman, Early Christian, Byzantine, and Early Medieval. Not offered in 1980–81. Instructor: Price.

Art 104. Nineteenth-Century Art. *9 units (3-0-6); second term.* An introductory course to late eighteenth- and nineteenth-century European and American art (painting, sculpture, architecture), in which works will be studied in terms of art movements, artists, iconography, and the cultural context in which they were produced. Instructor: Price.

Art 105. Modern Art. *9 units (3-0-6); third term.* An introductory course to late nineteenth- and twentieth-century European and American art (painting, sculpture, architecture), in which master works will be studied in terms of morphology, iconography, art movements, an individual's *oeuvre,* materials, and the cultural context that produced them. Instructor: Price.

Art 110. History of Western Architecture: An Introduction. *9 units (3-0-6); first term.* A survey of the history of Western architecture from ancient times to the present, focusing on great monuments. Analyses of masterworks of architecture will consider building types, forms, technology, and the fulfillment of specific cultural functions from the Egyptian tomb to the "skyscraper" office building in the USA. Town planning, the landscaped environment, architect and architect/engineer will also be topics of discussion. Instructor: Price.

ASTRONOMY

Undergraduate Courses[1]

Ay 1. Introduction to Astronomy. *9 units (3-1-5); third term.* This course, primarily for freshmen, surveys astronomy, radio astronomy and astrophysics, emphasizing the application of physics in astronomy. Instructor: Goldreich.

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 distributions. Stellar spectra, magnitudes and colors. Structure and dynamics of the galaxy. Laboratory exercises including double star orbits and the use of an astrograph. Instructor: J. Cohen.

Ay 21. Galaxies and Radio Sources. *9 units (3-0-6); second term. Prerequisite: Ay 20.* The extragalactic distance scale. Clusters of galaxies. Introduction to cosmology. Galactic and extragalactic radio sources. Instructor: Sargent.

Ay 22. Solar System Astronomy. *9 units (3-0-6); third term.* The surface of the sun. 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: Zirin.

Ay 30. Current Trends in Astronomy. *3 units (2-0-1); second term.* Weekly seminar designed for sophomore astronomy majors only; to be held in faculty homes in the evening. Purpose is to introduce the students to the faculty and their research. Graded pass/fail. Instructors: Sargent 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. 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.

[1]See also Ge 101 a.

Advanced Courses

Ay 100. Astronomical Measurements and Instruments. *12 units (3-3-6); third term.* The theory of optical instruments; spectrographs; the Schmidt and other wide-field telescopes. Laboratory instruments. Radio telescopes, radiometers and interferometers. Techniques and detectors in infrared and x-ray astronomy. Laboratory exercises. Instructors: Oke, Wannier.

Ay 101. The Physics of Stars. *11 units (3-2-6); first term. Prerequisite: Ay 20.* The physics of stellar atmospheres and interiors. Instructor: Blandford.

Ay 102. Plasma Astrophysics and the Interstellar Medium. *9 units (3-0-6); second term. Prerequisite: Ay 20.* An introduction to fluid mechanics; sound waves and shock waves. Introduction to magnetohydrodynamics; Alfven waves and plasma waves with applications to the interstellar medium. Supernova remnants. The interstellar magnetic field. The physics of H I and H II regions. Interstellar dust. Instructor: Blandford.

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 that require a synthesis of previous formal course work. Instructor: Sargent.

Ay 131. Stellar Atmospheres. *9 units (3-0-6); second 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. Instructor: J. Cohen.

Ay 132. Stellar Interiors. *9 units (3-0-6); third 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: Young.

Ay 133 ab. Radio Astronomy. *9 units (3-0-6); first, second terms. For seniors and graduate students only. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) or equivalents.* Principles of radio receivers and telescopes. Observations and theory of galactic and extragalactic radio sources. Theory of bremsstrahlung and synchrotron emission. Discrete sources and their identification. The 21-cm hydrogen line and galactic structure. Instructor: Moffet.

Ay 134. The Sun. *9 units (3-1-5); first term.* The physical state of the sun as derived from observations from the ground and from space. 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 1980–81. Instructor: Zirin.

Ay 138. Interstellar Matter. *9 units (3-0-6); first term. Prerequisites: Ay 20 (undergraduates) 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. Interstellar molecules. Star formation. Given in alternate years; offered in 1980–81. Instructor: Wannier.

Ay 139. Stellar Dynamics and Galactic Structure. *9 units (3-0-6); second term. Prerequisites: Ay 20 (undergraduates) 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; not offered in 1980–81.

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 Mount Wilson, Las Campanas, Palomar, and Big Bear Observatories and the Owens Valley Radio Observatory, and on other researches that 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 or her. Approval of 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 or her. Approval of the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy. Graded pass/fail.

Ay 201. Astronomical Instruments and Radiation Measurement. *9 units (3-2-4); second term. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) or equivalents.* The use of the photographic plate as a scientific instrument. Astronomical optics. Theory of reflectors, Schmidts and spectrographs. Photoelectric detectors, photometric systems and their applications. Given in alternate years. Not offered in 1980–81.

Ay 207 ab. Galaxies and the Universe. *9 units (3-0-6); first, second terms. Prerequisites: Ay 20 (undergraduates) or equivalents.* Structure, stellar content, and evolution of normal galaxies. Seyfert and compact galaxies, QSO's, and other peculiar objects. The second term, which may be taken independently, will cover topics in observational cosmology, including dynamics, the microwave, and x-ray background, and the formation of galaxies and clusters. Given in alternate years; offered in 1980–81. Instructors: Oke, Young.

Ay 208. Modern Observational Astronomy. *6 units (1-0-5); third 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 on Mount Wilson and Palomar Mountain. Students will be permitted to register for only one term. Given in alternate years. Not offered in 1980–81.

Ay 215. Seminar in Theoretical Astrophysics. *9 units (3-0-6); second term. 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 1980–81.

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 and at high temperatures. Hydrodynamics; shock waves, magnetohydrodynamics. Radiation processes (thermal, synchroton, bremsstrahlung, inverse Compton, and coherent). Relativistic gravity. Given in alternate years; not offered in 1980–81.

Ay 234. Seminar in Radio Astronomy. *6 units (2-0-4); second term. Prerequisite: Ay 133 ab.* Recent developments in radio astronomy for the advanced student. Current publications and research in progress will be discussed by students and staff. Given in alternate years; not offered in 1980–81.

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 136. Solar System Astrophysics.
Ay 137. Topics in Space Astronomy and Physics.
Ay 151. Seminar in Stellar Atmosphere Theory.
Ay 152. Advanced Stellar Interiors.
Ay 203. Cosmical Electrodynamics.
Ay 204. Advanced Spectroscopy.

Ay 206. Variable Stars.
Ay 213. Selected Topics in Observational Cosmology.
Ay 214. Theoretical Cosmology.
Ay 216. Dynamics and Formation of Galaxies and Clusters.
Ay 217. Theoretical Astrophysical Spectroscopy.

BIOINFORMATION SYSTEMS

Undergraduate Course

BIS 80 abc. Undergraduate Research. *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 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. Bioinformation systems staff. Course supervisor: McCann.

Advanced Courses

Bi/BIS 121 abc. Biosystems Analysis. *6 units (2-0-4); three terms. Prerequisite: Bi 150 or instructor's permission.* 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.

BIS 240 ab. Image Processing and Computer Vision. *9 units (2-2-5); second, third terms.* This course covers topics in digital image processing, pattern recognition and scene analysis. Algebraic point operations, digital filtering and spatial frequency domain operations are described. The application of Bayesian decision theory to pattern classification is presented, including supervised and unsupervised learning. Syntactic methods in scene analysis are discussed with examples from 3-dimensional images of biological objects and simple scenes. Algorithms are presented for obtaining 3-dimensional descriptors from stereo pairs. The course will include a summary of current research in computer vision and student projects.

BIS 280. Research in Bioinformation Systems. *Units in accordance with work accomplished.* Approval of student's research adviser and his or her department adviser must be obtained before registering.

BIS 282. Reading in Research Areas. *6 units or more by arrangement; first, second, third terms. Prerequisites: CS 137, CS 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. Only qualified students will be admitted after consultation with the instructors. A written report will usually be required. Instructors: Fender and McCann.

BIOLOGY

Undergraduate Courses

Bi 1. Introduction to Biology. *9 units (3-3-3); second term.* This course and its sequel, Bi 9, cover biology at the cellular level. After introducing basic concepts which are necessary for understanding biological systems at the molecular level, Bi 1 emphasizes the cellular processes that are involved in the organization and expression of genetic information, including what is commonly called molecular biology and an introduction to topics in developmental biology and immunology. Graded pass/fail. Instructors: Brokaw 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 7. Organismic Biology. *9 units (3-3-3); 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, Konopka.

Bi 9. Cell Biology. *9 units (3-3-3); third term.* Bi 9 continues the coverage of biology at the cellular level, begun in Bi 1. Topics covered include cytoplasmic structure, membrane structure and function, cell motility, and cell-cell recognition. Emphasis is placed on both the ultrastructural and biochemical approaches to understanding these topics. Instructors: Lazarides and staff.

Bi 22. Special Problems. *Units to be arranged; first, second, third terms.* Special problems involving independent research in biology; 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: Konopka 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: Konopka and staff.

Advanced Courses

(A) Subjects intended for graduate and undergraduate students.

Bi 103. Physiology. *9 units (3-0-6); first term. Prerequisites: Bi 7, Bi 9 or consent of instructor.* A lecture and discussion course covering the function and control of various human organ systems such as renal, respiratory, cardiovascular, endocrine, and neuromuscular systems. Instructor: Crandall.

Bi 106. Developmental Biology of Animals. *9 units (2-3-4); second term. Recommended prerequisite: Bi 9.* Lectures and discussions dealing with various aspects of embryological development; cytoplasmic localization and cell interaction in early development, gene function and oogenesis, the role of accessory cells, gene regulation, the evolution of developmental processes and patterns of macromolecular syntheses in early embryological life. Laboratory optional. Instructor: Davidson.

Bi/Ch 110 abc. Biochemistry. *12 units (4-0-8); first, second, third terms. Prerequisite: Ch 41 or instructor's permission.* Lectures and discussions on the molecular basis of biological structure and function. The course emphasizes macromolecular structure and the metabolic processes involved in energy storage and utilization and considers the storage, transmission, and expression of genetic information in prokaryotes and eukaryotes. It also includes other topics in biochemistry of higher organisms, such as molecular regulatory mechanisms and the biochemistry of cell membranes. Instructors: Campbell, Maniatis, Raftery, Richards.

Bi 111. Biochemistry Laboratory. *10 units (0-8-2); second term. Open to students enrolled in Bi/Ch 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/Ch 110. Instructors: Mitchell and staff.

Bi 114. Immunology. *12 units (4-0-8); first term. Prerequisite: Bi 122 or equivalent.* A course on the principles and methods of immunology and their application to various biological problems. Instructor: Douglas.

Bi 115. Virology. *10 units (3-4-3); third term. Prerequisite: Bi/Ch 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 instructor's permission.* Laboratory research projects to serve primarily as a means of acquiring experience with some of the methods and problems of immunology. Given in alternate years; not offered in 1980–81. Instructor: Owen.

Bi/BIS 121 abc. Biosystems Analysis. *6 units (2-0-4); first, second, third terms. Prerequisite: Bi 150 or instructor's consent.* 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.

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: Meyerowitz, Lewis.

Bi 125. Principles and Methods of Gene Transfer and Gene Manipulation in Eukaryotic Cells. *9 units (3-0-6); third term. Prerequisite: Bi/Ch 110.* A lecture and discussion course dealing with modern approaches to "genetic intervention" in eukaryotic cells. Topics discussed will include mutagenesis of cultured animal cells and selection schemes, gene transfer into cultured cells mediated by naked DNA, chromosomes and viruses, transformation of yeast by chromosomal DNA and plasmids, neoplastic transformation of plant cells by *Agrobacteria* plasmids, nuclear transplantation and gene injection into amphibian eggs and oocytes, selective drug-induced gene amplification in cultured animal cells, somatic cell hybridization. Instructor: Attardi.

Bi/Ch 132 ab. Biophysical Chemistry of Macromolecules. *9 units (3-0-6); second, third terms. Prerequisite: Ch 21 or equivalent.* The biophysical chemistry of nucleic acids, proteins, and membranes. Topics are chosen because of their relevance to molecular biology. Given in alternate years; offered in 1980–81. Instructors: Chan and Hopfield.

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. Offered in alternate years; offered in 1980–81. In charge: Dreyer and staff.

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. Offered in alternate years; offered in 1980–81. Instructor: Revel.

Bi 136. Optical Methods in Biology Laboratory. *8 units (0-6-2); first term.* Laboratory accompanying Bi 135. Enrollment limited. Offered in alternate years; offered in 1980–81. Instructor: Revel.

Bi 141. Selected Topics in Evolution Theory. *6 units (2-0-4); second term. Prerequisite: Bi/ Ch 110 or Bi 122.* Lectures and readings with emphasis on genetic and molecular processes in evolution. Topics include experimental approaches to the origin of life, molecular evolution of proteins, evolution of the genome, mathematical models of evolution, and biological aspects of planetary exploration. Not all topics are covered every year. Instructors: Horowitz, Dickerson and staff.

Bi 150. Neurobiology. *10 units (4-0-6); first term.* Lectures and discussions on general principles of the organization and function of nervous systems, providing both an overview of the subject and a foundation for advanced courses. Topics include neurocytology and gross neuroanatomy; developmental neurobiology; the biophysical basis for action potentials, synaptic transmission, and sensory transduction; and the integration of these processes in sensory and motor pathways of the central nervous system. Laboratory demonstrations offer experience with the experimental preparations discussed in the course. Instructors: Hudspeth, Van Essen.

Bi 151. Integrative Physiology of the Central Nervous System. *9 units (3-0-6); second term.* A trip through the vertebrate visual system, from retinal image to visuomotor behavior, to illustrate the principles of integrative neurophysiology. Instructor: Pettigrew.

Bi 152. Behavioral Biology. *6 units (2-0-4); second term.* Introduction to ethology and behavioral genetics. Topics include causation, development, evolution, and genetic analysis of animal behavior, with examples from both invertebrates and vertebrates. Instructors: Konishi and Benzer.

Bi 155. Psychobiology. *6 units (2-0-4); second term.* Readings and discussion on the topic of mind-brain relations. Coverage will include key issues and recent conceptual developments concerning consciousness, value structure, and determinism in behavior and decision-making, with reference to humanist implications. Instructor: Sperry.

Bi 156. Neurochemistry. *9 units (3-0-6); third term. Prerequisite: Bi 150 or instructor's permission.* A lecture and discussion course covering neurotransmitters and their receptors, neuroendocrinology, cellular and molecular aspects of neurons and glia, including synaptogenesis and other cellular interactions in the development of the nervous system. Offered in alternate years; offered in 1980–81. Instructor: Brockes.

Bi 157. Comparative Nervous Systems. *9 units (2-3-4); third term.* An introduction to the comparative study of the gross and microscopic structure of nervous systems. The main emphasis will be on the vertebrate nervous system; the highly developed central nervous systems found in arthropods and cephalopods will also be examined. Variation in nervous system structure with function and with behavioral and ecological specializations and the evolution of the vertebrate brain will be discussed. Offered in alternate years; offered in 1980–81. Instructor: Allman.

Bi 158. Primatology. *9 units (3-1-5); third term.* Evolutionary and behavioral biology of primates. Topics will include fossil primates, comparative anatomy, physiology and ethology of primates, and tool invention and symbolic communication in primates. Offered in alternate years; not offered in 1980–81. Instructor: Allman.

Bi 161. Neurophysiology Laboratory. *6 units (0-4-2); second term. Prerequisite: Bi 150, 151, or instructor's permission.* The principles of cellular neurophysiology are illustrated using the frog nerve-muscle preparation. Students conduct all aspects of the experiments, including dissections, fabrication of microelectrodes, and intracellular stimulation and recording. Not offered in 1980–81. Instructor: Lester.

(B) Subjects primarily for graduate students.

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: Meyerowitz.

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 211. Topics in Membrane and Synaptic Physiology. *6 units (3-0-3); first term.* Graduate seminar discussing the original literature on the biophysics and biochemistry of processes mediated by the neuronal cell membrane. Particular emphasis on current aspects of synaptic transmission. Offered in alternate years; not offered in 1980–81. Instructor: Lester.

Bi 212. Topics in Ethology and Behavioral Genetics. *6 units (2-0-4); second term.* Reading and discussions of original papers related to animal behavior and its analysis by ethological and genetic methods. Offered in alternate years; not offered in 1980–81. Instructors: Benzer and Konishi.

Bi 213. Selected Topics in Integrative Neurophysiology. *6 units (2-0-4); third term. Prerequisite: Bi 151 or instructor's permission.* A reading and discussion course on current problems in the vertebrate central nervous system. The emphasis will be upon those areas that shed light on the mechanisms of neural plasticity. Offered in alternate years; offered in 1980–81. Instructor: Pettigrew.

Bi 214. Sensory Transduction. *6 units (2-0-4); second term.* Anatomy, biophysics, physiology, and psychophysics of sensory transduction processes in both vertebrates and invertebrates. Visual and auditory-vestibular senses will be emphasized, but touch, taste, olfaction, thermoreception, and electroreception will be included. Extensive discussions of the original research literature. Offered in alternate years; offered in 1980–81. Instructor: Hudspeth.

Bi 215. Topics in Cellular Neurobiology. *6 units (2-0-4); third term.* An advanced reading and discussion course on various aspects of the cell biology of neurons and glia, stressing the use of tissue culture to investigate particular problems in the development and function of the nervous system. Offered in alternate years; not offered in 1980–81. Instructor: Brockes.

Bi 216. Topics in Neurochemistry. *6 units (2-0-4); first term.* Topics of current interest in the biochemistry of the nervous system, including behavioral aspects to be selected from the following areas: subcellular fractionation, neurotransmitters, neurosecretion, receptors, hormone action, hereditary and acquired human disorders. Offered in alternate years; offered in 1980–81. Instructor: Konopka.

Bi 217. Central Mechanisms in Perception. *6 units (2-0-4); first term.* Readings and discussions of behavioral and electrophysiological studies of the systems for the processing of sensory information in the brain. Offered in alternate years; offered in 1980–81. Instructor: Allman.

Bi 218. Cellular Basis of Behavior. *6 units (2-0-4); third term.* Lectures and seminars will emphasize one of the following topics during each quarter that the course is offered: neural and humoral factors in the temporal organization of behavior; hormones and the nervous system; mechanisms of plasticity. Students will give seminars dealing with current research, drawn from the literature, in the selected topic area. Instructor: Strumwasser.

Bi 219. Topics in Developmental Neurobiology. *6 units (2-0-4); third term.* This course will be concerned with the development of the vertebrate nervous system. Particular emphasis will be placed on understanding the factors that underlie the formation of specific neural connections.

The format will involve reading and discussing original papers in a few selected areas. Among the topics covered will be: 1) the influence of genetic and environmental factors in development; 2) the specificity of connections formed during re-innervation; and 3) patterns of abnormal neurogenesis in mammalian mutants. Offered in alternate years; offered in 1980–81. Instructor: Van Essen.

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. Primarily for graduate students. 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. Instructor: Lester.

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: neurophysiology (280), biochemistry (281), neurochemistry (282), developmental biology (283), genetics (284), immunology (285), molecular biology (286), virology (287), biophysics (288), psychobiology (289), cell biology (290), neurobiology (291).

BUSINESS ECONOMICS AND MANAGEMENT

Advanced Courses

BEM 100 abc. Business Economics and Management. *9 units (3-0-6); first, second, third terms. Open to graduate students.* This course endeavors to bridge the gap between engineering and business. The principal divisions 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. Instructors: Morrisroe, Forsythe.

BEM 102. Topics in Management Science. *9 units (3-0-6). Prerequisite: Ec 11a.* This course considers various management and industrial organization topics including queuing, inventory and reliability theory, optimal stopping with applications to job search and R&D. The underlying theory of simple stochastic processes will be developed as needed. Instructor: Reinganum.

BEM 110. Personnel Problems of Management. *9 units (3-0-6); first, second, third terms.* Introduces potential managers to how they can improve productivity by working effectively with their superiors, associates, and subordinates in selecting, developing, and motivating individuals while complying with company policies, union contracts, and federal and state regulations. Instructors: Staff.

BEM 123. Methods of Operations Research. *9 units (3-0-6). Prerequisite: Ma 1 abc.* This course will deal with techniques of optimization for problems in business and economics. The main emphasis will be on linear and nonlinear programming. Other topics will include dynamic programming, and methods for global optimization, such as branch and bound and implicit enumeration methods. Instructor: McKelvey.

BEM 145. Investment Analysis and Portfolio Management. *9 units (3-0-6).* This course introduces students to aspects of security analysis and portfolio theory. Problems in the valuation of financial instruments including stocks, bonds, options, warrants, and futures contracts, and the construction of an efficient portfolio from these instruments will be considered. Instructor: Forsythe.

CHEMICAL ENGINEERING

Undergraduate Courses

ChE 10. Introduction to Chemical Engineering Systems. *9 units (3-3-3); third term.* Basic concepts in transport phenomena and chemical kinetics are discussed with respect to a variety of problems of current interest to society. Instructor: Shair.

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. In the third quarter chemical reaction equilibria and phase equilibria with practical applications. Instructor: Gavalas.

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 of 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.

ChE 90. Chemical Engineering Systems. *9 units (3-3-3); third term. (Not open to freshmen.)* Same as ChE 10 but with projects selected to suit the needs and interests of upperclass students. Instructor: Shair.

Advanced Courses

ChE 101. Chemical Kinetics and Reactor Design. *9 units (3-0-6); third term. Prerequisites: Ch 21 ab, ChE 103 ab.* Chemical kinetics. Ideal chemical reactors. Temperature effects in chemical reactors. Residence time distribution theory. Noncatalytic fluid-solid reactions. Fluid-fluid heterogeneous reactions. Heterogeneous reactors, with emphasis on simultaneous transport and chemical reaction. The packed bed reactor. Instructor: Stephanopoulos.

ChE 103 abc. Transport Phenomena. *9 units (3-0-6); first, second, third terms. Prerequisites: AMa 95 or AM 113 ab, or concurrent registration in either.* A rigorous development of the basic differential equations of conservation of momentum, energy, and mass in fluid systems. Solution of problems involving fluid flow, heat transfer, convective diffusion, and staged and continuous unit operations. Instructors: Herbolzheimer (ac), Stephanopoulos (b).

ChE 105. Process Control. *9 units (3-0-6); second term. Prerequisite: AMa 95 abc or AM 113 abc, or concurrent registration in either.* Feedback control of linear systems. Frequency response. Sampled-data systems. Introduction to multivariable control. Instructor: Seinfeld.

ChE 110 ab. Optimal Design of Chemical Systems. *9 units (3-0-6); first, second terms. Prerequisites: ChE 63, ChE 101, ChE 103 or equivalent, or concurrent registration in ChE 103.* Principles of transport phenomena, chemical kinetics, chemical equilibria, and economics will be used in optimal design of chemical systems of major importance. Instructor: Corcoran.

ChE 111. Simulation and Design of Chemical Systems. *9 units (3-0-6); third term. Prerequisites: appropriate background in unit operations, reactor design, physical chemistry, and engineering economics (equivalent of ChE 110 ab).* Emphasis will be placed upon the simulation and optimization characteristics of chemical systems using FLOWTRAN. Instructor: Corcoran.

ChE 126 ab. Chemical Engineering Laboratory. *9 units (1-6-2); first, second terms.* Projects illustrative of problems in transport phenomena, unit operations, chemical kinetics, and reactor control are performed. Instructors: Shair (a), Seinfeld (b).

Graduate and Advanced Undergraduate Courses

ChE/Env 157 abc. Fundamentals of Air Pollution Engineering. *9 units (3-0-6); first, second, third terms. Open to graduate students and seniors with instructors' permission.* Principles necessary to understanding the sources, atmospheric behavior, and control of air pollutants. First term: Air quality and emission standards, air pollution sources, generation of pollutants in combustion systems. Second term: Fundamentals of particulate air pollutants, aerosol physics and chemistry, gas-to-particle conversion processes, control techniques for particulate pollutants, pollutant effects on visibility. Third term: Atmospheric chemistry, atmospheric diffusion, control techniques for gaseous pollutants. Instructors: Flagan, Cass, Seinfeld.

ChE 161. Advanced Chemical Kinetics and Reactor Design. *9 units (3-0-6); first term. Prerequisites: ChE 101 or equivalent.* Theories of reaction rates. Heterogeneous catalysis, including physical structure and characterization of catalysts. Catalyst poisoning. Combustion. Fluidized bed reactors. Statistical estimation of kinetic parameters. Stability of chemical reactors. Instructor: Bailey.

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. Localized and nonlocalized adsorption. General theories of heterogeneous catalysis by metals, semiconductors and insulators. Instructor: Weinberg.

ChE 163. Fundamentals of Biochemical Engineering. *9 units (3-0-6); second term. Prerequisites: ChE 101 or instructor's permission.* A first course in microbial and enzyme processes, natural or artificial, with applications to industrial fermentations, enzyme utilization, and wastewater treatment. Topics: Rudiments of microbiology; isolation and utilization of enzymes; kinetics of enzyme catalyzed reactions; substrate utilization and kinetics of microbial growth; microbial interactions of mixed cultures; transport phenomena in microbial systems; design and analysis of biological reactors; applications in industrial operations and natural systems. Instructors: Bailey, Stephanopoulos.

ChE/Ch 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 and distribution functions. The ideal crystal lattice. Instructor: Weinberg.

ChE 165. Applied Chemical Thermodynamics. *9 units (3-0-6); second term. Prerequisite: ChE 63 abc or equivalent.* Thermodynamics applied to both open and closed systems including those involved with chemical change. Ideal and real systems. Instructor: Shair.

ChE 166 ab. Engineering Properties of Polymeric Materials. *9 units (3-0-6); first, second terms. Prerequisite: AMa 95 or equivalent.* Basic engineering properties of polymeric materials for the materials scientist and the chemical, mechanical, aeronautical, electrical, and civil engineer. Instructor: Tschoegl.

ChE 167. Advanced Polymer Science. *9 units (3-0-6); third term. Prerequisite: ChE 166 ab or equivalent.* A course in the science of synthetic macromolecules: their characterization and properties. The emphasis is on an understanding of polymer properties in terms of molecular structure. Instructor: Tschoegl.

ChE 168. Polymer Science Laboratory. *9 units (0-7-2); third term. Prerequisite: ChE 166 ab or equivalent.* An introduction to some of the basic techniques employed in the synthesis and characterization of synthetic polymers. Instructor: Tschoegl.

ChE 169. Fundamental Concepts of Thermodynamics. *9 units (3-0-6); third term. Prerequisite: ChE 63 ab or equivalent.* An axiomatic exposition of the concepts and formalism of equilibrium thermostatistics and irreversible thermodynamics. Instructor: Tschoegl.

Ae/ChE 172 abc. Optimal Control Theory. *9 units (3-0-6); first, second, third terms.* Parameter optimization problems. Optimization problems for dynamical systems with terminal and path constraints (calculus of variations). Linear-quadratic approach to feedback controller design. Numerical methods for solving two-point boundary value problems. Selected topics in mathematical system theory. Optimal estimation, prediction, and smoothing for linear systems with additive Gaussian noise. Optimal control in the presence of uncertainty. Instructors: Staff.

ChE 173 ab. Advanced Transport Phenomena. *9 units (3-0-6); first, second terms. Prerequisite: AM 113 or AMa 95, or concurrent registration in either, or instructor's permission.* Foundations of heat, mass and momentum transfer. Governing differential equations; unidirectional flows; laminar flow of incompressible fluids at high and low Reynolds number; bubbles, drops and other small particles; forced and free convection heat and mass transfer. Selected topics from: transport processes in suspensions, packed beds or porous media; and mixing processes, such as Taylor diffusion. Instructor: Leal.

ChE 174. Special Topics in Transport Phenomena. *9 units (3-0-6); third term. Prerequisite: AM 113 or AMa 95, or concurrent registration in either, or instructor's permission.* Advanced problems in heat, mass and momentum transfer. Introduction to the mechanics of non-Newtonian liquids; selected topics in hydrodynamic stability theory; and transport processes in turbulent flows. Other topics may be discussed, depending upon the needs and interests of the class. Instructor: Leal.

ChE 280. Chemical Engineering Research. *Offered to Ph.D. candidates in Chemical Engineering.* Main lines of research now in progress are covered in detail in Section II.

CHEMISTRY

Undergraduate Courses

Ch 1 abc. General and Quantitative Chemistry. *6 units (3-0-3); first, second, third terms.* Lectures and recitation dealing with the general principles of chemistry and methods used in chemical research. The first quarter will focus on fundamental laws and theories of chemistry, particularly those aspects that relate to the electronic structure of atoms and molecules, chemical bonding, and chemical equilibrium. The second quarter will cover organic, organometallic, and inorganic chemical reactions with emphasis on molecular structure, stereochemistry, factors affecting reactivity, and the study of reaction mechanisms. The third quarter will discuss the principles and application of various physical methods employed in chemical research, including mass, ir, uv-visible, and nmr spectroscopy, techniques for precise structural determinations, radiochemistry and the use of radioisotopes, and chromatography. Graded pass/fail. Instructors: Dickerson, Richards.

Ch 2 abc. Advanced Placement in Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission.* Ch 2 will cover the principles of chemistry with emphasis on molecular symmetry, electronic structure of atoms and molecules, and modern methods for the determination of molecular structure. Graded pass/fail. Instructors: Baldeschwieler, Bercaw, Hopfield.

Ch 3 ab. Fundamental Techniques of Experimental Chemistry. *6 units (0-6-0), 3 a; 5 units (1-3-1), 3 b.* Ch 3 a introduces the basic principles and techniques of synthesis and analysis and develops the laboratory skills and precision that are fundamental to experimental chemistry, and is offered first, second, and third terms. Enrollment for first and second terms will be limited and is recommended only for students who have reasonable competence in the following areas: 1) chemical stoichiometry, 2) elementary chemical thermodynamics, 3) computations based on equilibrium relationships, 4) elementary chemical kinetics, and 5) introductory co-ordination chemistry. It is anticipated that most students will enroll for Ch 3 a third term by which time the above topics will have been presented in Ch 1. Ch 3 b, which is offered all three terms, provides an option for those who wish to experience the more sophisticated and demanding synthesis and characterization procedures of Ch 4 ab, but who lack the scheduling flexibility to enroll for the full 9 units assigned to these modules. Graded pass/fail.

Ch 4 ab. Synthesis and Analysis of Organic and Inorganic Compounds. *9 units (1-6-2); offered on first/second and second/third term bases. Prerequisite: Ch 3 a or instructor's permission.* This two-quarter laboratory introduces the student to methods of synthesis, separation, and instrumental analysis used routinely in chemical research. In Ch 4 a, spectroscopic techniques of analysis are emphasized, whereas chromatographic analysis serves as the unifying theme in Ch 4 b. Instructors: Collins and staff.

Ch 5 ab. Advanced Techniques of Synthesis and Analysis. *9 units (1-6-2); first, second terms. Prerequisite: Ch 4 ab.* The emphasis will be on modern synthetic chemistry. The specific experiments may change from year to year. For 1980–81, multistep syntheses of natural products, coordination complexes and air-sensitive organometallic complexes will be carried out using advanced synthetic methods and instrumentation. Instructors: Dervan, Grubbs.

Ch 14. Chemical Equilibrium and Analysis. *6 units (2-0-4); first term.* A systematic treatment of ionic equilibria in solution. Topics covered include acid-base equilibria in aqueous and nonaqueous solutions, complex ion formation, chelation, oxidation-reduction reactions, and some aspects of reaction mechanisms. Instructors: Anson, Schaefer.

Ch 15. Chemical Equilibrium and Analysis Laboratory. *10 units (0-6-4); first term. Prerequisites: Ch 1 abc, Ch 14 (may be taken concurrently).* Laboratory experiments are offered to illustrate 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, Raftery, Schaefer.

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.* The main emphasis is on atomic and molecular theory, quantum mechanics, statistical mechanics, thermodynamics, and chemical kinetics. Instructors: Marcus, McKoy.

Ch 24 ab. Introduction to Biophysical Chemistry. *9 units (3-0-6); second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc, Ch 21 a or Ph 2 abc.* Fundamental physical chemistry, with an emphasis on those topics most important in biology. Thermodynamics and its applications to aqueous solutions and living systems, membrane potentials and the thermodynamics of transport, reaction kinetics and mechanisms, transport properties, applications of molecular spectroscopy in biology, and statistical mechanics with applications to biological polymers. Instructor: Davidson.

Ch 26 ab. Physical Chemistry Laboratory. *10 units (0-6-4); second, third terms. Prerequisites: Ch 1 abc and Ch 21 a or equivalent.* Laboratory exercises that provide illustrations of the principles of physical chemistry, an introduction to problems of current interest, and techniques of contemporary research. Instructors: Samson, Zewail.

Ch 41 abc. Chemistry of Covalent Compounds. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 1 abc or instructor's permission.* This course will cover the synthesis, structure, and mechanisms of reactions of covalent compounds. Emphasis will be on the study of molecules formed from carbon and other first- and second-row elements. Instructors: Dervan, Ireland.

Ch 80. Chemical Research. *Offered to B.S. candidates in chemistry. Prerequisite: consent of research supervisor.* Experimental and theoretical research experiment requiring a report containing an appropriate description of the research work. Graded pass/fail.

Ch 81. Independent Reading in Chemistry. *Units by arrangement. Prerequisite: instructor's permission.* Occasional advanced work involving reading assignments and a report on special topics. No more than 12 units in Ch 81 may be used as electives in the chemistry option. Graded pass/fail.

Ch 90. Oral Presentation. *2 units (1-0-1); second term.* Training in the techniques of oral presentation of chemical topics. Practice in the effective organization and delivery of reports before groups. Graded pass/fail. Instructors: Anson, Dickerson, Marsh.

Advanced Courses

Bi/Ch 110 abc. Biochemistry. *12 units (4-0-8); first, second, third terms. Prerequisite: Ch 41 or instructor's permission.* Lectures and discussions on the molecular basis of biological structure and function. The course emphasizes macromolecular structure and the metabolic processes involved in energy storage and utilization and considers the storage, transmission, and expression of genetic information in prokaryotes and eukaryotes. It also includes other topics in biochemistry of higher organisms, such as molecular regulatory mechanisms and the biochemistry of cell membranes. Instructors: Campbell, Maniatis, Raftery, Richards.

Ch 112. Inorganic Chemistry. *9 units (3-0-6); second term. Prerequisite: Ch 41 abc or equivalent.* Introduction to group theory, ligand field theory, and bonding in coordination complexes and organotransition metal compounds. Systematics of synthesis, bonding, and reactivities of commonly encountered classes of transition metal compounds. Instructors: Bercaw, Gray.

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. Given in alternate years. Offered in 1980–81. Instructor: Anson

Ch 118 ab. Experimental Electrochemistry. *Units by arrangement; second, third terms.* Laboratory practice in the use of selected electrochemical instruments and techniques. The student may pursue a set of expository experiments or elect to carry out a research project in electrochemistry. Offered in 1980–81. Instructor: Anson.

Ch 120 abc. Nature of the Chemical Bond. *Part a, 9 units (3-0-6) second term; part b, 6 units (2-0-4) third term; part c, 6 units (1-1-4) third term. Prerequisite: Ch 21 a or an equivalent introduction to quantum mechanics.* Modern ideas of chemical bonding will be discussed with the emphasis on qualitative concepts and how they are used to make predictions of geometries, energies, excited states, and rules for chemical reactions. The objective of the course is to enable students to build a conceptual understanding sufficient for them to reliably apply the ideas and to make predictions of their own. Applications will emphasize molecules involving both main-group and transition metals and will include some discussion of impurity states in solids, and the bonding and reactions at surfaces of solids. Part c is a lab in which the student uses modern computer programs to calculate wavefunctions and properties of molecules. Part b is not a prerequisite for part c and need not be taken concurrently. Instructor: Goddard.

Ch 122 abc. Methods for the Determination of the Structure of Molecules. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or instructor's permission.* Modern methods used in the determination of the structure of molecules, including x-ray, electron, and neutron diffraction; mass spectrometry; optical, infrared, Raman, microwave, Mössbauer, nuclear magnetic, and electron spin resonance spectroscopy. Instructors: Baldeschwieler, Janda, Marsh.

Ch 125 abc. The Elements of Quantum Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or an equivalent brief introduction to quantum mechanics.* A first course in molecular quantum mechanics consisting of a quantitative treatment of quantum mechanics with applications to systems of interest to chemists. The course includes the basic elements of quantum mechanics, the electronic structure of atoms and molecules, the interactions of radiation fields and matter, scattering theory, and reaction rate theory. Instructors: Kuppermann, McKoy.

Ch 127 ab. Nuclear Chemistry. *9 units (3-0-6); first, second terms. Prerequisite: instructor's permission.* An introductory course on the properties of nuclei. Topics: radioactive decay; nuclear binding energies; interaction of radiation with matter; ion implantation; radiation damage; nuclear level structure; nuclear moments; nuclear reactions including fission. Topics covered depend on class interest. Given in alternate years. Not offered in 1980–81. Instructor: Burnett.

Ch 130 abc. Spectroscopy. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 125 abc.* This course will cover various topics in modern spectroscopy. The first term will include high resolution spectroscopy of small molecules, time-dependent perturbation theory, line shapes, angular momentum coupling, Stark effect, and Zeeman effect in context of rotational spectroscopy. An introduction to high resolution vibrational and electronic spectroscopy will also be given. The second term will cover time domain spectroscopy using the density matrix formulation. Examples will be taken primarily from nuclear magnetic resonance, including multiple-dimensional spectroscopic techniques. The third term will emphasize new laser techniques being used in chemistry—laser chemistry and laser spectroscopy. Background materials such as time-dependent processes and quantized coupling of radiation field to matter will also be presented. Not offered in 1980–81. Instructors: Janda, Zewail.

Ch 131. The Chemistry of Amino Acids, Peptides, and Proteins. *9 units (3-0-6); third term. Prerequisite: Ch 41 abc.* A discussion of the chemical reactions, structures, and functions of amino acids, peptides, and proteins. Given in alternate years. Not offered in 1980–81. Instructor: Schroeder.

Bi/Ch 132 ab. Biophysical Chemistry of Macromolecules. *9 units (3-0-6); second, third terms. Prerequisite: Ch 21 abc or the equivalent.* The biophysical chemistry of nucleic acids, proteins, and membranes. Topics are chosen because of their relevance to molecular biology. Given in alternate years. Offered in 1980–81. Instructors: Chan, Hopfield.

Ch 135 ab. Chemical Dynamics. *9 units (3-0-6); second, third terms. Prerequisites: Ch 21 abc and Ch 41 abc or equivalent, or with consent of instructor.* Rate energetics and mechanisms of chemical reactions. Theory of elementary processes. Application to simple and complex organic, inorganic, and enzymatic systems. Given in alternate years. Offered in 1980–81. Instructor: Beauchamp.

Ch 140 abc. Special Topics in Chemistry. *Units by arrangement; first, second, third terms.* Lectures on a series of subjects of current interest at the forefront of chemistry. Not offered in 1980–81.

Ch 144 ab. Advanced Organic Chemistry. *9 units (3-0-6); first, second terms. Prerequisite: Ch 41 abc or equivalent.* Lectures will focus on the design and execution of experiments in the study of organic reaction mechanisms. A critical analysis of current problems in physical organic chemistry will be presented such that research papers can be read with a real application of their chemical context and relevance. Topics such as thermochemical estimates, carbonium ions, carbanions, carbenes, nitrenes, free radicals, biradicals, orbital symmetry, photochemistry, thermal reactions, and electrophilic and nucleophilic substitution will be covered. Instructor: Dougherty.

Ch 154. Organometallic Chemistry. *6 units (2-0-4); third term. Prerequisite: Ch 112 or equivalent.* A general discussion of the reaction mechanisms, synthetic and catalytic uses of transition metal organometallic compounds. Instructor: Grubbs.

ChE/Ch 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 and distribution functions. The ideal crystal lattice. Instructor: Weinberg.

Ch 180. Chemical Research. *Units by arrangement. Offered to M.S. candidates in chemistry.* Graded pass/fail.

Ch 212. Advanced Inorganic Chemistry. *9 units (2-0-7); second term. Prerequisites: Ch 112 and Ch 21 abc or concurrent registration.* Thorough treatment of the electronic structures, spectroscopy, photochemistry, and reaction mechanisms of inorganic molecules, with emphasis on transition metal complexes. Given in alternate years. Not offered in 1980–81. Instructor: Gray.

Ch 213 abc. Advanced Ligand Field Theory. *12 units (1-0-11); first, second, third terms. Prerequisite: Ch 21 abc or concurrent registration.* A tutorial course that 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 227. Advanced Topics in Chemical Physics. *9 units (3-0-6); third term. Prerequisite: Ch 125 or equivalent.* Experimental and theoretical aspects of molecular beam scattering will be discussed. Topics to be covered will include reactive scattering of simple systems, photofragment spectroscopy, and data analysis methods, as well as a discussion of beam production and product detection methods. Instructor: Sparks.

Ch 229 abc. X-Ray Diffraction Methods. *6 units (2-0-4); first, second, third terms.* The techniques of structure analysis by X-ray diffraction, protein crystallography, direct phase analysis methods, lattice vibrations, and refinement and assessment of accuracy of structure determination. Given in alternate years. Offered in 1980–81. Instructor: Samson.

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. Given in alternate years. Not offered in 1980–81. Instructors: Evans, Ireland.

Ch 244 a. Topics in Chemical Biology. *6 units (3-0-3); first term.* Topics treated will include the molecular basis of membrane structure and function, enzymatic catalysis, regulation of protein behavior, and immunochemistry. A proportion of the course will consist of reports and accompanying discussions by participating students on topics within these areas. Not offered in 1980–81.

Ch 247 a. Organic Reaction Mechanisms. *6 units (2-0-4); third term.* A mechanistic view of free radical reactions using examples from biological systems will be developed. Topics such as initiation, termination, and propagation of radical reactions *in vivo,* mechanisms of lipid damage, spin labeling, photosynthesis, oxygen radicals and oxygen toxicity, and radical reactions in proteins and nucleic acids will be discussed. Not offered in 1980–81. Instructor: Dervan.

Ch 280. Chemical Research. By arrangement with members of the faculty, properly qualified graduate students are directed in research in chemistry. Hours and units by arrangement.

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 a reinforced concrete building, arch bridge, gravity dam, or engineering facility. Each project considers initial conception, cost-benefit, and optimum design, and concludes with 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.* 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, interparticle reactions, and soil structure. Linear constitutive relations for soils, including steady state and transient water flow. In the second term, attention is given to nonlinear soil behavior, theories of yielding, plasticity, and problems of plastic stability. Failure modes of footings, walls, and slopes. Text: *Principles of Soil Mechanics,* Scott. Instructor: Scott.

CE 124. Special Problems in Structures. *9 units (3-0-6); any term.* Selected topics in structural mechanics and advanced strength of materials to meet the needs of first-year graduate students. Instructors: Staff.

CE 130 abc. Civil Engineering Seminar. *1 unit (1-0-0); each term.* All candidates for the M.S. degree in Civil Engineering are required to attend a graduate seminar, in any division, each week of each term. Graded pass/fail. Instructor: Jennings.

CE 150. Foundation Engineering. *9 units (3-0-6); third term. Prerequisite: CE 115 ab.* Methods of subsoil exploration. Study of types and methods of design and construction of foundations for structures, including single and combined footings, mats, piles, caissons, retaining walls, cofferdams, and methods of underpinning. Instructor: Scott.

CE 180. Experimental Methods in Earthquake Engineering. *9 units (1-5-3); third term. Prerequisite: AM 151 abc or equivalent.* Laboratory work involving calibration and performance of basic transducers suitable for the measurement of strong earthquake ground motion, and of structural response to such motion. Study of principal methods of dynamic tests of structures including generation of forces and measurement of structural response. Instructor: Jennings.

CE 181. Principles of Earthquake Engineering. *9 units (3-0-6); first 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; engineering implications of geological phenomena, including earthquake mechanisms, faulting, fault slippage, and the effects of local geology on earthquake ground motion. Instructor: Jennings.

CE 182. Structural Dynamics of Earthquake Engineering. *9 units (3-0-6); second term. Prerequisite: AM 151 ab.* Response of structures to earthquake ground motion; nature of building code requirements and their relation to actual behavior of structures such as long-span suspension bridges, and fluids in tanks and reservoirs; earthquake design criteria. Instructor: 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 300. Civil Engineering Research.

For courses in Environmental Engineering Science and Hydraulics see separate sections.

COMPUTER SCIENCE[1]

Undergraduate Courses

CS/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 circuitry. The formulation of logical equations; their realization in hardware; binary arithmetic; its implementation with logical functions. Design and construction of a simple computer. Graded pass/fail. Instructor: Campbell.

CS 10. Introduction to Computing. *6 units (2-0-4); third term.* State machines, stored program machines, control structures, modular program design, symbolic control and data manipulation, assemblers, compilers and high-level programming language. Instructors: Staff.

[1]For linguistics see page 330.

CS/EE 11. Digital Electronics Laboratory. *6 units (0-3-3); third term. Prerequisites: CS/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 CS/EE 4. The student is expected to design, build, and test his or her own digital system. Graded pass/fail. Instructor: Bacon.

CS 80 abc. Undergraduate Research in Computer Science. *Units in accordance with work accomplished. Consent of both research adviser and course supervisor required before registering.* This course provides supervised research in computer 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: Staff.

Advanced Courses

CS 112. Principles of Digital Information Processing. *9 units (3-3-3); first term. Prerequisites: CS/EE 4 and CS 10 or their equivalents.* CS 112 presents the principles and concepts of information processing systems with emphasis on the design of stored program, synchronous computers, minimization of Boolean functions, switching theory, arithmetic algorithms, machine models, and assembler language programming. Instructor: Ray.

CS 114. Microprocessor Systems. *9 units (3-3-3); second term. Prerequisite: CS 112 or equivalent.* This course presents the issues peculiar to microprocessors and microprocessor systems. Emphasis is on student solutions to real problems using development aids and interactive computing. Instructor: Ray.

CS 116. Technology, Architecture, and Applications of Computers. *6 units (3-0-3); third term. Prerequisite: CS 112 or equivalent.* CS 116 offers a series of seminars on the technology, architecture, and applications of computers. About half of the lectures will be given by guests from industry and from the academic departments at Caltech. Instructor: Ray.

CS/EE 119 abc. Principles of Waveform Processing. *9 units (3-3-3).* An introductory course designed to provide the basic skills for research in and application of signal processing. Topics include: 1) Basic linear signal processing theory: convolution, the Fourier transform, Fourier series, the z-transform, the DFT and FFT, sampling and filtering; 2) the uncertainty principle: band-limited and time-limited signals, windowing; 3) the Hilbert transform: causality and spectral factorization, frequency modulation; 4) elementary stochastic processes: spectral estimation, smoothing, filtering and prediction; 5) nonlinear signal processing theory: Polynomial systems, homomorphic processing; 6) speech processing: speech models, linear predictive coding; and 7) image processing: image transforms, coding, restoration, and enhancement. The lab consists of computer programming projects, including an FFT, convolution, filter design, and specialized studies, which provide the student with practical day-to-day experience in digital signal processing. This course will be held in alternate years, beginning in 1981–82. CS/EE 119 c only will be held during first term, 1980–81. Instructor: Kajiya.

CS/EE 121. Microprocessor Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor; third term. Prerequisite: CS 114 or equivalent.* A project laboratory to permit the student to design and build a microprocessor system. Instructor: Ray.

CS 137. Systematic Computer Programming. *12 units (3-3-6); first term. Prerequisite: CS/EE 10 or equivalent.* 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 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. Instructors: Staff.

CS 138. Data Structures and Algorithms. *12 units (3-3-6); second term. Prerequisite: CS 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. Instructors: Staff.

CS 139. Multiprogramming and Resource Sharing. *12 units (3-3-6); third term. Prerequisites: CS 137, CS 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. Instructors: Staff.

CS 140 abc. Programming Laboratory. *12 units (3-9-0); first, second, third terms. Prerequisites: CS 137, CS 138 or CS 286.* 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: Thompson.

CS 141 abc. Formal Models of Computation. *9 units (3-0-6); first, second, third terms.* This course enables students to be familiar with the main theoretical results of computer science, points out to what extent these results are relevant to computer applications, and facilitates 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: Kajiya.

CS/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 studied. Real-life data bases from a variety of subject areas will be analyzed. The computer will be used extensively. Not offered in 1980–81. Instructor: Thompson.

CS 150 ab. Control of Movement in Intelligent Systems. *9 units (3-3-3); first and second terms.* Special attention is placed on the relationship between man-made machines that exhibit artificial intelligence (robots), and biological organisms with natural intelligence. Topics include: kinematics and dynamics of manipulators, manipulator design criteria, trajectory generation and control, adaptation and motor learning, visual and tactile sensing, automatic planning and problem solving, legged locomotion. Students will develop programming or construction projects related to one or more of these topics. Instructors: Staff.

CS 153. Robotics Project Laboratory. *9 units (1-8-0); third term. Prerequisites: CS 150 ab or permission of instructor.* A project laboratory that permits the student to design and build a system that incorporates the essential components of a robot; sensing, computation, and control.

CS 180. Masters Thesis Research. *Units (total of 45) are determined in accordance with work accomplished. Incoming M.S. students should register for 9 units first term.*

CS/EE 181 abc. Integrated Circuit Design. *12 units (3-3-6); first, second, third terms. Prerequisite: proficiency in semiconductor device physics, circuit design, and logic design.*

An advanced course in the design, production, and use of large-scale integrated circuits. Emphasis on system realization in LSI. Instructors: Mead, Seitz.

CS/EE 183 ab. Integrated Digital Communication. *9 units (3-0-6); first, second terms. Prerequisites: At least two terms chosen from among EE 60, EE 160 abc, EE 163 abc, or CS/EE 119 abc, or graduate standing in Electrical Engineering or Computer Science.* Covers the concepts and systems used in transmitting and switching signals and data digitally in communication networks, with emphasis on common-carrier and computer communication. Subjects include digital encoding and transmission, pulse code modulation switching, circuit switching, packet switching, computer communications, and analysis and design of digital switching networks. The emphasis throughout is on the changes in communication concepts being wrought by the digital revolution. Offered in alternate years; offered in 1980–81. Instructor: Posner.

CS 185. Self-Timed Systems. *9 units (3-0-6); second term. Prerequisite: CS 4 and/or permission of instructor.* Self-timed logic is a discipline of digital system design in which the system parts, called elements, keep time to themselves. Correct sequential operation of the system is insensitive to element and wiring delays. Relationship of time and sequence at the logical and organizational level, partial ordering of system events, concurrency, arbitration, design of self-timed elements are topics that will be considered. Instructor: Seitz.

CS 198. Special Topics. *9 units (3-0-6). Prerequisites: CS 137, 138, 139, or CS 110 or equivalent and permission of instructor.* Topics of interest in computer science are offered on an informal basis. Topics offered in the past or planned include: design of highly parallel computers, automatic circuit layout, and special purpose programming languages. Topics vary from quarter to quarter. May not be offered in any particular quarter. Instructors: Staff.

CS 270 abc. Computer Aided Design. *9 units (3-0-6).* An overall view of computer subsystem design flow in practice, and of required computer design aids: design languages and representations; design data bases and data structures; topological, geometrical and electrical models; algorithmic and analytic techniques for partitioning; design verification, simulation, testing, checking, and layout. Incorporation of programs into computer aided design systems. A principal goal of the course is the specification, design, carrying out, and documentation of portions of an actual design system, with the student working as a member of a design team. Instructors: Staff.

CS 280. Research in Computer Science. *Units in accordance with work accomplished. Approval of student's research adviser and his or her option adviser must be obtained before registering.*

CS 282 abc. Reading in Computer Science. *6 units or more by arrangement; first, second, third terms. Prerequisites: CS 137, CS 138 or equivalent.* A seminar in which a small group of students and the instructor discuss and summarize the mechanization of selected computations. The pertinent literature will be reviewed. Emphasis will be placed on original work by the student; a written report will ordinarily be expected. Instructors: Staff.

CS 284 abc. Computer Graphics. *9 units (3-3-3). Prerequisites: CS 10 and CS/EE 11 or permission of instructor.* The art of making pictures by computer and the software and hardware mechanisms used will be covered in lectures, films, programming exercises, and student projects. Topics covered will include: graphic output, graphic input, three-dimensional graphics, hidden surface algorithms, graphics programming systems, and graphics hardware. Instructors: Staff.

CS 286. Computer Architecture. *12 units (3-6-3); first term. Prerequisites: CS 137 or CS/EE 281. Instructor's permission to register also required.* Relative merits of hardware and software implementations of different computer functions. Examples will be taken from available and proposed systems. Intensive student participation leading to continuing student hardware and software projects is expected. Instructors: Staff.

CS 288 abc. Philosophy of Computing. *9 units (3-3-3). Prerequisite: instructor's permission.* Topics in the design and use of computers for advanced applications will be considered. What is the distinction between data and program? How are data elements identified? accessed? recognized? How do different computer architectures and computer languages reflect the way their designers answered these questions? Student participation in projects, reporting on selections from the literature, and class discussion expected. Since the content of this course may change from year to year, it may be repeated for credit. Instructors: Staff.

ECONOMICS

Undergraduate Courses

Ec/SS 11 a. Social Science Principles and Problems—Introduction to Microeconomics. *9 units (3-0-6); first, second terms.* An introduction to the methodology of social sciences, particularly economics, and the applications of that methodology to current social problems. Instructors: Davis, Plott.

Ec/SS 11 b. Social Science Principles and Problems—Non-Market Decisions. *9 units (3-0-6); second, third terms. Prerequisite: Ec/SS 11 a or equivalent.* This course concentrates on non-market decisions. It focuses on committee and legislative decisionmaking as well as providing an introduction to recent work in the theory of voting and the political process. Instructors: Fiorina, Bates.

Ec/SS 11 c. Social Science Principles and Problems—Applications to Public Policy. *9 units (3-0-6); third term. Prerequisite: Ec/SS 11 b or equivalent.* 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. Not offered in 1980–81. Instructor: Noll.

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 15. Introduction to Macroeconomics: Principles and Problems. *9 units (3-0-6); second term. Prerequisite: Ec/SS 11 a or equivalent.* Problems of inflation and depression and the tools of monetary and fiscal policy. Instructors: Klein, Oliver.

Ec 98 abc. Senior Research and Thesis. *Prerequisite: instructor's permission.* Senior economics majors wishing to undertake research may elect a variable number of units, not to exceed 12 in any one term, for such work under the direction of some member of the economics faculty.

HSS 99, See page 325 for description.

Advanced Courses

Ec 101. Selected Topics in Economics. *9 units (3-0-6).* Instructors: Staff, visiting lecturers.

Ec 115. Population and Environment. *9 units (3-0-6); third term.* This course will be concerned with: 1) the causes and consequences of rapid population growth; and 2) the problem of reducing the rate of growth through control of fertility. Instructor: Scudder.

Ec 116. Contemporary Socioeconomic Problems. *9 units (3-0-6); first term. Prerequisites: Ec/SS 11 a and Ec/SS 11 b or equivalent.* 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. Not offered in 1980–81. Instructor: Klein.

Ec 118. Environmental Economics. *9 units (3-0-6); third term. Prerequisite: Ec/SS 11 a or equivalent.* The methods of price and welfare theory are used to analyze the causes of air, water, and other environmental pollution, to examine their impact on economic welfare, and to evaluate selected policy alternatives for managing our environment. Instructors: Staff.

Ec 120. International Economic Theory. *9 units (3-0-6); third term. Prerequisites: Ec/SS 11 a and Ec/SS 11 b or equivalent.* An investigation of the factors affecting the exchange of goods and services and the flow of capital between markets. Theory is stressed in this course. Instructor: Oliver.

Ec 121 ab. Intermediate Microeconomics. *9 units (3-0-6); first, second terms. Prerequisites: Ec/SS 11 a and Ec/SS 11 b or equivalent.* 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. Instructors: Wilde, Reinganum, Border.

Ec 122. Econometrics. *9 units (3-0-6); second term. Prerequisite: Ma 112 a.* The application of statistical techniques to the analysis of economic data. Instructor: Grether.

Ec 124 abc. Mathematical Methods of Economics. *9 units (3-0-6). Prerequisites: Ma 108 a and Ec 121 ab (can be taken concurrently).* Mathematical tools of modern economic theory and their applications to consumer theory, general equilibrium, and welfare economics will be presented. Emphasis will be on developing rigorous exposition by the students. Not offered in 1980–81. Instructor: Staff.

Ec 125 ab. The Economics of International Relations. *9 units (3-0-6); first, second terms. No prerequisite.* An examination of the economic and political factors that influence relations among nations. Among the topics discussed are foreign exchange markets, international banking and business, the pattern of international trade and payments, the International Monetary Fund and the World Bank, the European Common Market and the American Foreign Aid Program. The foreign economic policy of the United States is analyzed in some detail. This course emphasizes theory less than does Ec 120. Instructor: Oliver.

Ec 126 ab. Money, Income, and Growth. *9 units (3-0-6); first, second terms. Prerequisites: Ec/SS 11 a and Ec/SS 11 b or equivalent or instructor's permission.* This course includes an intensive study of Keynes's *General Theory of Employment* and post-Keynesian developments in the theory of income, consumption, investment, and growth. Instructors: Staff.

Ec 127. 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. The Elements of Dynamic Economics. *9 units (3-0-6); first term. Prerequisite: Ec/SS 11 a or equivalent.* This course is concerned with explaining: 1) the role of competition as a determinant of the rate of progress; and 2) the relationship between microbehavior and macroperformance. Instructor: Klein.

Ec 129. Economic History of the United States. *9 units (3-0-6); second term. Prerequisite: Ec/SS 11 a or equivalent.* An examination of certain analytical and quantitative tools and their application to American economic development. Instructor: Davis.

Ec 130 ab. Political Foundations of Economic Policy. *9 units (3-0-6); first, second terms.* Mathematical theories of individual and social choice are introduced as an approach to the class problems of welfare economics and economic policy. Not offered in 1980–81. Instructor: Plott.

Ec 131. Labor Economics. *9 units (3-0-6). Prerequisite: Ec/SS 11 a or equivalent.* This course will focus on the modern theory of labor markets. Empirical evidence will be used to supplement theoretical results. Instructor: Wilde.

Ec/PS 134. The Political Economy of Urban Areas. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* This course will focus on development of a theory of urban government using analytic concepts from microeconomics and political science. Not offered in 1980–81. Instructors: Staff.

Ec 135. Marxist Economics. *9 units (3-0-6); second term. Prerequisite: Ec/SS 11 a or equivalent.* A critical survey of the economic theory of capitalism as developed in the writings of Marx, Engels, and Lenin. Not offered in 1980–81. Instructor: Quirk.

Ec 138. Introduction to Welfare Economics. *9 units (3-0-6). Prerequisite: Ec/SS 11 a.* Economic efficiency of various market arrangements will be discussed as well as modern developments in the theories of decentralization and informational efficiency. Not offered in 1980–81. Instructor: Border.

Ec 140. Economics of Energy Policy. *9 units (3-0-6); third term. Prerequisite: Ec 121 ab or equivalent.* The course focuses on issues in contemporary resource/energy policies with particular emphasis on federal energy independence policy. After a brief survey in theory of resource economics, major issues are identified and their current solutions are contrasted to other alternatives in terms of feasibility and optimality. Not offered in 1980–81. Instructors: Staff.

Ec 143. Resource Economics. *9 units (3-0-6). Prerequisite: Ec/SS 11 a.* This course covers various topics in the allocation of natural resources. It will focus on problems of extraction, exploitation, exploration, etc. for renewable and nonrenewable resources, e.g., fisheries, fresh water, fossil fuels. Instructor: Quirk.

Ec 150. Independent Study on Population Problems. *Units to be arranged. Prerequisite: Ec 115 or equivalent.* This course covers a broad range of problems including the technological, economic, demographic, sociological, political, and biological aspects of population growth, movement, and density. Graded pass/fail. Instructors: Scudder, Bonner, Munger.

ELECTRICAL ENGINEERING

Undergraduate Courses

CS/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 circuitry. The formulation of logical equations; their realization in hardware; binary arithmetic; its implementation with logical functions. Design and construction of a simple computer. Graded pass/fail. Instructor: Campbell.

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; their characterization in frequency and time domain. Amplifier gain, frequency response. Power, dynamic range, design of power amplifiers. Design and construction of a typical electronic device such as a tape recorder or Hi-Fi amplifier. Graded pass/fail. Not offered in 1980–81.

CS/EE 11. Digital Electronics Laboratory. *6 units (0-3-3); third term. Prerequisites: CS/EE 4 and approval of project proposal. 6 units credit allowed toward freshman laboratory re-*

quirement. An introductory nonstructured project laboratory designed to provide an opportunity for projects related to the course CS/EE 4. The student is expected to design, build, and test his or her own digital system. Graded pass/fail. Instructor: Bacon.

EE 13 ab. Circuit Theory. *9 units (3-0-6); first, second terms. Prerequisites: Ma 1 abc and Ph 1 abc.* Analysis of linear systems in the time and frequency domains. Loop and node equations, two terminal pair networks, Fourier and Laplace transforms, convolution, autocorrelation, feedback systems, flow graphs, and distributed linear systems. Introductory synthesis and filter theory. Computer solution of problems. Not offered in 1980-81.

EE 14 abc. Introduction to Electronic Engineering. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Linear circuit analysis, Kirchoff's laws and the circuit elements, transient and steady-state network solutions, phasor notation and manipulation, Thevenin and Norton theorems, piece-wise linear analysis, power considerations, introduction to Laplace transform and the pole-zero description of network characteristics. Physical principles of device operation, silicon diodes, FET's and transistors, conduction in semiconductors, drift and diffusion, temperature effects and device characteristics and limitations, models. Active circuit analysis, distortion, frequency response and multistage amplifiers, stability and Nyquist's Theorem, large signal analysis, multivibrators and power amplifiers. Instructor: Mullen.

EE 40. Fundamentals of Energy Processing Systems. *9 units (3-0-6); first term. Prerequisites: Ma 2 abc, Ph 2 abc, EE 14 abc, EE 90 abc.* Introduction to electrical energy processing systems as distinct from information processing systems. Elementary magnetic devices: generators, motors, and transformers. The special problems of electronic power processing. Instructor: Cuk.

EE 60. Communication System Fundamentals. *9 units (3-0-6); third term. Prerequisites: Ma 2 abc, EE 14 abc.* Laws of radio and guided transmission, noise as a limiting factor, AM and FM signals and signal-to-noise ratio, sampling and digital transmission, errors, information theory, error correction. Emphasis will be on fundamental laws and equations and their applications rather than on derivations. Instructor: Posner.

EE 78 abc. Senior Thesis, Experimental. *9 units; first, second, third terms. Prerequisite: instructor's permission.* This course is intended to provide supervised experimental research experience, and is open only to senior electrical engineering majors. Requirements will be set by individual faculty members, but will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Electrical Engineering Undergraduate Committee. Not offered on a pass/fail basis. Instructor: Bridges (in charge).

EE 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 electrical engineering majors. Requirements will be set by individual faculty members, but will include a written report based upon the work performed. The selection of topic and the final report must be approved by the Electrical Engineering Undergraduate Committee. Not offered on pass/fail basis. This course cannot be used to satisfy the laboratory requirement in EE. Instructor: Bridges (in charge).

EE 90 abc. Laboratory in Electronics. *Units by arrangement in multiples of 4 units (0-3-1); first, second, third terms.* An introductory laboratory normally taken in the sophomore and/or junior year. Experiments acquaint the student with the characteristics of linear and passive electronic circuits and devices and the behavior of simple linear and nonlinear active elements. Individual projects may be performed. *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. EE 90 a will not be offered in 1980-81. Instructor: Wilts.

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 CS 112, 114, 116 (may be taken concurrently). Open to seniors, others only with consent of instructor.* An opportunity to do original projects in electronics and electronic circuits. Selection of significant projects, the engineering approach, demonstration of a finished product through 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: Bacon.

Advanced Courses

EE/Mu 107 abc. Projects in Music and Science. *Units to be individually arranged, up to a maximum of 9.* One two-hour meeting each week with a second meeting at the discretion of the instructor. In this course, a small number of students will carry out, singly or in groups, projects of study or research exploring the connections of music with the sciences, such as the possibility of rules for expressive performance, objective versus subjective in audio, or materials and instrument design. EE/Mu 107 a will be devoted to Analytic Listening to Live and Reproduced Sound; it may be taken by itself and has no prerequisites. *EE/Mu 107 b & c, devoted to the projects, require instructor's permission and 107 a as prerequisites.* Credit in music or EE but not in both. Instructor: Boyk.

EE 112 abc. Active Filter Synthesis. *9 units (2-3-4); first, second, third terms. Prerequisite: AMa 95 abc.* Realization of electrical filter functions through use of operational amplifiers and digital filters. Laplace and z-transform theory will be used extensively. Laboratory work will include construction and testing of various filter designs. Digital systems will be realized using a general purpose laboratory digital filter and also by computer modelling. Instructor: Martel.

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.* Topics in various fields of electronics by guest lecturers from industry. Specific topics and scope announced prior to registration. A seminar format. Graded pass/fail. Offered as announced. Instructors: Staff.

EE 117 ab. Power Electronics. *9 units (3-1-5) second term; (3-2-4) third term. Prerequisite: EE 14 abc or equivalent.* Introduction to repetitively switched power circuits for ac-to-dc, dc-to-ac, and dc-to-dc conversion and/or regulation of voltage or current in high-power applications: power supplies, motor controls, power amplifiers. Components, control techniques, analysis, and design. Laboratory part of the course includes the design of a switching dc-to-dc converter (part a), closed loop regulator (part b), and verification of the analysis technique and measurement methods through the laboratory assignments (part b). Instructor: Cuk.

CS/EE 119 abc. Principles of Waveform Processing. *9 units (3-3-3).* An introductory course designed to provide the basic skills for research in and application of signal processing. Topics include: 1) Basic linear signal processing theory: convolution, the Fourier transform, Fourier series, the z-transform, the DFT and FFT, sampling and filtering; 2) the uncertainty principle: band-limited and time-limited signals, windowing; 3) the Hilbert transform: causality and spectral factorization, frequency modulation; 4) elementary stochastic processes: spectral estimation, smoothing, filtering and prediction; 5) nonlinear signal processing theory: polynomial systems, homomorphic processing; 6) speech processing: speech models, linear predictive coding; and 7) image processing: image transforms, coding, restoration, and enhancement. The lab consists of computer programming projects, including an FFT, convolution, filter design, and specialized studies, which provide the student with practical day-to-day experience in digital signal processing. This course will be held in alternate years, beginning in 1981–82. CS/EE 119 c only will be held during first term, 1980–81. Instructor: Kajiya.

CS/EE 121. Microprocessor Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor; third term. Prerequisite: CS 114 or equivalent.* A project laboratory to permit the student to design and build a microprocessor system. Instructor: Ray.

EE 151 abc. Electromagnetism. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc, AMa 95 abc.* Primarily for electrical engineering students. Electrostatics, magnetostatics, Maxwell's equations, waveguides, cavity resonators, and antennas. Topics on propagation in the ionosphere, propagation over the earth's surface, and modern microwave tubes. Instructor: Rutledge.

EE 155 abc. Electromagnetic Fields. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 106 abc or equivalent.* Advanced course in electromagnetic theory and its application to the theory of electromagnetic fields in matter, the theory of electric and magnetic properties of matter, and the theory of electromagnetic wave propagation. Not offered in 1980-81.

EE 160 abc. Introduction to Communication Science and Systems. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ma 2 abc, Ph 2 abc.* Relevant to communication in its diverse scientific and commercial applications. The first quarter taken alone provides an introduction to the theory of signal detection in the presence of noise; suitable also for students in other areas such as astronomy, physics, and seismology. The second quarter covers communication signals over terrestrial and space links. The third quarter covers communication channels and sources, including data, voice, and video. Fulfills EE 60 requirement for those electrical engineers interested in communications. Instructor: Rauch.

EE 163 abc. Introduction to Communication Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc.* Mathematical models of communication processes; signals and noise as random processes; correlation functions and spectra; modulation and spectral occupancy; error probability and signal-to-noise ratio; optimum detection and estimation in digital and analog communication systems. Fundamentals of information and coding theory, including channel capacity and Shannon's Theorem; block and convolutional codes; and rate distortion theory. Instructor: Lesh.

EE 165 abc. Topics in Telecommunication System Engineering. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 160 abc or EE 163 abc or permission of instructor.* For students having some familiarity with telecommunication elements and models. Considered are approaches to the engineering design of overall telecommunication systems based on specifications and constraints. Topics will include terrestrial, satellite, and deep space communication with both transmission and switching considered. Topics covered and examples used depend on instructor's and students' interests. Instructor: Yuen.

CS/EE 181 abc. Integrated Circuit Design. *12 units (3-3-6); first, second, third terms. Prerequisite: proficiency in semiconductor device physics, circuit design, and logic design.* An advanced course in the design, production, and use of large-scale integrated circuits. Emphasis on system realization in LSI. Instructors: Mead, Seitz.

EE 182 abc. Bipolar Device and Electronic Circuit Modeling. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 14 abc.* Modeling of devices used in LSI circuits and determination of their parameters. Estimation of bandwidth, transient response, and sensitivity, including use of SPICE circuit analysis program. Analysis of high-frequency IC's, including current gain cells, high-speed level shifters, and differential amplifiers. Instructor: Choma.

CS/EE 183 ab. Integrated Digital Communication. *9 units (3-0-6); first, second terms. Prerequisites: At least two terms chosen from among EE 60, EE 160 abc, EE 163 abc, or CS/EE 119 abc, or else graduate standing in Electrical Engineering or Computer Science.* Covers the concepts and systems used in transmitting and switching signals and data digitally in communication networks, with emphasis on common-carrier and computer communication.

Subjects include digital encoding and transmission, pulse code modulation switching, circuit switching, packet switching, computer communications, and analysis and design of digital switching networks. The emphasis throughout is on the changes in communication concepts being wrought by the digital revolution. Offered in alternate years; offered in 1980–81. Instructor: Posner.

EE 191. Advanced Work in Electrical Engineering. *Units to be arranged.* Special problems relating to electrical engineering will be arranged. Primarily for undergraduates. Students should consult with their advisers. Graded pass/fail.

EE 194. Microwave Laboratory. *9 units (1-4-4); first term. Prerequisite: APh 106 abc, or 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. Not offered in 1980–81.

EE 243 abc. Quantum Electronics Seminar. *6 units (3-0-3); first, second, third terms.* Advanced treatment of topics in the field of quantum electronics. Each weekly seminar consists of a review and discussion of results in the areas of quantum electronics and optoelectronics. Instructor: Yariv.

EE 255 abc. Problems in Electromagnetic Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 155 abc or equivalent.* A course in the advanced mathematical methods of electromagnetic theory and gravitational electrodynamics. Text: Course notes. Not offered in 1980–81. Instructor: Papas.

EE 291. Advanced Work in Electrical Engineering. *Units to be arranged.* Special problems relating to electrical engineering. Primarily for graduate students. Students should consult with their advisers.

ENGINEERING (GENERAL)

E 5. Laboratory Research Methods in Engineering and Applied Science. *6 units (1-3-2); second term. 6 units credit allowed toward freshman laboratory requirement.* An introduction to experimental methods and problems typical of a variety of engineering fields. Staff members representing various areas of interest within engineering and applied science will supervise experiments related to their specialty. The experiments will be selected from such fields as fluid mechanics, elasticity and plasticity, dynamics and vibration, heat transfer, gas-dynamics, 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 or her. Instructors: Gould and staff.

E 10. Technical Seminar Presentations. *2 units (1-0-1); second term (the first 36 persons to register will be accommodated this term. Any additional students registered will be scheduled for the third term).* This course in seminar presentations is designed to meet the needs of engineers and engineering managers. The student receives guidance and practice in organizing and preparing the topic for presentation and in speaking with the help of visual aids, including the blackboard, the overhead projector, and the slide projector. Instructors: Staff.

E 13. System Dynamics. *12 units (3-0-9); first term. Prerequisites: Ma 1 abc, Ph 1 abc, or instructor's permission. This course may be substituted for EE 13 a and serves or may serve as a prerequisite to EE 13 b.* Predicting the behavior of systems of physical members from their mathematical models—mechanical, electrical, fluid, thermal, and others. Natural dynamic characteristics and stability: s-plane analysis and Routh's method. Dynamic coupling and natural modes. Forced response using Fourier, impulse, and Laplace techniques. Not offered in 1980-81.

E 101. Introduction to Automatic Control. *9 units (3-0-6); third term. Prerequisite: E 13 or equivalent.* Design of linear feedback control systems for error, stability, and dynamic response specifications. Analysis by the root-locus technique of Evans and the frequency-response techniques of Nyquist, Bode, and Nichols. Introduction to the state-space approach. Examples from aeronautics, electronics, and civil engineering. Not offered in 1980-81. Instructors: Staff.

E 102 abc. Introduction to Systems Analysis and Control. *9 units (3-0-6); first, second, third terms. Prerequisites: E 13, E 101 or equivalent.* Analysis of linear and nonlinear systems, stability and control of dynamical systems. Noise and stochastic processes, filtering and estimation theory, nonlinear system identification theory. Not offered in 1980-81. Instructor: Caughey.

E 103 abc. Analysis of Experimental Data. *9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission.* The basic statistical and mathematical concepts needed for the effective analysis and interpretation of experimental data are presented. Statistical inference, linear hypotheses, regression. Experimental design, practical problems in measurement. Time series analysis. Not offered in 1980-81. Instructor: Kroeker.

E 126 abc. Analysis and Synthesis of Engineering Systems. *9 units (3-0-6); first, second, third terms.* A variety of systems drawn from civil, mechanical, electrical, and aerospace engineering will be studied in detail. Students will analyze and synthesize a number of engineering systems using interactive computer facilities. Not offered in 1980–81.

E 150 abc. Engineering Seminar. *1 unit (1-0-0); each term.* All candidates for the M.S. degree in Applied Mechanics, Electrical Engineering, Materials Science, and Mechanical Engineering are required to attend any graduate seminar in any division each week of each term. Graded pass/fail. Instructors: Staff.

ENGINEERING GRAPHICS

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, orthographic projection and basic descriptive geometry solutions helpful in computer augmented design or graphics systems. Instructor: Welch.

ENGINEERING SCIENCE

Advanced Courses

ES 200 abc. Topics in Bioengineering. *9 units (3-0-6); first, second, third terms.* This course will spend the first two terms on the foundation of low-Reynolds-number fluid physics, including the motion of a rigid or flexible body with or without electric charges, flows of suspensions, and transfer processes. The third term will be devoted to various applications to rheology, blood flow in living systems, chemical flow problems, motility of micro-organisms, and bioconvection. Instructors: Leal, 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. Registration limited to freshmen and sophomores or with the permission of the instructor.* This course provides an introduction to the engineering design of measures to limit man's impact on his surrounding environment. Topics covered include global and local cycles in the hydrosphere, atmosphere, and biosphere; energy and materials balance approaches to analysis of environmental problems; removal of pollutants at their source by physical separation, chemical or biochemical reactions, or process redesign. The process of establishing environmental goals is discussed, as well as methods for illuminating choices between alternative means of reaching such goals. Instructor: Cass.

Env 20. Energy and the Environment. *9 units (3-0-6); second term.* This course explores the flow of energy and examines the limitations of nonrenewable resources such as fossil fuels. Present and possible future sources of energy are considered, with emphasis on the environmental aspects of extraction, transportation, and utilization. The effects of various energy alternatives on water resources are also examined. Instructor: Flagan.

Env 90. Undergraduate Research in Environmental Engineering Science. *Units by arrangement; any term. Approval of research supervisor required prior to registration.* Independent research on current environmental problems; laboratory or field work is encouraged. A written report is required for each term of registration. Seniors may 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/Ge 103 abc. Oceans and Atmospheres. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 and Ph 2.* Natural physical and chemical processes in the earth's fluid envelope. First term: geophysical fluid dynamics, ocean currents, temperatures, and salinity. Second term: atmospheric dynamics and thermodynamics, radiative transfer, climate change. Third term: atmospheric, oceanic and ionospheric chemistry and photochemistry, global effects of environmental pollution. Instructors: List, Ingersoll, Yung.

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).* The hydrologic cycle and its relation to man; statistical analysis and simulation of hydrologic data; dynamic similitude; turbulent shear flow in rivers and estuaries; introduction to stratified flow, turbulent plumes and buoyant jets; hydraulic models. Transport and dispersion of solutes, sediments and heat in rivers, lakes, estuaries and coastal waters; heat transfer, evaporation and density stratification in natural waters. Engineering of outfalls for wastewater and thermal discharges. Flow through porous media, wells, groundwater recharge, and seawater intrusion in aquifers. Instructor: Brooks.

Env 116. Experimental Methods in Air Pollution. *9 units (1-4-4); third term. Prerequisite: ChE/Env 157 abc.* Methods of sampling and measurement of particulate and gaseous pollutants with applications to pollution sources, gas cleaning equipment, and smog formation. Experiments will include measurement of gaseous and particulate pollutant emissions, use of on-line systems for measuring aerosol-size spectra, and aerosol measurements in photochemical smog. Instructors: Flagan and staff.

Env 142 ab. Chemistry of Natural Water Systems. *9 units (3-0-6); first, second terms. Prerequisite: Ch 1 abc, Ch 14, or equivalent.* Chemistry of electrolyte solutions, heterogeneous processes, and redox reactions applied to quantitative description of natural waters. Chemical characteristics of lakes, streams, and seawater: comparison of real systems with stoichiometric, equilibrium, and steady-state models; properties of colloids in natural water systems; coagulation-flocculation processes; adsorption phenomena. Instructor: Morgan.

Env 143. Water Chemistry Laboratory. *6 units (1-4-1); third term. Prerequisite: Env 142 ab.* Laboratory experiments and measurements dealing with the major and minor constituents of natural waters. Topics include seawater chemistry, heterogeneous equilibria, rates of precipitation, redox processes, adsorption, and particle coagulation. Measurement techniques include electrometry, spectrophotometry, liquid and chromatography, light scattering, and atomic absorption spectrophotometry. Instructors: Hoffmann, Morgan.

Env 144. Ecology. *6 units (2-1-3); second term.* Basic principles of ecology and ways in which human activities can influence natural populations. (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.* An exposition of basic biological principles concerning interrelations between organisms, particularly those directly affecting man and his environment. Extensive reading is required, covering a broad scope of biological literature. Instructor: North.

Env 146 ab. Analysis and Design of Water and Wastewater Systems. *9 units (3-0-6); second, third terms. Prerequisites: APh/ME 17 abc, ME 19 abc, or equivalents.* The application of science and engineering sciences to water supply and treatment for municipal use; treatment and disposal of liquid wastes; unit operations as applied to environmental systems; the designs of works; and economic aspects of projects. Instructor: Hoffmann.

Env 150 abc. Seminar in Environmental Engineering Science. *1 unit (1-0-0); each term.* Seminar on current developments and research within the field of environmental engineering science, with special consideration to work at the Institute. Graded pass/fail.

ChE/Env 157 abc. Fundamentals of Air Pollution Engineering. *9 units (3-0-6); first, second, third terms. Open to graduate students and seniors with instructors' permission.* Principles necessary to understanding the sources, atmospheric behavior, and control of air pollutants. First term: Air quality and emissions standards, air pollution sources, generation of pollutants in combustion systems. Second term: Fundamentals of particulate air pollutants, aerosol physics and chemistry, gas-to-particle conversion processes, control techniques for particulate pollutants, pollutant effects on visibility. Third term: Atmospheric chemistry, atmospheric diffusion, control techniques for gaseous pollutants. Instructors: Flagan, Cass, Seinfeld.

Env 200. Advanced Topics in Environmental Engineering Science. *Units by arrangement, any term.* Course to explore new approaches to environmental problems. The topics covered vary from year to year, depending on the interests of the students and staff. Visiting professors may present portions of the course from time to time.

Env/Ge 203 abc. Advanced Oceans and Atmospheres. *9 units (3-0-6); first, second, third terms. Prerequisite: Env/Ge 103 abc.* First term: atmospheric dynamics and numerical modeling. Second term: remote sensing and radiative transfer. Third term: modern physical oceanography. Offered in alternate years (1981–82). Instructors: Ingersoll, Yung, List.

Env 206. Special Problems in Biological Engineering Science. *Units by arrangement, any term. Prerequisite: AMa 95 abc.* Special topics in the application of engineering principles to biological and medical problems can be explored on mutual agreement between advanced students and one or more of the participating faculty. Instructors: Leal, Wu.

Env 214 abc. Advanced Environmental Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Hy 101 or Ae/APh 101, AMa 101 or AM 125.* A study of the transport and dispersing properties of fluid motions in the air, oceans, estuaries, rivers, lakes, and groundwater. Emphasis is given to the processes and scales of motion that are important to engineering problems of pollution control. Offered in 1980–81 and alternate years. Instructor: List.

Env 250. Advanced Environmental Seminar. *4 units (2-0-2); each term. Prerequisite: instructor's permission.* A seminar course for advanced graduate students and staff to discuss current research and technical literature on environmental problems. As the subject matter changes from term to term, it may be taken any number of times. Instructors: Staff.

Env. 300. Thesis Research.

Other closely related courses (listed elsewhere) are: ChE 103, Ae/ChE 172, ChE 173, Hy 101, Hy 111, Hy 113, Hy 121, Hy 210, Hy 211, and Hy 213.

Graduate students may also enroll in graduate courses offered by Scripps Institution of Oceanography under an exchange program. Graduate students majoring in environmental engineering science should consult the executive officer for more information.

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. The emphasis and topics of consideration vary with the individual instructor and with class interests. Classes are limited in size and individually handled by full-time faculty members. All registrants must be prepared to devote six weekend days to field trips. Instructors: Fall: Burnett; Spring: Kanamori.

Ge 2. Geophysics. *9 units (2-1-6); second term. Prerequisites: Ge 1, Ma 2 a, Ph 2 a.* 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, the transport of heat within the earth, and global tectonics. Three one-day field trips to sites of geophysical interest are an integral part of the course. Text: *Physics of the Earth,* Stacey. Instructor: Minster.

Ge 4. Introduction to the Solar System. *6 units (3-0-3); third term.* An introductory survey course emphasizing current knowledge of the bodies in our solar system. Meteoritic data and astrophysical observations on young stars provide information on the processes and materials of the early solar system. The properties of interplanetary dust, asteroids, and comets are discussed in relation to the known types of meteorites. The post-Apollo view of the Moon is summarized and used as a basis for comparison with other small planets such as Mercury and the Jovian satellites. Venus and Mars are considered in the light of recent spacecraft experiments. Jupiter is discussed as an example of an outer planet. Instructor: Burnett.

Ge 5. Geobiology. *9 units (3-0-6); second term. Prerequisites: Ge 1, Ch 1, Bi 1, or consult instructor.* An examination of biologically related processes and environments in the crust throughout the span of earth history. Consideration is given to the environmental influence that the change from a reducing to an oxidizing atmosphere had upon the evolution of life processes and to the subsequent progression of organisms and organic activity throughout the oxidizing era. 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; first, second, third terms.* Guidance in seeking research opportunities and in formulating a research plan leading to preparation of a Bachelor's Thesis is available from the Division Undergraduate Research 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); first, second, third terms.* Presentation of papers on research in geological and planetary sciences by guest speakers. Graded pass/fail. Instructor: Stolper.

Ge 101 abc. Introduction to the Earth and Planets. *Prerequisites: Ma 2, Ph 2.*

101 a. Introduction to Planetary Science. *9 units (3-0-6); first term.* 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. Instructor: Goldreich.

101 b. Advanced Physical Geology. *9 units (3-3-3); second term.* Topics include impact and volcanic processes, glacier mechanics, eolian processes, the role of catastrophe in fluvial processes. Quaternary stratigraphy, and the evolution of a major river system. One three-day field trip. Instructor: Saleeby.

101 c. Geophysics. *9 units (2-1-6); third term.* An introduction to the physics of the earth. Topics covered include the present internal structure of the earth, theories of the origin and evolution of the earth, the earth's gravity and magnetic field, and fundamentals of wave propagation in earth materials. The contributions that heat flow, gravity, paleomagnetic, and earthquake mechanism data have made to our understanding of geodynamics are discussed. Local one-day field trips. Text: *Physics of the Earth,* Stacey. Instructor: Helmberger.

Ge 102. Oral Presentation. *2 units (1-0-1); third term.* Training in the technique of oral presentation. Practice in the effective organization and delivery of reports before groups. Successful completion of this course is required of all candidates for degrees in the division. Instructor: Muhleman.

Env/Ge 103 abc. Oceans and Atmospheres. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 and Ph 2.* Natural physical and chemical processes in the earth's fluid envelope. First term: geophysical fluid dynamics, ocean currents, temperatures, and salinity. Second term: atmospheric dynamics and thermodynamics, radiative transfer, climate change. Third term: atmospheric, oceanic and ionospheric chemistry and photochemistry, global effects of environmental pollution. Instructors: List, Ingersoll, Yung.

Ge 104 abc. Advanced General Geology. *9 units (3-4-2). Prerequisites: Ch 1 or 2, Ma 1, Ph 1.*

104 a. Minerals as Physical, Chemical, and Geological Systems. *First term.* Atomic structure and physical properties of the solid state, with emphasis on the important minerals. Topics include relations between bonding forces, structure, composition, properties, and conditions of formation of minerals. The occurrence and properties of the major mineral groups that are important at the earth's surface and in the interior will be studied in the laboratory. Instructor: Rossman.

104 b. Igneous, Sedimentary, and Metamorphic Rocks. *Second term.* A study of rocks and the chemical and physical processes affecting their origin. The genesis of igneous rocks and silicate crystal-melt-fluid equilibria. Sedimentary minerals and rocks, processes, physical stratigraphy, and depositional environments. Metamorphic processes, rocks and minor structural features. Instructor: Taylor.

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. Problems of the Precambrian history of the earth. Instructors: Lowenstam, Silver.

Ge 105 ab. Geological Field Training and Problems. *9 units (0-9-0); first and second 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. Instructor: Allen.

Ge 107. Structural Geology. *9 units (3-3-3); third term. Prerequisites: Ge 104 ab, Ge 105 ab.* A problem course in the interpretation and description of geologic structures. Includes use of descriptive geometry and stereographic projection in the solution of geologic problems, as well as an understanding of the mechanical properties of rocks, and the use of geologic scale models. Instructor: Kamb.

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.* Methods of optical crystallography. Measurement of optical constants with the polarizing microscope. X-ray determination of lattice parameters. Characterization and identification of minerals by optical and X-ray methods. Systematic application of these methods to the study of important mineral groups. 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 114, Ch 21 a.* The mineralogical and chemical composition, origin, occurrence, and classification of igneous rocks considered mainly in the light of chemical equilibrium and of experimental studies. Detailed consideration of the structures, phase relations, and identification of the major igneous minerals. Instructor: Stolper.

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. Not offered in 1980–81.

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: Stolper.

Ge 121 abc. Advanced Field and Structural Geology. *12 units (0-9-3); first, second, third terms. Prerequisites: Ge 104 abc, Ge 105 ab, Ge 107.*

121 a. Field and supporting laboratory studies in the geometries and mechanisms of several rock deformational regimes. Subjects include metamorphic tectonites, thrust and wrench faults, melanges, and olistostromes. Instructor: Saleeby.

121 b. Field mapping investigations of igneous and metamorphic problems in various tectonic settings in southern California and adjacent regions. Instructor (1980–81): Silver.

121 c. Field mapping investigations in various areas of predominantly sedimentary rocks in southern California, with emphasis on sedimentary processes and Quaternary geology. Instructor (1980–81): Sieh.

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, or magnetic field measurements. A final report, embodying calculations and interpretations, is required. Offered in alternate years (1981–82). Instructor: Westphal.

Ge 123. Summer Field Geology. *30 units (6 weeks). Prerequisites: Ge 104 abc, Ge 105 ab.* 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 a 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: Sieh in charge, and staff.

Ge 124 ab. Magnetostratigraphy. Application of paleomagnetism to the solution of problems in stratigraphic correlation and to the construction of a high-precision geological time scale. Offered in alternate years (1980–81). Instructor: Shoemaker.

124 a. *9 units (3-3-3); second term. Prerequisites: Ge 104 abc, Ge 105 ab.* The principles of rock magnetism and physical stratigraphy are reviewed; emphasis is on the detailed application of paleomagnetic techniques to determination of the history of the geomagnetic field.

124 b. *6 units (0-0-6); spring recess. Prerequisite: Ge 124 a.* An eight-day field trip to the Colorado Plateau to study the physical stratigraphy and magnetic zonation of the rocks in this well-known region.

Ge 126. Introduction to Quaternary Geology. *12 units (3-3-6); first term. Prerequisite: Ge 107.* An introduction to study of the evolution of the earth's surface during the past million years. Topics include sedimentary, erosional, and tectonic processes involved in the development of landscapes; Pleistocene and Holocene stratigraphy; the use of soils, weathering rates, radiocarbon dating, palynology, and other tools in deciphering recent geological history. The laboratory will involve the use of aerial photographs and an individual research project. Offered in alternate years (1980–81). Instructor: Sieh.

Ge 127. Field Studies in Quaternary Geology. *9 units (1-8-0); second term. Prerequisite: Ge 126 or instructor's consent.* Exercises intended to present a selection of problems and methods in Quaternary geology, such as those associated with active faults, coastal terraces, landslides, and ancient lakes. Methods for studying Quaternary processes and deposits, including interpretation of geomorphic features and soil profiles; use of aerial photographs and plane table and alidade; and methods of subsurface mapping and age determination. Offered in alternate years (1981–82). Instructor: Sieh.

Ge 130. Introduction to Geochemistry. *6 units (2-0-4); first term. Prerequisites: Ch 1, Ma 2 abc, Ph 2 abc.* 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 solar system and the various planetary bodies. Information gained from the study of meteorites and lunar rocks is emphasized, as well as detailed consideration of sources of solar system elemental abundances. Offered in alternate years (1980–81). Instructor: Burnett.

Ge 135. Regional Geology of Southern California (Seminar). *6 units (3-0-3); second term. Prerequisites: Ge 104 abc, Ge 105 ab or equivalent.* Reading and discussion of selected topics in the geology of southern California and adjacent areas, with emphasis on outlining the important regional research problems. Instructor: Silver.

Ge 136. Regional Field Geology of Southwestern United States. *9 units (1-0-8); third term. Prerequisites: Ge 104 or Ge 105, or instructor's permission.* At least nine days of weekend field trips into areas of southwestern United States displaying highly varied geology are involved. Each student is assigned the major responsibility of being the resident expert on a pertinent subject for each trip. Graded pass/fail. Instructors: Sieh, Allen.

Ge 137. Laboratory Techniques in the Earth Sciences. *9 units (1-4-4); second term.* Introduction in the use of tools and techniques used in earth sciences research. Experiments of geological and geochemical interest are done using the electron microprobe, emission spectrograph, spectrophotometer, X-ray diffractometer and spectrometer, mass spectrometers, vacuum extraction lines and other available tools and techniques used in the research projects in the division. Additional units may be elected. Instructor: Epstein.

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. Students may enroll for any or all terms of this course without regard to sequence. Instructors: Staff and visitors.

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 that can be tested by all possible observational techniques including radio interferometry, planetary occultation, and radar astronomy. Offered in alternate years (1981–82). Instructor: Muhleman.

Ge 154. Planetary Atmospheres. *9 units (3-0-6); third term. Prerequisites: junior-level courses in math and physics, Env/Ge 103 or stellar atmospheres highly desirable.* Current problems in fluid dynamics, radiative transfer, and atmospheric chemistry as suggested by recent ground-based and spacecraft-related data on the planets and their satellites. Offered in alternate years (1980–81). Instructors: Ingersoll and Yung.

Ge 160 abc. Seismological Laboratory Seminar. *1 unit (1-0-0); first, second, third terms.* Presentation of current research in geophysics by students, staff, and visitors. Graded pass/fail. Instructor: Anderson.

Ge 166. Physics of the Earth's Interior. *9 units (3-0-6); second term.* Interpretation of the observed geophysical data describing the earth's interior in terms of the earth's evolution, ongoing geodynamic processes, and composition and thermal state of the mantle and core. Instructor: Anderson.

Ge 167. Planetary Physics. *9 units (3-0-6); first term. Prerequisites: Ph 106 abc, AMa 95 abc or AM 113 abc.* Solar system dynamics, with emphasis on slow changes in the orbit and rotation rates of planets and satellites. Topics to be discussed include tidal friction, resonant orbits and rotation rates, gravitational fields of planets and satellites, dynamics of polar wandering and continental drift. Offered in alternate years (1981–82).

Ge 175. Plate Tectonics. *6 units (3-0-3); first term.* Reading and discussion in sea floor spreading and plate tectonics. The first part of the course will be devoted to a review of the basic concepts and ideas—the second part will be reserved for discussion of selected problems. Offered in alternate years (1980–81). Instructor: Minster.

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. Offered in alternate years (1981–82). Instructor: Allen.

Env/Ge 203 abc. Advanced Oceans and Atmospheres. *9 units (3-0-6); first, second, third terms. Prerequisite: Env/Ge 103 abc.* First term: atmospheric dynamics and numerical modeling. Second term: remote sensing and radiative transfer. Third term: modern physical oceanography. Offered in alternate years (1981–82). Instructors: Ingersoll, Yung, List.

Ge 212 ab Thermodynamics of Geological Systems. *9 units each term (3-0-6); first, second terms. Prerequisite: Ch 21 abc, Ge 115 abc or equivalent.* Chemical thermodynamics, with emphasis on applications to geologic problems. Topics to be covered include heat flow, diffusion, phase transformations, silicate phase equilibria, solid solutions, the effect of H_2O in silicate melts, and equilibrium in a gravitational field. Text: *Chemical Thermodynamics*, Prigogine and Defay. Offered in alternate years (1980–81). Instructors: Taylor, Wasserburg.

Ge 213. Advanced Seminar in the Earth Sciences. *5 units. Prerequisites dependent upon topics. Offered by announcement only.* Seminar on special topics and problems of current interest.

Ge 214. Advanced Mineralogy. *9 units (3-3-3); third term. Prerequisite: Ge 114, Ch 21 or instructor's permission.* The origin of color, pleochroism, and luminescence in minerals, infrared absorption spectroscopy of mineral substances, the relationship of the various types of X-ray and optical spectra, and the effects of site population upon optical properties. The laboratory involves the measurement of the optical and infrared spectra of selected minerals. Offered in alternate years (1980–81). Instructor: Rossman.

Ge 215 abc. Topics in Advanced Petrology. *12 units each term (3-6-3); first, second, third terms. Prerequisites: Ge 115, Ch 21.*

215a. 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. Offered in alternate years (1981–82). Instructor: Taylor.

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. Offered in alternate years (1981–82). Instructor: Silver.

215 c. Advanced Metamorphic Petrology. *Third term.* Lectures, seminars, and laboratory studies on metamorphic petrogenesis and rocks. Emphasis is placed on the interpretation of natural assemblages and of mineral relations. Offered in alternate years (1981–82). Instructor: Albee.

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 of geologic importance. Topics may include nucleosynthesis, 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 model systems. Offered in alternate years (1981–82). Instructor: Wasserburg.

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. Instructor: Murray.

225 c. Planetary Research with Spacecraft. *1 unit (1-0-0); third term.* Review of potential or recently completed scientific exploration by means of spacecraft. Instructor: Muhleman.

Ge 226. Observational Planetary Astronomy. *9 units (3-0-6); third term.* Optical and infrared radiation detectors, spectrometers, polarimeters, and photometers will be discussed in the context of the observational study of the planets. Other topics will include the design of observational programs and the assessment of the reliability of data by critical analysis of observational literature. Offered in alternate years (1980–81). Instructor: Westphal.

Ge 229. Glaciology. *9 units (3-0-6); offered by announcement only.* Origin and behavior of the North American ice sheet, physical conditions and structures of existing glaciers, glacier flow, erosional and depositional processes and products. Instructor: Kamb.

Ge 230. Geomorphology Seminar. *5 units; offered by announcement only.* 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: Sieh.

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. Tectonics. *9 units (3-0-6); second term. Prerequisites: Ge 121 a, b, c or equivalents. (May be taken concurrently with approval of instructors.)* Tectonic evolution of the North American Cordillera. Craton-ocean plate interactions; emplacement of all octhonous terranes;

reactivation of cratonic lithosphere; regional sedimentation and stratigraphic patterns; tectonic significance of igneous and metamorphic belts; relation of neotectonic patterns to paleotectonic records. Instructors: Saleeby, Silver.

Ge 261 abc. Advanced Seismology. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or equivalent.* 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); first, second, third terms. Prerequisites: AMa 101 or Ph 129 abc or equivalent.* A systematic review of basic continuum theory with special emphasis on geophysical applications. The theory is then applied to selected topics in hydrodynamics, elastic and anelastic processes in planetary dynamics, seismic source theory, heat transport processes, etc. Major methods of mathematical physics are reviewed as required by the topics under study. Offered in alternate years (1981–82). Instructor: Minster.

Ge 282 abc. Geological Sciences Seminar. *1 unit; first, second, third terms.* Presentation of papers by invited investigators. In charge: Minster.

Ge 297. Advanced Study. Students may register for up to 15 units of advanced study under the direction of a faculty member.

Ge 299. Thesis Research. Original investigation, designed to give training in methods of research, to serve as theses for higher degrees, and to yield contributions to scientific knowledge.

GERMAN *(See Languages)*

HISTORY

Courses above H 10 are open only to students who have fulfilled the freshman humanities requirements.

Undergraduate Courses

H 1 abc. Introduction to Europe. *9 units (3-0-6); first, second, third terms.* From the Middle Ages to the present day. Topics and reading will vary from instructor to instructor, but will usually include feudalism, the Renaissance and Reformation, seventeenth-century England, the French Revolution and Napoleon, the Industrial Revolution, nineteenth-century liberalism and nationalism, Marx, overseas expansion, the Russian Revolution, fascism, the two World Wars, and the Cold War. Instructors: Staff.

H 2 abc. Revolution to Roosevelt. *9 units (3-0-6); first, second, third terms.* 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. Instructors: Staff.

H 3 ab. Traditional Europe: Society, Material Life and Values before 1800. *9 units (3-0-6).* Introduction to patterns of life and thought in pre-industrial Europe, stressing the structure of economic, political, and cultural life. The first quarter covers the period 300AD–1400AD; the second, 1300–1800. Either quarter may be taken independently. Instructors: Benton, Searle.

H 6 abc. American Life and Thought. *9 units (3-0-6); first, second, third terms.* 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 ab. Introduction to Asia. *9 units (3-0-6); first, second terms.* "Asia" includes that civilizational expanse from Morocco to Japan. No textbook; instead, a variety of books including narrative histories, biographies, novels, and anthropological studies that illuminate aspects of the life, thought, religion, history, politics, and economic development of the area. Instructors: Dirks, Fay.

H 23. Cultural History of Early Medieval Europe. *9 units (3-0-6).* From the end of the Roman Empire to the First Crusade. Shows how classical, Christian, and barbarian cultures combined to form a new civilization. Not offered in 1980–81. Instructor: Benton.

H 24. Cultural History of the High Middle Ages and Renaissance. *9 units (3-0-6).* Europe from the twelfth through the fifteenth centuries. Shows relationship of art, literature, music, and social relations to political, economic, and religious institutions. Not offered in 1980–81. Instructor: Benton.

H 25. Europe in the Seventeenth and Eighteenth Centuries. *9 units (3-0-6). Not for students who have taken H 1 a.* A survey of Europe in this period: may cover the English Revolution, the Enlightenment, and the French Revolution. Not offered in 1980–81. Instructor: Fay.

H 26. Europe in the Nineteenth and Twentieth Centuries. *9 units (3-0-6); second term. Not for students who have taken H 1 b or c.* A survey of Europe in this period: may cover the Industrial Revolution, Victorian England, Marx, overseas expansion and contraction, the Russian Revolution, the two World Wars, the Cold War, the formation of Israel. Instructor: Fay.

H 40. Reading in History. *Units to be determined for the individual by the department. Elective, in any term.* Reading in history and related subjects, done either in connection with the regular courses or independently of any course, but under the direction of members of the department. A brief written report will usually be required. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

H 97 ab. Junior Tutorial. *9 units (2-0-7); second, third terms. Prerequisite: instructor's permission.* Designed 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 normally will 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 normally will 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. Not offered in 1980–81. Instructor: Benton.

H/Psy 107 ab. Psychohistory. *9 units (3-0-6).* An examination of the influence of psychological factors in the course of history and of historical forces in the shaping of groups and individuals. Students are encouraged to take both courses in sequence, though each is a self-contained unit and may be taken separately. H/Psy 107 a will cover the premodern period and H/Psy 107 b the modern period. Taught in alternate years; section b not offered in 1980–81. Instructor: Benton.

H 108. Europe and Asia. *9 units (2-0-7); third term.* Topics in the interrelation of Europe and Asia. May include the Crusades, Turkey in Europe, Russia in Asia, the spice trade, the opening of China and Japan, and Jews and Arabs. Not offered in 1980–81. Instructor: Fay.

H 109. Protestant, Catholic, and Jew. *9 units (2-0-7).* Topics in the political and social history of religion in Europe since the fall of Rome. May include Joan of Arc, Luther, the Spanish Armada, the Enlightenment, Victorian conformity, and the "final solution." Instructor: Fay.

H 112. Contemporary Europe. *9 units (3-0-6); third term.* This course will deal with some of the public issues, social trends, and cultural developments that 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); first term.* An attempt to discover and interpret the major recurring characteristics of Russian history and society, with attention particularly to developments in the Soviet period. Not offered in 1980–81. Instructor: Ellersieck.

H 121. India and Pakistan. *9 units (3-0-6); third term.* The development of religious, mythological, and philosophical traditions in South Asia and the implications of this development for contemporary society and polity. Particular attention will be paid to Hindu thought. Instructor: Dirks.

H 130. History of War. *9 units (3-0-6); second term.* 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 131. History through Film. *9 units (2-2-5).* An approach to historical problems in part through the medium of full-length, fictional motion pictures. Each term will focus on a specific theme. Not offered in 1980–81. Instructor: Rosenstone.

H 132. Japan. *9 units (3-0-6).* An introduction to Japanese civilization, past and present. Stress will be placed on the interrelation between art, culture, philosophy, politics, and society. Not offered in 1980–81. Instructor: Rosenstone.

H 147. The Far West and the Great Plains. *9 units (3-0-6).* The exploration and development of the great regions of western America. Special attention will be paid to the influence of the natural environment, and the exploitation of it by such industries as the fur trade, mining, cattle ranching, farming, and oil. 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/SS 150. Problems in the History of English Law and Society. *9 units (3-0-6); first term.* The course will consider aspects of the development of law and society in pre-industrial England. Taking a particular problem, which may differ from one term to another, it will consider the relationship between actions at common law, legal administration, legislation, social structure, and the economic basis of society. Instructor: Searle. *Not available for credit toward social science requirement.*

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. Not offered in 1980–81. Instructor: Kousser.

H 152. America in the Era of Roosevelt and Truman. *9 units (3-0-6); second term.* Topics in the history of the depression, World War II, and the origins of the Cold War. Not offered in 1980–81. Instructors: Kevles, Rosenstone.

H 153. America since World War II. *9 units (3-0-6); third term.* Topics in the recent social, cultural, and political history of the United States. Not offered in 1980–81. Instructors: Kevles, Rosenstone.

H 156. The History of Modern Science. *9 units (3-0-6).* Selected topics in the development of the physical and biological sciences since the seventeenth century, with emphasis on the evolution of scientific ideas as a problem in intellectual history. Not offered in 1980–81. Instructor: Kevles.

H 157. Science in America, 1865–present. *9 units (3-0-6).* A study of the social and political history of American science, emphasizing the relationship of the research community to universities, industry, and government. Instructor: Kevles.

H 158. Ideas and Ideals in America. *9 units (3-0-6).* An exploration of changing notions of the self, and the relationship between the individual and the social order in the period since the eighteenth century. Not offered in 1980–81. 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. Not offered in 1980–81. 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. Not offered in 1980–81. Instructor: Rosenstone.

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 (3-0-6); 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, flow in stratified fluids, stability; acoustic fields, sound radiation and scattering, acoustic energy transport; one-dimensional steady gas-dynamics, 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 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 their 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 approximately three regular experiments, but with the permission of the instructor they may propose special investigations of brief research projects of their own. 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. Not offered every year. 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 course to meet the needs of advanced graduate students.

Hy 201 abc. Turbomachines. *6 units (2-0-4); first, second, third terms. Prerequisite: Hy 101 or instructor's permission.* A study of the theory and operation of hydraulic fluid machines, principally pumps, and turbines. Recent two- and three-dimensional inviscid flow design theories will be studied. Special consideration will be given to the effects of cavitation in methods of design and behavior of large systems. 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. The course material in the third term may vary depending upon the needs and interests of the class. Instructor: Wu.

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 turbulent fluids. This will include discussion and interpretation of results of laboratory and field studies of alluvial streams, and wind erosion. Not offered every year. Instructor: Brooks.

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 that 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. The course may be taken any number of times with the permission of the instructor. Instructors: Staff.

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. Not offered every year. Instructor: Raichlen.

Hy 300. Thesis Research.

INDEPENDENT STUDIES PROGRAM

Students who have chosen to enter the Independent Studies Program (ISP) instead of a formulated undergraduate option may enroll in special ISP courses. These courses are designed to accommodate individual programs of study or special research that fall outside ordinary course offerings. The student and the instructor first prepare a written course contract specifying the work to be accomplished and the time schedule for reports on progress and for work completed. The units of credit and form of grading are decided by mutual agreement between the instructor, the student, and his or her advisory committee. See page 210 for complete details.

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 and burning characteristics of solid and liquid propellants, liquid propellant fuel systems, combustion instability. Subsonic and supersonic compressors and turbines, basic gas turbine propulsion cycle and its variations, inlets and diffusers. Nuclear rockets, nuclear air breathing cycles. Instructors: Marble, Zukoski.

JP 131. Combustion Technology. *9 units (3-0-6); third term. Prerequisites: APh/ME 17 and ME 19.* Application of fluid dynamic and chemical principles to the study of combustion processes including the theoretical and experimental treatment of laminar and turbulent flames; the combustion of liquid droplets and solid particles; and technical aspects of gas, oil and coal combustion. Not offered every year. Instructor: Zukoski.

JP 170. Jet Propulsion Laboratory. *9 units (0-9-0); third term.* Laboratory experiments related to propulsion problems. Instructor: Zukoski.

JP 213 abc. Gas Dynamics and Combustion in Propulsion Systems. *6 units (2-0-4); each term. Prerequisites: JP 121 abc or Ae/APh 101 abc or Hy 101 abc, or equivalent.* Topics from theory of real gases; gas dynamics of reacting mixtures. Inlet diffusers for supersonic and hypersonic air-breathing engines; effects of real gases, rarefied gas and low Reynolds number flow; diffuser stability. Review of laminar and turbulent flame theory; combustion of solid and liquid propellants; combustion in boundary layers, wakes, and mixing regions; flame stability. Nozzles for rockets and air-breathing engines; nozzle flow with chemical reactions, characteristic theory, integral methods, two-phase flow. Not offered every year. Instructor: Marble.

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 325 for description.

Undergraduate and Graduate 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.* The course aims at providing a superior reading knowledge plus competence in general conversation. Students who have had French in secondary school or college must consult with the instructor before registering. Instructor: Ghattas.

L 103 abc. Intermediate French. *9 units (3-0-6); first, second, third terms. Prerequisite: L 102 abc or equivalent.* Grammar review, conversation practice, introduction to French history, literature, and politics, and exposure to basic scientific and technical reading and communicating. 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.* Each term treats a body of French literature from the standpoint of a dominant theme. Conducted in French. Instructor: A. Smith.

L 130 abc. Elementary German. *10 units (3-1-6); first, second, third terms.* The course covers grammar fundamentals and their use in aural comprehension, speaking, reading, and writing. Students who have had German in secondary school or college must consult with the instructor before registering. Instructor: Carmely.

L 132 abc. Intermediate German. *9 units (3-0-6); first, second, third terms. Prerequisite: L 130 abc, or equivalent.* Reading of short stories and plays, grammar review, and aural and oral drill. Students who have studied German elsewhere must consult with the instructor before registering. Instructor: Aebi.

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. 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. Prerequisite: L 132 abc or equivalent.* The reading and discussion of works by selected nineteenth- and twentieth-century authors. Conducted in German. Not offered in 1980–81. Instructors: Staff.

L 141 abc. Elementary Russian. *10 units (3-1-6); first, second, third terms.* The course covers grammar and builds toward the capacity to understand, speak, read, and write Russian. Students who have had Russian in secondary school or college must consult with the instructor before registering. Instructor: Zaydman.

L/Lit 152 ab. French Literature in Translation: Classical and Modern. *9 units (3-0-6).* The first term deals with French "classical" literature of the seventeenth and eighteenth centuries, the second term with the years from 1939 to the present, and with literary responses to "the Absurd." Readings are in English, but students may read French originals. Instructor: A. Smith.

L 153 abc. Intermediate Russian. *9 units (3-0-6); first, second, third terms. Prerequisite: L 141 abc or equivalent.* Grammar review, readings, discussion, and reports on material from Russian science, culture, and history. Instructor: Pariser.

L/Lit 154. French Literature in Translation: The French Novel. *9 units (3-0-6); second term.* Famous novels of the sixteenth to the twentieth century are read against the historical, sociological, and philosophical background. Readings are in English, but students may read the French originals. Instructor: A. Smith.

L/Lit 160 ab. German Literature in Translation. *9 units (3-0-6).* The first term covers the period from the Middle Ages through the Romantic Age. The second term surveys the literature of the twentieth century, stressing Kafka, Hesse, T. Mann, Frisch, Duerrenmatt, and Grass. Instructor: Carmely.

L/Lit 165 abc. Russian Literature in Translation. *9 units (3-0-6); first, second, third terms.* The course traces the development of Russian literature in its socio-historical context from the

Classical period to contemporary Soviet texts. Authors will range from Pushkin to Solzhenitsyn. All readings in English. Instructor: Pariser.

L 166 abc. Russian Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 153 or equivalent and by special arrangement with the instructors.* Reading and discussion of representative works of selected nineteenth- and twentieth-century Russian authors. Conducted in Russian. Students are advised to take these courses in sequence. Instructors: Pariser, Zaydman.

LINGUISTICS

Advanced Courses

Lin 101 a. Introductory Linguistics. *9 units (3-0-6); first term.* Language is a system that carries meaning to sound. Phonology is the study of sound; semantics is the study of meaning. Syntax is about the ways we go from phonology to semantics. Phonetics, phonemic theory, morphology, phrase structure grammar, transformational grammar. Extensive reading required. Instructor: B. Thompson.

Lin 101 b. Linguistic Theory. *9 units (2-1-6); second term.* Current models of language structure, especially in syntax and semantics. Transformational generative grammar, case grammar, generative semantics, semantic theories. A research project is required. Instructor: B. Thompson.

Lin/SS 103. Psycholinguistics. *9 units (2-1-6); third term.* A seminar-type course on language behavior as a reflection of conceptual processes. Language acquisition, aphasia and other language disturbances, linguistic memory and grammar organization, language and the brain, multilingualism. A research project is required. Instructor: B. Thompson.

Lin/SS 104. Sociolinguistics. *9 units (2-1-6).* Language in social interaction studied in a seminar-research-type course. Experiments required. Readings in language variation (dialects, slang, jargon, scientific, and other). Taught alternate years; not offered in 1980–81. Instructor: B. Thompson.

Lin/SS 105. Computational Linguistics. *9 units (2-1-6); first term. Prerequisite: Lin 101 a or Lin 101 b or equivalent.* English as a language for communication with computers. Problems in parsing and semantic data base analysis. Review through readings of natural language processing systems, including speech recognition and other AI (artificial intelligence) applications. Research required. Taught alternate years; offered in 1980–81. Instructors: B. Thompson, F. Thompson.

LITERATURE

Courses above Lit 10 are open only to students who have fulfilled the Freshman Humanities requirements.

Courses Primarily for Freshmen

Lit 1 abc. Literature Past and Present. *9 units (3-0-6); first, second, third terms.* An exploration of great literature from the Middle Ages or the Renaissance to the present, and a critical search for the permanent qualities that keep literature "alive." Instructors: Staff. *Students may not receive credit for both Lit 1 and Lit 2 a.*

Lit 2 a. Tragedy. *9 units (3-0-6); first term.* Readings in the theory and practice of tragedy, in an effort to understand the nature of the genre, the sources from which it springs, and the different forms it may take. Instructor: Mandel.

Lit 2 b. Comedy. *9 units (3-0-6); second term.* Readings in the theory and practice of comedy (and satire), as above (in Lit 2 a). Instructors: Staff.

Lit 4. Introduction to Poetry. *9 units (3-0-6); second, third terms.* What is poetry? Why does it exist? Why and how should one read it? Working from basic concepts in aesthetics, students will read and discuss a substantial range of poems, from simple to complex. Instructor: Mandel.

Lit 5. Literature of Initiation. *9 units (3-0-6); first term.* A study of the experience of initiation, the passage in an individual's life from innocence into experience, and the consequent emergence of a new identity during a critical period of confrontation, testing, and conversion. The reading will vary a good deal from year to year, but will include selected reading in anthropology and psychology as well as novels, short stories, and plays. Instructor: D. Smith.

Lit 6. The Hero and Society. *9 units (3-0-6).* This course will study the development of the hero from his role as a model of society's ideals through his emergence into the "anti-hero" of much contemporary literature. The reading matter will vary a good deal, but will be chosen from ancient, medieval, and modern literatures. Instructor: Clark.

Lit 7. Literature and Myth. *9 units (3-0-6).* A study of significant myths and of ways in which they have influenced the literature of Western civilization—particularly the literature of Britain and America. Not offered in 1980–81. Instructor: Ende.

Lit 8. The Self in Literature. *9 units (3-0-6).* In order to investigate the problem of the "self"—in its relation to other people and to the world at large—students will read a variety of literary works ranging from overt autobiographies to complex fictions on the nature of human identity. Not offered in 1980–81. Instructor: Splitter.

Lit 10. Sexual Identity in Literature. *9 units (3-0-6).* A study of male/female roles, relations, and conflicts as a literary theme and problem. Not offered in 1980–81. Instructors: Splitter, A. Smith.

Special Courses

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 literature 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.* 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.

Lit 98. Tutorial for Literature Majors. *9 units (2-0-7). Prerequisite: written permission of instructor and convener.* An individual program of directed reading and research designed to enable literature majors to undertake the study of an area not covered by regular courses. Instructors: Staff.

HSS 99. See page 325 for description.

Courses Primarily for Upperclassmen

Lit 102 ab. The Classical Heritage. *9 units (3-0-6); first, second terms.* A study of the major texts of ancient Greek and Roman civilization and their backgrounds. The first term will deal—in English translation—with such writers as Homer, Plato, Herodotus, and the writers of Greek lyric poetry, tragedy, and comedy; the second term with such figures as Virgil, Horace, Catullus, Ovid, Juvenal, Plautus, Terence, and Seneca. Not offered in 1980–81. Instructor: Pigman.

Lit 106 ab. English and Continental Medieval Literature. *9 units (3-0-6); second, third terms.* A study of major medieval literary works and their relationship to the philosophical and social context of the time. The first term will concentrate upon English texts, from *Beowulf* to Malory; the second term will deal with other European literature in translation, including Old French epic and romance and the Icelandic saga. The first term is not a prerequisite to the second. Instructor: Burchmore.

Lit 108. Seminar in Creative Writing. *9 units (3-0-6); second, third terms.* An introduction to some of the techniques of writing prose and poetry. Students will do their own writing, which periodically will be reviewed by the instructor. Instructor: Eshleman.

Lit 112 ab. English Renaissance Literature. *9 units (3-0-6).* A study of the major genres and themes of English Renaissance literature from the Reformation of the early sixteenth century through the metaphysical poets of the seventeenth century. First term: Skelton, More, Spenser, Marston, Wyatt, Marlowe, Shakespeare (sonnets), Jonson. Second term: Middleton, Webster, Donne, Herbert, Vaughan, Crashaw, Marvell. Not offered in 1980–81. Instructor: La Belle.

Lit 114 ab. Shakespeare. *9 units (3-0-6).* A close study of Shakespeare's plays with an emphasis on his language, dramatic structures, characters, and themes. Each term will concentrate on a detailed consideration of one of Shakespeare's major comedies or tragedies, followed by a survey of three or four other plays. The first term is not a prerequisite for the second. Not offered in 1980–81. Instructor: La Belle.

Lit 116. Milton. *9 units (3-0-6).* Milton's important short works, his epics, and selections from his prose will be read against the background of the major issues of the seventeenth century. Not offered in 1980–81. Instructor: Pigman.

Lit 120. Satire and Common Sense in Restoration and Eighteenth-Century Literature. *9 units (3-0-6).* A seminar on the great writers, the prevailing genres, and the critical theories of the Restoration, Augustan, and mid-eighteenth-century period. Instructor: Clark.

Lit 122 abc. The English Novel. *9 units (3-0-6).* A course designed to trace the development of the English novel from the eighteenth century to the present. The first term will be devoted to a study of the early novelists, through Scott; the second to the great Victorians; and the third to modern British and Irish novelists. Not offered in 1980–81. Instructors: Clark, Splitter.

Lit 125 ab. Romanticism. *9 units (3-0-6). Prerequisite: 27 units of literature.* An approach to the poets of the Romantic period and to Romanticism, the birth of poetic subjectivity and its primary concerns: enchantment and the internalization of romance, the relation of man to external nature, wrestling with one's poetic precursors. Section b not offered in 1980–81. Instructor: Ende.

Lit 126. Victorian Poetry and Prose. *9 units (3-0-6).* The major poets and prose writers (exclusive of the novel) will be read against the background of the great issues of the period and in the light of the more important aesthetic movements in England and abroad. Not offered in 1980–81. Instructors: Staff.

Lit 130 abc. The Nineteenth- and Twentieth-Century Novel. *9 units (3-0-6).* A three-term exploration of the late nineteenth- and twentieth-century European, English, and American novel. No term is a prerequisite to the other terms. The course will provide a study of the great seminal figures. Section c not offered in 1980–81. Instructors: D. Smith, Splitter.

Lit 132. American Naissance-Renaissance. *9 units (3-0-6).* A survey of major figures of an emerging national literature in the romantic period. Such authors as Irving, Brown, Cooper, Poe, Emerson, Thoreau, Hawthorne, and Melville will be considered. Instructor: D. Smith.

Lit 134. Hawthorne and Melville. *9 units (3-0-6).* An in-depth critical reading of America's first two great novelists. Not offered in 1980–81. Instructor: D. Smith.

Lit 136. Nineteenth-Century American Poetry. *9 units (3-0-6).* The course will emphasize the works, lives, and backgrounds of Walt Whitman and Emily Dickinson, though it may touch upon other poets as late as 1914. Not offered in 1980–81. Instructors: Staff.

Lit 138. The Gilded Age. *9 units (3-0-6).* A survey of the major figures from the post-Civil War period to the First World War. The course will include such writers as Twain, James, Howell, Norris, Wharton, Dreiser, and Stephen Crane. Instructor: D. Smith.

Lit 140. Twain and James. *9 units (3-0-6).* An in-depth critical reading of the two writers who dominated post-Civil War American literature. Not offered in 1980–81. Instructor: D. Smith.

Lit 142 abc. Twentieth-Century American Literature. *9 units (3-0-6); first, second, third terms.* The first two terms will deal with the principal American writers, mostly novelists, whose work appeared between the two world wars. The third term will be a study of the work of post-World War II novelists, dramatists, and poets. Not offered in 1980–81. Instructor: D. Smith.

Lit 146 ab. Twentieth-Century American and British Poetry. *9 units (3-0-6); second term.* A two-term seminar on the major poets and poetic theories from the turn of the century to the present. The first term will concentrate on American poets; the second term, which may be taken independently of the first, will be devoted to British poets. Section b will not be offered in 1980–81. Instructor: Clark.

Lit 149. Twentieth-Century Latin American Literature and Society. *9 units (3-0-6); second, third terms.* Analysis and discussion of major works of fiction by such writers as García Márquez, Vargas Llosa, Cortázar, Borges, Puig, Amado, and Fuentes. Attention will be paid to social, historical, political, and literary background. More general background second term, more focus on selected social problems third term, but can be taken separately. Instructor: Berg.

L/Lit 152 ab. French Literature in Translation: Classical and Modern. *9 units (3-0-6).* The first term deals with French "classical" literature of the seventeenth and eighteenth centuries; the second term with the years from 1939 to the present, and with literary responses to "the Absurd." Readings are in English, but students may read French originals. Instructor: A. Smith.

L/Lit 154. French Literature in Translation: The French Novel. *9 units (3-0-6); second term.* Famous novels of the sixteenth to the twentieth century are read against the historical, sociological, and philosophical background. Readings are in English, but students may read the French originals. Instructor: A. Smith.

L/Lit 160 ab. German Literature in Translation. *9 units (3-0-6).* The first term covers the period from the Middle Ages through the Romantic Age. The second term surveys the literature of the twentieth century, stressing Kafka, Hesse, T. Mann, Frisch, Duerrenmatt, and Grass. Instructor: Carmely.

L/Lit 165 abc. Russian Literature in Translation. *9 units (3-0-6); first, second, third terms.* The course traces the development of Russian literature in its socio-historical context from the Classical period to contemporary Soviet texts. Authors will range from Pushkin to Solzhenitsyn. All readings in English. Instructor: Pariser.

Lit 170 abc. From Mysteries to Absurdism: A Survey of Drama. *9 units (3-0-6). The first and second terms are prerequisites, respectively, for the second and third.* The first term will take the student from the origins of "modern" drama in the Middle Ages to the Classical Age in seventeenth-century France. The second term begins with the "Age of Elegance" in the late seventeenth century and concludes with the "Triumph of the Bourgeoisie" in the nineteenth century. The third term surveys the theatre from Ibsen to the present. Section c not offered in 1980–81. Not offered on a pass/fail basis. Instructor: Mandel.

Lit 180. Special Topics in Literature. *9 units (3-0-6).* See Registrar's announcement for details. Instructors: Staff.

Lit 184. Science Writing 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 people with little or no technical background. Students are required to write a 700-word essay each week. Subjects for the weekly essays are articles selected by the instructor from current journals or magazines. Instructor: Bengelsdorf.

MATERIALS SCIENCE

Undergraduate Courses

APh/MS 4. Introduction to Materials Science. *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 arrangement of atoms and the electron states in solids are discussed and employed to understand thermal, electric, and magnetic properties. Diffusion and phase transformations are discussed briefly. An understanding of mechanical properties is developed from the concept of dislocations. Texts: *The Physics of Engineering Solids,* Hutchison and Baird (first and third terms); *Solid State Physics,* Dekker (second term). Instructor: Wood.

MS 15 abc. Principles of Materials. *9 units (3-0-6); first, second, third terms.* The principles involved in the selection, the thermal treatment, and the mechanical treatment of engineering materials. Metallic materials are of major interest, with some consideration given to ceramics and polymers. The primary emphasis is on the utilization of phase transformations and strengthening mechanisms to obtain desired properties. Instructor: Buffington.

MS 90. Materials Science Laboratory. *9 units (1-6-2); third term.* An introductory laboratory designed to acquaint the student with relationships between structure and properties of crystalline solids. Experiments involve structure determination by X-ray diffraction, mechanical property measurements, and crystal defect observation by chemical etching, X-ray topography, and transmission electron microscopy. Individual projects may be performed, depending upon the student's interests and abilities. Instructor: Vreeland.

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 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 120. Kinetics of Crystal Imperfections. *9 units (3-0-6); first term.* Treatment of crystal imperfections, their interactions, and their influence on some physical and mechanical properties; taught at the level of Friedel, *Dislocations.* Instructors: Lau, Vreeland.

MS 121. Solid State Diffusion. *9 units (3-0-6); 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.* Instructors: Buffington, Lau.

APh/MS 126 abc. The Electronic Structure of Metals and Alloys. *9 units (3-0-6); first, second, third terms. Prerequisite: an introductory course in quantum mechanics.* The basic principles of quantum mechanics and thermodynamics applied to understanding electronic band structure, metallic cohesion, structural stability, phase equilibrium and the kinetics of phase transitions, metastable states, lattice dynamics and elastic behavior, transport properties, superconductivity, magnetism, and the physics of metallic surfaces and thin metals films. Comparison of theory with experimental data and phenomenological concepts will form an integral part of the course with some discussion of current technological areas of application including superconducting devices and high field magnets, magnetic memory devices, radiation damage to metals, and corrosion resistance. Instructor: Johnson.

MS 130. Metallography and Pyrometry. *9 units (0-6-3); first term. Prerequisite: MS 15 or equivalent.* Metallurgical studies of materials of current technological interest utilizing optical metallography and photomicrography, temperature measurements, and cooling curves to study phase transformations. Instructor: Wood.

MS 131. Crystal Defects. *9 units (1-6-2); second term. Prerequisite: MS 120.* 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 that utilize optical microscopy, electron microscopy, and X-ray topography. Instructor: Vreeland.

MS 132. X-Ray Metallography Laboratory. *9 units (0-6-3); third term. Prerequisite: MS 5 a.* Experiments on X-ray emission spectra and absorption edges. Determination of crystal structures by the Von Laue and Debye-Scherrer methods. Use of the X-ray spectrometer. Study of preferred orientation in cold worked metals. Application of X-ray diffraction methods to the study of the phase diagrams. Instructors: Staff.

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 205 ab. Dislocation Mechanics. *9 units (3-0-6); second, third terms. Prerequisite: MS 120.* 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 300. Thesis Research.

MATHEMATICS

Undergraduate Courses

Ma 1 abc. Freshman Mathematics. *9 units (4-0-5); first, second, third terms. Prerequisites: high school algebra and trigonometry.* Calculus, ordinary differential equations, and infinite series. Linear algebra, vectors, and analytic geometry. Instructor: Apostol.

Ma 2 abc. Sophomore Mathematics. *9 units (4-0-5); first, second, third terms.* A continuation of the topics introduced in Ma 1 and an introduction to partial differential equations, probability and numerical analysis. Instructors: De Prima, Hoffman, Roth.

Ma 4 ab. Computer Graphic Techniques in Mathematics. *6 units (1-3-2); second and third terms.* The course provides an experimental approach to mathematical analysis using the computer and graphic display terminals. The computer will be used as an investigative tool in the formulation of mathematical principles. Observations and conjectures will be discussed and analyzed mathematically. Problems for study will be assigned initially, but increasing independence in the choice and execution will be given to students. No computer programming knowledge is required. Instructor: Dean.

Ma 5 abc. Introduction to Abstract Algebra. *9 units (3-0-6); first, second, third terms.* Groups, rings, fields, and vector spaces are presented as axiomatic systems. The structure of these systems is studied, making use of the techniques of automorphisms, homomorphisms, linear transformations, subsystems, direct products, and representation theory. Many examples are treated in detail. Instructors: Aschbacher, Dean.

Ma 31. Introduction to the Constructive Theory of Functions. *9 units (3-0-6); third term. Prerequisite: Ma 1 abc.* Polynomial approximation. The Weierstrass theorem and the Bernstein polynomials. Extremal properties of the Chebyshev polynomials. Markov's theorems. Classical orthogonal polynomials. Applications to interpolation and approximation integration. Instructor: Leviatan.

Ma 91 a. Representations of the Symmetric Group. *9 units (3-0-6); second term.* Instructor: Wales.

Ma 91 b. Numerical Algebra. *11 units (3-2-6); second term.* Instructor: Todd.

Ma 91 c. Numerical Analysis. *11 units (3-2-6); third term.* Instructor: Todd.

Ma 92 abc. Senior Thesis. *9 units (0-0-9); first, second, third terms. Prerequisite: approval of adviser.* Open only to seniors who are qualified to pursue independent reading and research. The work must begin in the first or second term and be supervised by a member of the staff. Students will submit a thesis at the end of the year. Graded pass/fail.

Ma 98. Reading. *3 units or more by arrangement.* Occasionally a 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 abc. Differential Geometry. *9 units (3-0-6).* Not offered in 1980–81.

Ma 103 ab. Algebraic Geometry. *9 units (3-0-6); first, second terms. Prerequisite: Ma 5 abc.* Introduction to algebraic curves, intersection theory, Bézout's theorem, Riemann-Roch theorem, geometry of special curves. Instructor: Morton.

Ma 104 ab. Projective Geometry. *9 units (3-0-6): first, second terms. Prerequisite: Ma 5 abc.* Foundations of projective geometry and finite projective planes. Not offered in 1980–81.

Ma 108 abc. Advanced Calculus. *12 units (4-0-8); first, second, third terms.* The basic course in analysis. Topics include metric spaces, Lebesgue integration, Fourier series and integrals, introduction to complex analysis. The emphasis is on fundamental concepts that equip the student for further reading and study. Instructors: Fuller, Janssen.

Ma 109. Delta Functions and Generalized Functions. *9 units (3-0-6); first term. Prerequisite: Ma 108, AMa 95 or equivalent.* Introduction to operational calculus and to delta functions. Laplace transforms. Applications to ordinary and partial differential equations. Not offered in 1980–81.

Ma 112 abc. Statistics. *9 units (3-0-6); first, second, third terms.* A complete short course in probability and typical statistical methods. Nonparametric methods, estimation, sequential analysis, hypothesis testing, and Bayes procedures. Instructors: Dilworth, Lorden.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 abc or equivalent.* First order logic and model theory; computability theory, undecidability, and Gödel's incompleteness theorems; set theory, the axiom of choice, and the continuum hypothesis. Instructor: Kechris.

Ma 118 abc. Functions of a Complex Variable. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 or equivalent.* Review of the basic concepts and methods of analytic function theory. Topics selected from: entire and meromorphic functions, conformal mapping, Riemann surfaces, special functions and differential equations, uniform algebras. Instructor: Squires.

Ma 120 abc. Abstract Algebra. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5.* Abstract development of the basic structure theorems of groups, commutative and non-commutative rings, lattices, and fields. Instructor: Dilworth.

Ma 121 abc. Combinatorial Analysis. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5.* Elementary and advanced theory of permutations and combinations. Theory of partitions. Theorems on choice including Ramsey's theorem and the Hall-Konig theorem. Existence and construction of block designs with reference to statistical design of experiments, linear programming, and finite geometries. Instructor: Ryser.

Ma 122 abc. Introduction to Group Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 abc.* A study of the basic properties of finite groups. Instructors: Hall, Hayden.

Ma 123 abc. Matrix Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 abc.* Fundamental concepts, matrix equivalences, canonical forms, nonnegative real matrices, integral matrices, combinatorial matrix theory. Not offered in 1980–81.

Ma 125 abc. Analysis of Algorithms. *11 units (3-2-6); first, second, third 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. Not offered in 1980–81.

Ma 128 abc. Lie Algebras. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 5, Ma 108, some knowledge of the theory of differentiable manifolds.* An introduction to the study of Lie groups, Lie algebras, and their representation. Emphasis will be placed upon the interplay between the geometry of a Lie group and the algebraic properties of its associated Lie algebra. Topics will include: foundations of the theory of Lie groups, classification of semisimple Lie algebras and their finite-dimensional representations, nilpotent and solvable Lie algebras, analysis on compact Lie groups, geometry of homogeneous spaces. Instructor: Conn.

Ma 137 a. Real Variable Theory. *9 units (3-0-6); first term. Prerequisite: Ma 108 or equivalent.* The Lebesgue theory of measure, integration and differentiation, Lp spaces of measurable functions. The Riesz representation theorems. Functions of bounded variation, absolute continuity. The Radon-Nikodym theorem. Instructor: Schep.

Ma 142 abc. Introduction to Partial Differential Equations. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 or equivalent.* Distribution theory. Local existence and nonexistence of solutions; Cauchy-Kovalevsky theorem, local solvability of constant-coefficient operators, examples of locally non-solvable equations. Classical examples: Laplace, heat, and wave operators. Sobolev spaces. Local regularity of elliptic operators and elliptic boundary value problems. Overdetermined systems and elliptic complexes. Applications to geometry and several complex variables to be chosen from: Hodge theory, deformation theory of complex manifolds, the δ-Neumann problem. Not offered in 1980–81.

Ma 143 ab. Introduction to Functional Analysis. *9 units (3-0-6); second, third terms. Prerequisite: Ma 137 a.* Point-set topology. General theory of topological vector spaces, Banach spaces, Hilbert spaces. Hahn-Banach extension principle, Banach-Steinhaus uniform boundedness principle, Krein-Milman theorem, closed graph theorem, open mapping theorem. Weak topologies. Banach algebras. Spectral analysis in Hilbert space. Instructor: Schep.

Ma 144 ab. Probability. *9 units (3-0-6); first, second terms.* Basic theory, including characteristic functions and limit theorems, random walk. Markov chains. Poisson process, Brownian motion. Instructor: Lorden.

Ma 150 abc. Combinatorial Topology. *9 units (3-0-6); first, second, third 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 1980–81.

Ma 152 abc. Geometry of Surfaces. *9 units (3-0-6). Prerequisite: Ma 108 or equivalent.* Surfaces are studied from the viewpoints of algebraic topology, differential geometry, complex variable theory and analysis. Not offered in 1980–81.

Ma 153 abc. Geometrical Methods in Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 or equivalent.* Applications of differential (especially symplectic) geometry to the mechanics of particles and waves. Topics to be covered include manifolds, tangent and cotangent bundles, vector fields and differential forms, lagrangian and hamiltonian systems, variational methods, small oscillations, stability, periodic orbits, Lie groups and mechanical systems with symmetry, geometric quantization, quasiclassical asymptotics. Further topics will be chosen according to the interests of the class. Not offered in 1980–81.

Ma 160 abc. Number Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 abc or equivalent.* Topics selected from: elementary number theory, zeta functions, distribution of primes, modular functions, asymptotic theory of partitions, geometry of numbers, ideal theory in algebraic number fields, units, valuations, discriminants, differents, and local theory. Not offered in 1980–81.

Ma 165. Diophantine Analysis. *9 units (3-0-6); third term. Prerequisite: Ma 5.* An introduction to transcendental number theory: transcendence of e and π. Lindemann's theorem, irrationality of ζ (3), Gelfond-Schneider theorem. Instructor: Morton.

Ma 190 abc. Elementary Seminar. *9 units; first, second, third 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 c. Several Complex Variables. *9 units (3-0-6); third term.* Elementary theory of functions of several complex variables, Hartog's phenomenon, domains of holomorphy, pseudoconvexity, solving the d-bar operator on pseudoconvex domains, local theory, Weierstrass preparation theorem, sheaf theory, and Cartan's theorems A and B. Instructor: Squires.

(B) The following courses are open primarily to graduate students.

Ma 216 abc. Advanced Mathematical Logic. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 116 or equivalent.* Topics to be chosen from model theory and its applications to algebra, infinitary logic and admissible sets, ordinary and generalized recursion theory, consistency and independence results in set theory, large cardinals, descriptive set theory. Content varies from year to year so that students may take the course in successive years. Instructor: Woodin.

Ma 221 abc. Advanced Combinatorial Analysis. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 121 or instructor's permission.* The course will include material on combinatorial designs, graphs, and codes with emphasis on the algebraic aspects of the theory and topics of current research interest. Special topics to be covered include strongly regular graphs, partial geometries, association schemes, theory and constructions of t-designs, combinatorial configurations arising from finite projective geometries, coding theory, geometric lattices (matroids), and possibly convexity and combinatorial optimization. Instructor: Wilson.

Ma 222 ab. Advanced Group Theory. *9 units (3-0-6); second, third terms. Prerequisite: Ma 120 or Ma 122 or instructor's permission.* Discussion of topics related to current areas of interest in group theory. Not offered in 1980–81.

Ma 223 abc. Matrix Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 120 or equivalent.* Algebraic, arithmetic and analytic aspects of matrix theory. Not offered in 1980–81.

Ma 224 abc. Lattice Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 120 or instructor's permission.* 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 1980–81.

Ma 243 ab. Advanced 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: Luxemburg.

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 316 abc. Seminar in Mathematical Logic. *9 units. Three terms.* Instructor: Kechris.

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.* Instructors: Wales, Ryser.

Ma 340 abc. Special Topics in Analysis. *9 units. Three terms.*

Ma 345 abc. Seminar in Analysis. *6 units. Three terms.* Instructors: Luxemburg, Schep.

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. *Three terms.*

See also the list of courses in Applied Mathematics.

MECHANICAL ENGINEERING

Undergraduate Courses

ME 1 ab. Introduction to Design. *9 units (1-6-2); second, third terms. Prerequisites: Gr 1 or instructor's permission.* The student is introduced to the field of design in its broadest sense through a coordinated series of short design projects, seminars by practicing designers, and related field trips. Useful graphical and analytical techniques are developed as effective tools for rapid engineering approximations in preliminary layout and design. Elements of mechanisms and computer-aided design are treated along with other basic aspects of design such as selection of materials and standard components, manufacturing methods, functional, economic, and aesthetic considerations. At least one of the projects will involve some actual machine shop experience in the construction of a simple prototype or working model. Instructor: Welch.

ME 5 abc. Design. *9 units (1-6-2); first, second, third terms. Prerequisites: ME 1 ab, MS 15 abc, or instructor's permission.* The aim of this course is to develop creative ability and engineering judgment through actual project development work involving preliminary design, prototype modeling, and engineering analysis. Broadening the student's individual background experience is emphasized through the use of engineering case studies and personal working relationships with professional engineers and designers from industry whenever possible. Instructor: Welch.

APh/ME 17 abc. Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Introduction to the use of thermodynamics and statistical mechanics in physics and engineering. Entropy, temperature, and the principal laws of thermodynamics. The thermodynamic identity for open and closed systems. Canonical equations of state. Applications to cycles, engines, phase and chemical equilibria. Probability and stochastic processes. Kinetic theory of perfect gases. Statistical mechanics. Applications to gases, gas degeneration, equilibrium radiation, and simple solids. Instructor: Liepmann.

ME 19 abc. Fluid Mechanics and Gasdynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 abc, Ph 1 abc.* Basic equations of fluid mechanics, theorems of energy, linear and angular momentum, potential flow, elements of airfoil theory. Flow of real fluids, similarity parameters, flow in closed ducts. Boundary layer theory in laminar and turbulent flow. Introduction to compressible flow. Flow and wave phenomena in open channels. The third term may also include topics related to energy production and conversion; subjects such as the theory of fluid machinery and heat transfer may be introduced. Instructors: Acosta, Brennen, Sabersky.

ME 22 abc. Introduction to Thermal Engineering. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 17 abc, ME 19 abc (may be taken concurrently).* This course is intended to introduce the student to the principles of thermal energy transfer and thermal power conversion. Heat transfer by conduction, convection, and radiation will be reviewed. Analyses of open and closed cycles with and without phase change will be covered emphasizing applications to power generation, heat pumps, refrigeration, etc. The basic principles of fluid dynamic machines will be covered in order to introduce concepts of size and speed limitations. The course will conclude with some basic studies of thermal, solar, and nuclear power generation. Instructors: Acosta, Brennen.

Advanced Courses

ME 100. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses on 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, third terms. Prerequisite: ME 5 abc or equivalent.* Rational yet imaginative design approaches to machines and systems are developed at a more advanced level with the objective of a completed working model or prototype to be constructed for final testing. Suitable projects may be selected on a basis of individual student's interests or needs from a variety of fields: numerical control, electro-hydraulic systems, teleoperators, control systems and related hardware, computer graphics, etc. Instructor: Welch.

ME 102 abc. Principles of Energy Conversion and Distribution. *9 units (3-0-6); first, second, third terms. Prerequisites: APh/ME 17 abc and ME 19 abc or equivalent.* Analysis of stationary power plants and characteristics of components, i.e., turbines, combustion chambers or nuclear heat sources, heat exchangers, condensers, cooling towers, and electric generators; problems of transportation of fossil fuels, anti-pollution measures, standby power sources, storage and distribution of electric power; automotive power; direct conversion and alternative power sources. Instructor: Rannie.

ME 117 ab. Fundamental Design Principles of Combustion Engines. *9 units (3-0-6); second, third terms. Prerequisites: APh/ME 17 abc and ME 19 abc or equivalents. This course may be taken by undergraduates.* Introduction to the design of internal combustion engines, jet engines, ramjets, gas turbines, steam engines, Stirling engines. Analytical use of thermodynamics, combustion chemistry, and fluid mechanics in the rational design of systems having high efficiency and low pollution emissions. Many of the lectures will be given by staff members from the Jet Propulsion Laboratory. Instructor: Clauser.

ME 118 abc. Advanced Thermodynamics and Energy Transfer. *9 units (3-0-6); first, second, third terms. Prerequisites: APh/ME 17 abc, ME 19 abc, or equivalent.* Review of basic equations of fluid flow, energy, and mass transfer. Heat conduction in solids, heat transfer for laminar and turbulent flows in forced and free convection. Introduction to mass transfer and radiation as well as selected topics such as boiling heat transfer, two-phase flow, evaporation and condensation. Instructors: Acosta, Sabersky.

ME 126. Fluid Mechanics and Heat Transfer Laboratory. *9 units (0-6-3); third term. Prerequisites: APh/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 and fluid mechanics. The student may select several short projects from a rather wide list of possible experiments. Specific areas from which experiments may be selected include free and forced convection, boiling heat transfer, combustion, solid-state energy conversion, free surface flow, turbomachines, and fluidic controls. Instructors: Staff.

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 202 ab. Engineering Two-Phase Flows. *9 units (3-0-6); first and second terms. Prerequisites: AMa 95 abc, Hy 101 abc, or equivalents.* Selected topics in engineering two-phase flows with emphasis on practical problems in modern hydro-systems. Fundamental fluid mechanics and heat, mass, and energy transport in multiphase flows. Liquid/vapor/gas (LVG) flows, nucleation, bubble dynamics, cavitating and boiling flows, models of LVG flows; instabilities, dynamics and wave propagation; fluid/structure interactions. The course will include discussion of two-phase flow problems in conventional, nuclear, and geothermal power plants, marine hydrofoils, and other hydraulic systems. Instructor: Brennen.

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, and Materials Science.

MUSIC

Mu 12. Medieval-Early Baroque Western Music History. *9 units (3-0-6); first term.* Course content: the music history of the Medieval, Renaissance, and early Baroque periods; listening and stylistic analysis of representative works. Instructor: Britton.

Mu 13. Baroque-Early Romantic Western Music History. *9 units (3-0-6); second term.* Course content: the music history of the high Baroque, Classic, and early Romantic periods; listening and stylistic analysis of representative works. Instructor: Britton.

Mu 14. Romantic-Twentieth-Century Western Music History. *9 units (3-0-6); third term.* Course content: the music history of the high Romantic period and of the twentieth century; listening and stylistic analysis of representative works. Instructor: Britton.

Mu 15. Fundamentals of Music Theory. *9 units (3-0-6); first term. No prerequisite.* Course content: basic vocabulary and concepts of music theory (rhythm and pitch notation, intervals, scales, function of key signatures, etc.); development of aural perception via elementary rhythmic and melodic dictation, and sight-singing exercises. Instructor: Britton.

Mu 16. Tonal Harmony and Intermediate Music Theory. *9 units (3-0-6); second term. Prerequisite: Mu 15 or entrance exam.* Course content: study of tonal harmony; techniques of chord progression, modulation, and melody writing according to common practice; ear training continued. Instructor: Britton.

Mu 17. Advanced Music Theory. *9 units (3-0-6); third term. Prerequisite: Mu 16 or entrance exam.* Course content: more advanced concepts of music theory, including chromatic harmony, contrapuntal techniques, and twentieth-century procedures; ear training continued. Instructor: Britton.

Mu 18 ab. Music for Piano Ensemble: History, Analysis, Performance. *9 units (3-0-6); first, second terms.* A historical survey of original piano music written for two players at one or two pianos from Bach to the present day (arrangements for eight hands will also be included). Attention will be focused on the stylistic trends of various periods and composers through written work and actual participation. Pianists with varying degrees of performing ability will be admitted to the class at the discretion of the instructor. Instructor: Schonbach.

Mu 20. Music and Dances of India. *9 units (3-0-6); first term.* Survey course of music and dances of India with live performances, films, and tapes. Also instruction in playing the sitar. Instructor: Rao.

Mu 21. Rhythmic Complexes. *9 units (3-0-6); second term.* Exploring simple to complex rhythms in various musics using the Tala system of India. Also instruction in playing hand drums. Instructor: Rao.

Mu 101. Selected Topics in Music. *Units to be determined by arrangement with the instructor.* Instructors: Staff and visiting lecturers.

EE/Mu 107 abc. Projects in Music and Science. *Units to be individually arranged, up to a maximum of 9.* One two-hour meeting each week with a second meeting at the discretion of the instructor. In this course, a small number of students will carry out, singly or in groups, projects of study or research exploring the connections of music with the sciences, such as the possibility of rules for expressive performance, objective versus subjective in audio, or materials and instrument design. EE/Mu 107 a will be devoted to Analytic Listening to Live and Reproduced Sound; it may be taken by itself and has no prerequisites. *EE/Mu 107 b & c, devoted to the projects, require instructor's permission and 107 a as prerequisites.* Credit in music or EE but not in both. Instructor: Boyk.

PHILOSOPHY

Courses above Pl 10 are open only to students who have fulfilled the freshman humanities requirements.

Undergraduate Courses

Pl 7 ab. Introduction to Philosophy. *9 units (3-0-6); first, second terms.* A study of the history of philosophy through readings in the sources. The two terms will concentrate, respectively, on modern and contemporary philosophy. Not offered in 1980–81. Instructors: Staff.

Pl 12. Induction. *9 units (3-0-6); third term.* 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: F. 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 17 abc. Introductory Philosophy. *9 units (3-0-6).* Topic-oriented examination of selected problems in philosophy. Historical and contemporary readings. Sections b and c not offered in 1980–81. Instructors: Staff.

Pl 20. The Psychology of Liberation: Laing, Brown, and Marcuse. *9 units (3-0-6); second term.* This course will examine some contemporary views on the elimination of repression in sex, art, and society. Readings from Laing's *Politics of Experience*, Brown's *Life Against Death*, and Marcuse's *Eros & Civilization*. Not offered in 1980–81. Instructors: Staff.

Pl 21. Theory of Knowledge. *9 units (3-0-6); second term.* An investigation of selected topics in the theory of knowledge including the difference between knowledge and true opinion; our evidence for belief in material objects and other minds; necessary truth; and the status of appearances. Not offered in 1980–81. Instructors: Staff.

HSS 99. See page 325 for description.

Advanced Courses

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); second 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. Not offered in 1980–81. Instructor: Jones.

Pl 104. Educational Issues and Problems. *9 units (3-0-6); first term.* 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 fields of education and psychology. Instructor: Browne.

Pl 105 abc. Philosophy of Science Seminar. *9 units (3-0-6). Three-term sequence. Pl 105 a or Pl 105 b strongly recommended as preparation for Pl 105 c.* Topics to include the structure and function of scientific methods, concepts, theories, and explanation. Pl 105 c is concerned primarily with the behavioral sciences. Not offered in 1980–81. Instructors: Staff.

Pl 106 ab. Philosophy of Language. *9 units (3-0-6); first, second terms.* An investigation of some contemporary issues in the philosophy of language: the analytic-synthetic distinction, theories of sense and reference, the status of speech acts. Readings from Quine, Putnam, Russell, Strawson, Kripke, and others. An effort will be made to show how these issues relate to more traditional philosophical problems. Not offered in 1980–81. Instructors: Staff.

Pl 107. Seminar in the Philosophy of Mind. *9 units (3-0-6); first term.* A study of selected topics on the philosophy of mind. Possibilities include sense-datum theory, mind-brain identity thesis, machine consciousness, Gödel's Theorem and its implications. Not offered in 1980–81. Instructors: Staff.

Pl 108 ab. Friedrich Nietzsche. *9 units (3-0-6); second, third terms.* A close reading of Nietzsche's major works including *The Birth of Tragedy, The Gay Science, Beyond Good and Evil, On the Genealogy of Morals, Twilight of the Idols, Ecce Homo.* Not offered in 1980–81. Instructors: Staff.

Pl 113. Reading in Philosophy. Same as Pl 13 but for graduate credit.

PHYSICS

Undergraduate Courses

Ph 1 abc. Classical Mechanics and Electromagnetism. *9 units (4-0-5); first, second, third terms.* The first year of a two-year course in introductory classical and modern physics. Topics covered include Newtonian mechanics, electricity and magnetism, and special relativity. Emphasis is placed on both physical insight and the ability to solve problems. Graded pass/fail. Instructors: Goodstein and others.

Ph 2 abc. Waves, Quantum Mechanics, and Statistical Physics. *9 units (4-0-5); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or their equivalents.* The second year of a two-year introductory course in classical and modern physics. Topics to be covered include electromagnetic waves, optics, introductory quantum mechanics, thermodynamics, and statistical mechanics. Instructors: Tombrello and others.

Ph 3. Physics Laboratory. *6 units; first, second, third terms.* The six units cover one three-hour laboratory session per week, an individual conference with the instructor, prelab preparation, and analysis of experimental results outside the laboratory period. This introductory course emphasizes quantitative measurements, the treatment of measurement errors, and graphical analysis. A variety of experimental techniques will be employed. The experiments include studies of d.c. meters, the oscilloscope, the Maxwell top, electrical and mechanical resonant systems, and radioactivity. Instructors: Hitlin and assistants. Graded pass/fail.

Ph 4. Physics Laboratory. *6 units; third term only. Prerequisite: Ph 3 or equivalent.* As in Ph 3, the six units cover one laboratory period per week, plus other activities outside the lab. The student will choose from a variety of experiments encompassing both classical and atomic physics. Some examples are the transient response of a resonant circuit, the Millikan oil drop experiment, electron diffraction, viscosity, diffraction of electromagnetic waves, and sound waves in a cavity. Instructors: Hitlin and assistants. Graded pass/fail.

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: Hitlin 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 is made. Instructors: Gomez, Hitlin and assistants.

Ph 7. Physics Laboratory. *6 units; third term. Previous laboratory experience, such as obtained in Ph 6 or other sophomore laboratories, is desirable.* 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: Gomez, Hitlin and assistants.

Ph 12 abc. Quantum and Statistical Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or their equivalent.* A one-year course primarily for students intending further work in the Physics option. Topics in quantum mechanics will include: interpretation of the wave-function, one-dimensional problems, and central potentials. Statistical mechanics topics will include thermodynamics, introductory kinetic theory, and quantum statistics. This course may be taken to fulfill the Institute Ph 2 requirement. Instructor: Koonin.

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: Barish.

Ph 78 abc. Senior Thesis Experimental. *9 units; first, second, 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. See note under Ph 79 below.

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.

Note: Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with Professor Koonin, chairman of the Physics Undergraduate Committee, or any other member of the committee. It should be noted that a grade will not be assigned in Ph 78 or Ph 79 until the completion of the thesis, which is normally expected to take three terms. P grades will be given the first two terms, and then changed at the end of the course to the appropriate letter grade.

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. Instructor: Garmire.

Ph 98 abc. Quantum Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 12 abc, Ma 2 abc, or their equivalents.* A one-year course in quantum mechanics and its applications, for students who have completed Ph 12. The course will include scattering theory, approximation methods, symmetries, spin-½ systems, and selected topics in atomic, solid-state, nuclear, and particle physics. Not offered in 1980–81.

Advanced Courses

Ph 103 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. Students may register for any particular term or terms; they are independent. Instructors: Boehm, Drever, Stone.

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. Instructors: Barnes, Cowan, Davis.

Ph 118 ab. Electronic Circuits and Their Application to Physical Research. *9 units (3-3-3); first, second terms.* A course on the fundamentals of analog and digital electronics with emphasis on proven techniques of instrumentation for scientific research. The course will treat both the physical principles and properties of electronic components and circuits and the logical design of digital systems. 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. Not offered in 1980–81.

Ph 125 abc. Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 abc. Recommended: either AMa 95 abc or Ma 108 abc. Not available to students who have completed Ph 98 abc.* A fundamental course in quantum mechanics aimed at understanding the mathematical structure of the theory and its application to physical phenomena at the atomic 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: Walker, Zweig.

Ph 127 abc. Statistical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 92 abc, Ph 106 abc.* The course will present a thorough introduction to problems in physics that 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. Instructor: Mercereau.

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. Instructor: Peck.

Ph 135 abc. Applications of Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125 abc or equivalent.* Applications of quantum mechanics to topics in contemporary physics. Subject matter will include atomic, molecular, nuclear, and elementary particle physics; solid state physics; quantum electronics; lasers; superconductivity and superfluidity. Instructor: Schwarz.

Ph 136 abc. Applications of Classical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* Applications of classical physics to topics of interest in contemporary "macroscopic" physics. Subject matter typically will include continuum physics and classical field theory; elasticity and hydrodynamics; plasma physics; magnetohydrodynamics; thermodynamics and statistical mechanics; gravitation theory including general relativity and cosmology; modern optics. The course content will vary from year to year, depending on the instructor. An attempt will be made to organize the material so that the terms may be taken independently. Instructor: Thorne.

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 or her 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 or her departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 203 abc. Nuclear Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 92 abc and Ph 125 abc or equivalents.* The first two terms will survey at a quantitative level modern concepts in the fields of nuclear structure and nuclear reactions. Topics will include: nuclear systematics, independent-particle and collective models, radioactive decay modes, radiative transitions and heavy-ion reactions. The third term will be devoted to an introduction to special topics in nuclear physics pertinent to the explanation of various intermediate-energy and astrophysical phenomena; e.g., meson theory of nuclear forces, theory of nuclear matter under ordinary and extreme conditions, with applications to supernova physics and the physics of neutron stars. Instructor: Sandler.

Ph 205 abc. Relativistic Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125 abc or Ph 92 abc.* The course will cover relativistic quantum mechanics with an introduction to field theory. Topics covered include the Dirac equation, scattering theory, Feynman diagrams, quantum electrodynamics, second quantization, non-abelian gauge theories, Higgs symmetry-breaking, the Weinberg-Salam model, and renormalization. Instructor: Frautschi.

Ph 209 abc. Classical Electromagnetism. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc.* Electromagnetic fields in vacuum and in matter; boundary-value problems and Green's functions; retarded potentials; wave propagation; wave guides and cavities; radiation, dispersion and absorption; and special relativity. Instructor: Kavanagh.

Ph 213 ab. Nuclear Astrophysics. *9 units (3-0-6); first, second terms.* A lecture course in the applications of nuclear physics to astronomy, geochronology, cosmochronology and other fields. Topics included are: basic nuclear properties, nuclear reactions under astrophysical circumstances, energy generation and element synthesis, massive condensed objects, and nuclear evidence on the origin of the solar system and on the chronology of the Galaxy. Graded pass/fail. Not offered in 1980–81.

Ph 222. Many-Body Theory. *9 units (3-0-6); third term. Prerequisite: Ph 205 or equivalent.* Selected topics in the quantum theory of many particle systems are reviewed. Subject matter will include the application of field theory and graphical methods to specific physical problems of interest in condensed matter physics. These problems include the degenerate electron gas, electron-phonon interaction, superconductivity, and superfluid helium. Not offered in 1980–81.

Ph 224 abc. Space Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 92, Ph 106 or equivalent.* A course covering the experimental and theoretical aspects of X-ray, cosmic ray, and gamma ray astrophysics, with emphasis on topics of current research interest. Not offered in 1980–81.

Ph 229 abc. Advanced Topics in Mathematical Physics. *9 units (3-0-6); third term. Recommended preparation: Ph 129 abc or equivalent.* This course will cover specialized topics in mathematical methods of interest in physics. The subject matter will vary from year to year; it will be presented in one or two term blocks that may be taken independently. In 1980–81 this course will be offered only during the third term; it will cover statistical techniques for the analysis of experimental data, and how best to determine parameters by comparing theoretical predictions with data. Instructor: Fox.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205 abc (with permission of the instructor, may be taken concurrently).* A course in advanced techniques of elementary particle theory, including field theory, renormalization, groups and symmetries, gauge theories, current algebra, dispersion theory, and other approaches of current interest. Instructor: Politzer.

Ph 231 ab. High Energy Physics. *9 units (3-0-6); first, second terms. Prerequisites: Ph 125 abc or equivalent.* An introductory course on the properties and interactions of elementary particles that covers both the theoretical ideas and the experimental techniques used in high energy physics. The particle classification and symmetries will be described phenomenologically and related to the fundamental properties of quarks and leptons interacting via gauge bosons (gluons, photons, and W bosons). Observable consequences and simple calculations will be given in both Quantum Chromodynamics (including the parton model of strong interactions) and Quantum Flavor theories (or the weak interactions). A survey will be given of Regge theory, duality, and other topics in the strong interactions. Useful techniques—including Feynman diagrams, the Dirac equation, and helicity amplitudes—will be used in illustrative calculations. Instructor: Fox.

Ph 234 ab. Topics in Theoretical Physics. *9 units (3-0-6); second, third terms. Prerequisites: Ph 205 abc and Ph 231 ab, or instructor's permission.* Current topics of research in elementary particle theory will be presented. In 1980–81 the course will cover Yang-Mills theories, including symmetry breaking, and supergravity. Instructor: Gell-Mann.

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: Feynman.

Ph 237 abc. Theoretical Nuclear Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 203 abc and Ph 205 abc or equivalent.* A lecture and reading course on the microscopic treatment of the nuclear many-body problem. Topics to be covered include many-body techniques as applied to the structure of both nuclear matter and finite nuclei, microscopic and macroscopic descriptions of collective motion, the formalism and application of various nuclear reaction theories, and the use of weak and electromagnetic interactions as probes of nuclear structure. Not offered in 1980–81.

Ph 240 abc. Current Theoretical Problems in Particle Physics. *6 units (2-0-4); first, second, third terms. Prerequisite: Ph 230 abc or equivalent.* Problems connected with quark-gluon gauge theory of strong interaction, gauge theory of electromagnetic, weak, and associated interactions, and attempts at overall unification. Discussion and argument are encouraged. Graded pass/fail. Not offered in 1980–81.

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 at Caltech and elsewhere. Advanced students in physics and members of the physics staff take part.

Ph 242 abc. Physics Seminar. *9 units (2-0-7); first, second, third terms.* A seminar on current topics in physics including an overview of physics research at Caltech. There will be one two-hour meeting per week. Speakers will be chosen from both faculty and students. Not offered in 1980–81.

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 or her research leads directly toward the thesis for the degree of Doctor of Philosophy. Approval of the student's research supervisor and of his or her department adviser or registration representative must be obtained before registering. Graded pass/fail.

POLITICAL SCIENCE

HSS 99. See page 325 for description.

Advanced Courses

PS 101. Selected Topics in Political Science. *Units to be determined by arrangement with the instructor.* Instructors: Staff.

PS 102. Black Africa 800 A.D. to the Present. *9 units (2-0-7); second term.* 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. Instructor: Bates.

PS 109. The Presidency. *9 units (3-0-6).* This course is an introduction to the major topics in the study of the presidency. These include presidential elections, executive branch relations, the role of the president in shaping foreign and domestic policy and the substantial institutional constraints on the exercise of presidential power. Instructor: Kiewiet.

PS 110. Political Modernization and Development. *9 units (3-0-6).* Studies of the politics of developing nations. Focuses on the political consequences of rapid social and economic change. Not offered in 1980–81. Instructor: Bates.

PS 112. Behavioral Basis of Politics. *9 units (3-0-6).* Studies the development of political attitudes and public opinion. Topics include the role of the mass media, peer groups, and social institutions in the formation and stabilization of political opinions. Not offered in 1980–81. Instructors: Bates, Kiewiet.

PS 113. Social Inequality and Politics. *9 units (3-0-6).* Studies the role of social classes in politics. Includes classical Marxist literature, plus more recent empirical research on the relationship of social class to political behavior. Not offered in 1980–81. Instructor: Bates.

PS 115. Seminar on National Security. *9 units (2-0-7).* 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/SS 116. War, Diplomacy, and International Politics. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* This course examines the various theories of the sources and resolution of international conflicts. The second half will be devoted to applying these theories to case studies of conflicts such as the First and Second World Wars, the Vietnam War, the Cold War, and the Arab-Israeli crisis. Instructor: Cain.

PS 118. Democratic Theory. *9 units (3-0-6); second 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? Not offered in 1980–81. Instructors: Ferejohn, Cain.

PS/SS 119. The Politics of the Industrial State. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* The emphasis of this course will be on the institutions of and the behavior within industrialized democracies of the western world. Instructors: Cain, Kiewiet.

PS 120. American Electoral Behavior and Party Strategy. *9 units (3-0-6).* A consideration of existing literature on the voting behavior of the citizen, moving to an examination of theoretical and empirical views of the strategies followed by the parties. Instructors: Cain, Fiorina, Kiewiet.

PS 121. Congressional Policy Formation and Legislative Process. *9 units (3-0-6); second term.* An analysis of decisionmaking in legislative bodies with major emphasis on the American Congress. It also includes an investigation into the impact of Congressional structure and practices on the policies adopted by the Federal Government. Not offered in 1980–81. Instructors: Fiorina, Ferejohn.

PS/SS 122. Noncooperative Games in Social Science. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* An examination of the axiomatic structure and the behavioral interpretations of game theory models in social science. Will cover axiomatic utility theory and general noncooperative games. Instructors: Staff.

PS/SS 123. Cooperative Games in Social Science. *9 units (3-0-6). Prerequisite: PS/SS 122.* Various cooperative solutions to games will be discussed with particular application to voting, bargaining, and market games. Emphasis will be on solution concepts and existence theorems. Instructors: Staff.

PS 125. Peasant Politics. *9 units (3-0-6); second term.* The course will study the political role of the peasantry. Particular attention will be paid to rural political organization and the effect of market relationships. Not offered in 1980–81. Instructor: Bates.

PS 132. Formal Theories in Political Science. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* An examination of the axiomatic structure and the behavioral interpretations of game theoretic and social choice models and models of political processes based on them. Instructors: Staff.

PS 133. Comparative Politics. *9 units (3-0-6).* Selected topics in the study of the politics of non-American political systems. Areas of study would include: the politics of non-democratic states, including the Communist nations; the politics of developing societies; the politics of the Western European democracies. Particular emphasis will be placed on the effect of distinctive institutions on the performance of government and the content of public policy. Instructors: Staff.

Ec/PS 134. The Political Economy of Urban Areas. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* This course will focus on development of a theory of urban government using analytic concepts from microeconomics and political science. Not offered in 1980–81. Instructors: Staff.

PS 135. Political Geography of Developing Countries. *9 units (2-0-7); first term.* A study of the swift transition from colonialism or an undeveloped state to the present that 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. Instructor: Munger.

PS/SS 136. Bureaucratic Politics. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* An analysis of the role of the executive branch in public policy formation. A review of the relevant organization theory literature is included. Not offered in 1980–81. Instructor: Cain.

PS/SS 137. Organizational Theory. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* An examination of decisionmaking in the context of hierarchical organizations. Applications will be made to various political, governmental, and private organizations. Not offered in 1980–81. Instructors: Staff.

PS 141 ab. African Studies. *9 units (2-0-7); second, third terms.* Political and social change in sub-Saharan 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. Not offered in 1980–81. Instructor: Bates.

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. Not offered in 1980–81. Instructor: Cain.

PS/SS 202. American Electoral Processes. *9 units (3-0-6); first term. Prerequisite: PS/SS 122 (may be taken concurrently).* An in-depth analysis of American electoral processes with emphasis on the application of new theory and quantitative techniques. Instructors: Bates, Kousser.

PS/SS 203. Congress and the Executive. *9 units (3-0-6); second term. Prerequisite: PS/SS 202.* The course focuses on the analysis of executive and congressional decisionmaking. Emphasis on theory of committee and bureaucratic theory. Instructors: Cain, Bates, Kiewiet.

PS/SS 204. American Federal System. *9 units (3-0-6); third term. Prerequisite: PS/SS 203.* This course explores the problems raised by the division of political authority between federal, state and local governmental units. Instructors: Ferejohn, McKelvey.

PSYCHOLOGY

Undergraduate Courses

Psy 11. Introduction to Psychology. *9 units (3-0-6); first term.* A relatively free exploration of the variety of topics that comprise psychology. Topics may include, but are not limited to: historical background, development of personality and intellect, biological-evolutionary factors, issues in motivation, learning, social and abnormal psychology. Not offered in 1980–81. Instructor: Breger.

Psy 12. Introduction to Abnormal Psychology. *9 units (3-0-6); third 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: Breger.

Psy 25. Reading and Research in Psychology. *Units to be determined by the instructor.* Reading and research in psychology and related subjects. A written report will be required. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

Advanced Courses

Psy 100 ab. Psychological Development. *9 units (3-0-6); first, second terms.* 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.

H/Psy 107 ab. Psychohistory. *9 units (3-0-6).* An examination of the influence of psychological factors in the course of history and of historical forces in the shaping of groups and individuals. Students are encouraged to take both courses in sequence, though each is a self-contained unit and may be taken separately. H/Psy 107 a will cover the premodern period and H/Psy 107 b the modern period. Taught in alternate years; section b not offered in 1980–81. Instructor: Benton.

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

Ec/SS 11 a. Social Science Principles and Problems—Introduction to Microeconomics. *9 units (3-0-6); first, second terms.* An introduction to the methodology of social science, particularly economics, and the applications of that methodology to current social problems. Instructors: Davis, Plott.

Ec/SS 11 b. Social Science Principles and Problems—Non-Market Decisions. *9 units (3-0-6); second, third terms. Prerequisite: Ec/SS 11 a or equivalent.* This course concentrates on non-market decisions. It focuses on committee and legislative decisionmaking as well as providing an introduction to recent work in the theory of voting and the political process. Instructors: Fiorina, Bates.

Ec/SS 11 c. Social Science Principles and Problems—Applications to Public Policy. *9 units (3-0-6); third term. Prerequisite: Ec/SS 11 b or equivalent.* 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. Not offered in 1980–81. Instructor: Noll.

SS 98. Reading in Social Science. *Units to be determined for the individual by the department. Elective, in any term.* Reading in social science and related subjects, done either in connection with the regular courses or independently of any course, but under the direction of members of the department. A brief written report will usually be required. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

Advanced Courses

SS 101. Selected Topics in Social Science. *9 units (3-0-6).* Instructors: Staff, Visiting Lecturers.

Lin/SS 103. Psycholinguistics. *9 units (2-1-6); third term.* A seminar-type course on language behavior as a reflection of conceptual processes. Language acquisition, aphasia and other language disturbances, linguistic memory and grammar organization, language and the brain, multilingualism. A research project is required. Instructor: B. Thompson.

Lin/SS 104. Sociolinguistics. *9 units (2-1-6).* Language in social interaction studied in a seminar-research type course. Experiments required. Readings in language variation (dialects, slang, jargon, scientific and other). Taught in alternate years; not offered in 1980–81. Instructor: B. Thompson.

Lin/SS 105. Computational Linguistics. *9 units (2-1-6); first term. Prerequisite: Lin 101 a or Lin 101 b or equivalent.* English as a language for communication with computers. Problems in parsing and semantic data base analysis. Review through readings of natural language processing systems, including speech recognition and other AI (artificial intelligence) applications. Research required. Taught in alternate years: offered in 1980–81. Instructors: B. Thompson, F. Thompson.

PS/SS 116. War, Diplomacy, and International Politics. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* This course examines the various theories of the sources and resolution of international conflicts. The second half will be devoted to applying these theories to case studies of conflicts such as the First and Second World Wars, the Vietnam War, the Cold War, and the Arab-Israeli crisis. Instructor: Cain.

SS 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. Instructor: Oliver.

PS/SS 119. The Politics of the Industrial State. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* The emphasis of this course will be on the institutions of and the behavior within industrialized democracies of the western world. Instructors: Cain, Kiewiet.

PS/SS 122. Noncooperative Games in Social Science. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* An examination of the axiomatic structure and the behavioral interpretations of game theory models in social science. Will cover axiomatic utility theory and general noncooperative games. Instructors: Staff.

PS/SS 123. Cooperative Games in Social Science. *9 units (3-0-6). Prerequisite: PS/SS 122.* Various cooperatives solutions to games will be discussed with particular application to voting, bargaining, and market games. Emphasis will be on solution concepts and existence theorems. Instructors: Staff.

SS 130 abc. Law, Legal Processes, and the Control of Technological and Economic Risk. *9 units (3-0-6).* This course will attempt to provide familiarity with and insight into the distinctive ways that lawyers think about and deal with problems as well as to provide instruction in the substantive area. Instructor: Levine.

SS 132. Government Regulation of Business. *9 units (3-0-6). Prerequisite: Ec/SS 11 a, or introductory economics.* This course examines the economic, institutional, and legal implications of government regulation and includes comparisons with alternative mechanisms for organizing markets. Instructors: Levine, Noll.

SS 133. Topics in Anglo-American Law. *9 units (3-0-6); second, third terms.* An introduction to the American legal system through the study of a particular subarea of law, which may vary from term to term or year to year. Instructor: Levine. *May be taken more than once if the topic is different.*

PS/SS 136. Bureaucratic Politics. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* An analysis of the role of the executive branch in public policy formation. A review of the relevant organization theory literature is included. Not offered in 1980–81. Instructor: Cain.

PS/SS 137. Organizational Theory. *9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* An examination of decisionmaking in the context of hierarchical organizations. Applications will be made to various political, governmental, and private organizations. Not offered in 1980–81. Instructors: Staff.

SS 140 ab. Laboratory Experiments in the Social Sciences. *9 units (3-0-6); second, third terms.* 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. Instructor: Plott.

CS/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 studied. Real-life data bases from a variety of subject areas will be analyzed. The computer will be used extensively. Not offered in 1980–81. Instructor: F. Thompson.

H/SS 150. Problems in the History of English Law and Society. *9 units (3-0-6); first term.* The course will consider aspects of the development of law and society in pre-industrial England. Taking a particular problem, which may differ from one term to another, it will consider the relationship between actions of common law, legal administration, legislation, social structure, and the economic basis of society. Instructor: Searle. *Not available for credit toward social science requirement.*

The graduate courses listed below are not necessarily taught each year. They will be offered as need dictates.

SS 200. Selected Topics in Social Science. *Units to be determined by arrangement with instructors.* Instructors: Staff and visiting lecturers.

PS/SS 202. American Electoral Processes. *9 units (3-0-6); first term. Prerequisite: PS/SS 122 (may be taken concurrently).* An in-depth analysis of American electoral processes with emphasis on the application of new theory and quantitative techniques. Instructors: Bates, Kousser.

PS/SS 203. Congress and the Executive. *9 units (3-0-6); second term. Prerequisite: PS/SS 202.* The course focuses on the analysis of executive and congressional decisionmaking. Emphasis on theory of committee and bureaucratic theory. Instructors: Cain, Bates, Kiewiet.

PS/SS 204. American Federal System. *9 units (3-0-6); third term. Prerequisite: PS/SS 203.* This course explores the problems raised by the division of political authority between federal, state, and local governmental units. Instructors: Ferejohn, McKelvey.

SS 205. Microeconomic Theory I. *9 units (3-0-6); first term. Prerequisite: Ec 121 a or equivalent.* This course is an introduction to economic theory and its applications. It covers problems in modelling and specification as well as maximization. Instructors: Davis, Noll, Plott, Quirk.

SS 206. Microeconomic Theory II. *9 units (3-0-6); second term. Prerequisite: SS 205.* The course covers classical consumption theory, the theory of production, markets, externalities, and the question of public goods. Instructors: Quirk, Plott, Forsythe, Wilde, Border.

SS 207. Microeconomic Theory III. *9 units (3-0-6); third term. Prerequisite: SS 206.* The course covers modern economic theory including decision theory, game theory, the role of uncertainty, and investment theory. Instructors: Quirk, Forsythe, Wilde.

SS 208. Microeconomic Theory IV. *9 units (3-0-6); third term. Prerequisites: SS 206 and 207 (latter can be taken concurrently).* The course focuses on economic dynamics with particular reference to information theory. Instructors: Forsythe, Wilde.

SS 210 abc. Foundations of Political Economy. *9 units (3-0-6). Prerequisites: PS/SS 204 and SS 206.* Mathematical theories of individual and social choice applied to problems of welfare economics and political decisionmaking as well as construction of political economic processes consistent with stipulated ethical postulates, political platform formulation, the theory of political coalitions and decisionmaking in political organizations. Instructors: Ferejohn, Fiorina, Plott, McKelvey.

SS 211 abc. Advanced Economic Theory. *9 units (3-0-6).* Advanced work in a specialized area of economic theory, with topics varying from year to year according to the interests of students. Instructors: Quirk, Forsythe, Wilde, Reinganum. *Can be repeated for credit.*

SS 212 abc. Application of Microeconomic Theory. *9 units (3-0-6).* This course will be a working seminar in which the tools of microeconomic theory are applied in a systematic fashion to the explanation of events and the evaluation of policy. Instructors: Quirk, Wilde, Noll. *Can be repeated for credit.*

SS 213. Competition and Antitrust Policy. *9 units (3-0-6); first term. Prerequisite: Ec 128.* This course is concerned with the differences in antitrust policies that would result from taking static as opposed to dynamic points of view. Instructor: Klein.

SS 214. The Economics of Regulation. *9 units (3-0-6); first term.* An analysis of government controls on prices, profits, entry, and product quality in the private sector, with special emphasis on the energy sector. Instructor: Noll.

SS 215. Legal Aspects of the Economics and Politics of Regulation. *9 units (3-0-6).* An examination of the relationship between the law and governmental regulation of economic enterprise. Instructor: Levine.

SS 216. Interdisciplinary Studies in Law and Social Policy. *9 units (3-0-6).* A policy problem or problems involving the legal system will be studied using concepts from at least one social science discipline. Each offering will be taught by a law professor, alone or in conjunction with a member of the social science faculty. The topic will differ from term to term so the course may be taken more than once. Selected undergraduates may enroll in this course with the permission of the instructor. Instructors: Graetz, Levine and staff.

SS 222 ab. Econometrics. *9 units (3-0-6); second, third terms. Prerequisites: Mathematical Statistics and Ec 122.* 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 223. Advanced Topics in Econometric Theory. *9 units (3-0-6). Prerequisite: SS 222 ab; may be repeated for credit.* This course in quantitative methods is designed for second- and third-year social science graduate students. Subject matter to include theory of identification and estimation of simultaneous equations system. Instructor: Grether.

SS 224. Advanced Topics in Econometric Methods. *9 units (3-0-6). Prerequisite: SS 222 ab; may be repeated for credit.* This course in quantitative methods is designed for second- and third-year social science graduate students. Subject matter includes models with limited dependent variables and distribution lag models. Instructors: Grether, Kousser.

SS 225. Advanced Topics in Quantitative Methods for Policy Analysis. *9 units (3-0-6). Prerequisite: SS 222 ab; may be repeated for credit.* This course is designed for second- and third-year social science graduate students. Students will analyze recent empirical studies that relate to current policy questions using modern econometric techniques. Instructors: Cain, Grether, Kousser.

SS 228. Selected Topics in European Medieval History. *9 units (3-0-6).* The bibliography, sources, and methods of analysis appropriate for research on a variety of topics in medieval history, such as peasant life and production, organization of government, law and land tenure, demography, church-state relations, and history of mentalities. Instructors: Benton, Searle.

SS 229. Historical Dimensions of Economic Analysis. *9 units (3-0-6).* The first quarter provides an introduction to modern quantitative economic history and to the empirical literature on economic growth. The second quarter is a research seminar. Instructors: Davis, Galenson.

SS 230. Psychology and Organizational Behavior. *9 units (3-0-6).* Psychological theories of decisionmaking, small-group and organizational behavior, uncertainty and the tolerance for ambiguity and stress and change. Not offered in 1980–81. Instructor: Grether.

SS 231 abc. American Politics. *9 units (3-0-6).* A three-term course in American politics and political behavior. While drawing from contemporary materials, the course will emphasize the historical background of American political institutions. Instructors: Fiorina, Ferejohn, Kiewiet.

SS 232 abc. Historical and Comparative Perspectives in Political Analysis. *9 units (3-0-6). Prerequisite: PS/SS 204.* The course is designed to provide the student of American politics with a knowledge and understanding of developments in both the American past and in other parts of the world. Instructors: Bates, Cain, Kousser.

SS 233 abc. Public Policymaking. *9 units (3-0-6). Prerequisite: PS/SS 204.* An examination of the policymaking processes in national, state, and local governments and how various institutions affect policy choices. Not offered in 1980–81. Instructors: Ferejohn, Fiorina.

SS 234. Research Seminar in Modern Political Science. *9 units (3-0-6); may be repeated for credit.* Instructors: Staff.

SS 235. Bureaucracy and Organization Theory. *9 units (3-0-6); third term.* An examination of the political economy of organizations. Special attention is given to formal theories capable of explaining such phenomena as the problems of rigidity and control loss, and the patterns of information flow within organizations. Not offered in 1980–81. Instructors: Staff.

SS 238. Optimal Control Theory in Economics. *9 units (3-0-6); third term. Prerequisite: Ec 121 a or equivalent.* The subject material of this course is the optimal control of dynamic economic systems with applications to resource extraction, limit pricing, research and development, and capital accumulation. Instructor: Reinganum.

SS 240. Techniques of Policy Research. *9 units (3-0-6); third term. Prerequisites: SS 205, SS 206.* The application of social science theory and methods to the formulation and evaluation of public policy. Instructor: Noll.

SS 241 ab. Workshop in Policy Research. *9 units (3-0-6); second, third terms. Prerequisite: SS 240.* A working seminar in which the students and participating faculty apply the techniques examined in SS 240 to a policy problem of mutual interest. Not offered in 1980–81.Instructor: Noll.

SS 250. Research Seminar in Economic Theory. *9 units (3-0-6); may be repeated for credit. Prerequisite: SS 208.* A working seminar in which students and participating faculty examine current advanced topics in economic theory. Instructors: Staff.

SS 300. Research in Social Science. *9 units (3-0-6).* Instructors: Staff.

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