INFORMATION FOR STUDENTS

SEPTEMBER 1976

CALTECH

Cover illustrations: The path of a charged particle in the hydrogen bubble chamber mirrors the spiral of a delicate chambered nautilus shell.

INFORMATION FOR STUDENTS

1976-1977

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

September 1976

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 and Applied Science E & AS
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 1976-77

1976	First Term
September 22	Registration of entering freshmen — 1:00 p.m.-4:30 p.m.
September 23-25	New Student Orientation
September 27	General Registration — 8:30 a.m.-4:30 p.m.
September 27	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
September 28	Beginning of instruction — 8:00 a.m.
October 15	Last day for adding courses
October 16	Examinations for the removal of conditions and incompletes
November 1-5	Mid-Term week
November 5	Last day for admission to candidacy for Master's and Engineer's degrees
November 8	Mid-Term deficiency notices due — 9:00 a.m.
November 15-19	Pre-registration for second term, 1976-77
November 25-28	Thanksgiving recess
November 25-26	Thanksgiving holidays for employees
December 3	Last day for dropping courses, changing sections and track changes
December 11-17	Final examinations, first term, 1976-77
December 18	End of first term, 1976-77
December 19-January 2	Christmas recess
December 20	Instructors' final grade reports due—9:00 a.m.
December 23-24	Christmas holidays for employees
December 31	New Year's Day holiday for employees
1977	**Second Term**
January 3	General Registration — 8:30 a.m.-4:30 p.m.
January 3	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
January 4	Beginning of instruction — 8:00 a.m.
January 21	Last day for adding courses
January 22	Examinations for the removal of conditions and incompletes
February 7-11	Mid-Term week
February 14	Mid-Term deficiency notices due — 9:00 a.m.
February 21-25	Pre-registration for third term, 1976-77
March 4	Last day for dropping courses, changing sections and track changes
March 12-18	Final examinations, second term, 1976-77
March 18	Last day for obtaining admission to candidacy for the degree of Doctor of Philosophy
March 19	End of second term, 1976-77
March 20-27	Spring recess
March 21	Instructors' final grade reports due — 9:00 a.m.

1977	Third Term
March 28	General Registration — 8:30 a.m.-4:30 p.m.
March 28	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
March 29	Beginning of instruction — 8:00 a.m.
April 15	Last day for adding courses
April 16	Examinations for the removal of conditions and incompletes
April 25-29	Mid-Term week
May 2	Mid-Term deficiency notices due — 9:00 a.m.
May 6-7	Examinations for admission to upper classes, September 1977
May 16-20	Pre-registration for first term, 1977-78, and registration for summer research (graduate and undergraduate)
May 20	Last day for dropping courses, changing sections and track changes
May 27	Last day for final oral examinations and presenting theses for the degree of Doctor of Philosophy
May 27	Last day for presenting theses for Engineer's degree
May 28-June 3	Final examinations for senior and graduate students, third term, 1976-77
May 30	Memorial Day holiday
June 4-10	Final examinations for undergraduate students, third term, 1976-77
June 6	Instructors' final grade reports due for senior and graduate students — 9:00 a.m.
June 8	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
June 8	Curriculum Committee Meeting — 10:00 a.m.
June 8	Faculty Meeting — 2:00 p.m.
June 9	Class Day
June 10	Commencement
June 11	End of third term, 1976-77
June 13	Instructors' final grade reports due for undergraduate students — 9:00 a.m.
June 22	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
July 4	Independence Day holiday for employees
September 5	Labor Day

1977	First Term 1977-78
September 21	Registration of entering freshmen — 1:00 p.m.-4:30 p.m.
September 22-24	New Student Orientation
September 26	General Registration — 8:30 a.m.-4:30 p.m.
September 27	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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CAMPUS DIRECTORY

Information — Building 71

28. Alles Laboratory (Molecular Biology)
3. Alumni Swimming Pool
25. Arms Laboratory (Geological and Planetary Sciences)
77. Art Gallery
61. Athenaeum (Faculty Club)
77. Baxter, Donald E., M.D., Hall (Humanities and Social Sciences)
77. Baxter Lecture Hall
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)
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)
50. Firestone Laboratory (Flight Sciences and Applied Mathematics)
57. Fleming House (Undergraduate Residence)
31. Gates Building
31A. Gates Annex (Chemistry)
7. Grounds Operations Office
45. Guggenheim Laboratory (Aeronautics and Applied Physics)
56. Housing Office
90. Industrial Relations Center
35. Isotope Handling Laboratory
80. Jorgensen Laboratory (Information Science)
46. Karman Laboratory (Fluid Mechanics and Jet Propulsion)
86. Keck House (Graduate Residence)
78. Keck Laboratory (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)
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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 Agency
82. Transportation and Grounds Operations
51. Winnett Student Center
51. Caltech Y
8. Young Health Center

Section I

CALIFORNIA INSTITUTE OF TECHNOLOGY

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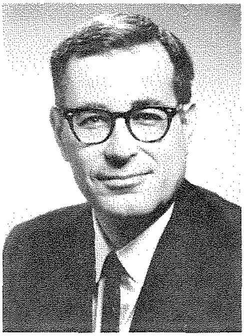

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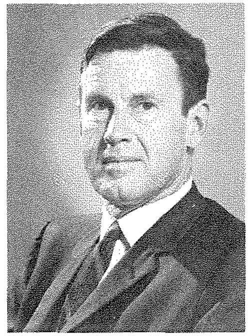

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1976-1977

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[1]Graduate Student Adviser
[2]Pre-Medical Adviser
[3]Undergraduate Student Adviser
[4]Joint appointment with Carnegie Institution of Washington

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[1]In residence 1975-76

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James B. Rand, Ph.D. .... *Biology*

Spencer Research Fellows

Takuji Kasamatsu, Ph.D .... *Biology*
Nancy Peters, Ph.D. .... *Biology*
Chun-Fang Wu, Ph.D .... *Biology*

Research Fellows

Manfred K.L. Albring, M.D.[1]
Francois Amalric, Ph.D.[2]
Robert C. Angerer, Ph.D.[3]
Frank W. Atencio, Ph.D.[4]
Gerald J. Audesirk, Ph.D.[13]
Paul B. Bell, Jr., Ph.D.[4]
Craig J. Benham, Ph.D.
Dorwin L. Birt, Ph.D.
Joseph Bonner, Ph.D.[4]
James M. Cecka, Ph.D.[4]
William R. Crain, Ph.D.[4]
Joseph G. Culotti, Ph.D.[3]
Jerry Daniels, Ph.D.[4]
Virginia W. Darr, Ph.D.[4]
Laura de Francesco, Ph.D.[4]
Angeline Douvas, Ph.D.[4]
Yadin Dudai, Ph.D.[2]
Susan G. Ernst, Ph.D.[6]
Romilio Espejo, Licenciado
Sandra J. Ewald, Ph.D.[7]
Barry Ganetzky, Ph.D.
James F. Hare, Ph.D.[8]
David A. Henderson, Ph.D.
Jeffrey J. Hubert, Ph.D.[4]
Deane B. Jacques, M.D.
Ernest Yuh Nung Jan, Ph.D.[9]
Lily Kung-Chung Jan, Ph.D.[4]
Donald D. Koblin, Ph.D.[10]
Amy So-Ming Lee, Ph.D.[3]
Lloyd H. Matsumoto, Ph.D.
Christian G. Merkel, Ph.D.
Ronald L. Meyer, Ph.D.
Joyce Norman, Ph.D.[4]
Kazuo Ogawa, D.Sc.
William R. Pearson, Ph.D.
David E. Pulleyblank, Ph.D.[11]
Barry S. Rothman, Ph.D.[13]
Jose Maria Sala-Trepat, Ph.D.
Walter H. Schroeder, Dr.rer.nat.
Elliot A. Stein, Ph.D.[4]
Masanori Suzuki, Ph.D.
Aladar Szalay, D.Sc.
Terry L. Thomas, Ph.D.[4]
Theodore C. Tutschulte, Ph.D.[13]
Demetrios Voreades, Ph.D.
Alana M. Wallace, Ph.D.[4]
(Robert) Bruce Wallace, Ph.D.[11]
Norma P. Williams, Ph.D.[13]
Andrew Wiseman, Ph.D.[12]
Barbara Yancey, Ph.D.

[1]Deutsche Forschungsgemeinschaft Fellow
[2]European Molecular Biology Organization Fellow
[3]American Cancer Society Fellow
[4]U.S. Public Health Service Fellow
[5]Jane Coffin Childs Memorial Fund for Medical Research Fellow
[6]The National Foundation March of Dimes
[7]The Arthritis Foundation
[8]Damon Runyon Memorial Fund Fellow
[9]Scottish Rite Schizophrenia Foundation
[10]Muscular Dystrophy Association of America
[11]Medical Research Council of Canada Fellow
[12]Helen Hay Whitney Foundation
[13]In residence 1975-1976

Graduate Students 1976-77

David Lee Armstrong
David John Asai
Eileen A. Bagdonas
Antony Clifford Bakke
Osgood Massee Bateman
John Richard Bell
Welcome William Bender
John Lovell Bixby
Elizabeth Peters Blankenhorn
Andrew Duncan Byers
Edwin Paul Ching
Arlene Yuen-Chin Chiu
Anne Chomyn
Toni Rosina Claudio
Susan Ellen Conrad
Michael Lee Cooper
David Paul Corey
Franklin David Costantini
Stephen Thomas Crews
Sheila Margaret Crewther
Mark Morris Davis
Michael Joseph DeNiro
Philip Warren Early
Jay Barry Edelman
Ernst-Peter Fischer
John Gregory Frelinger
Teryl Kenneth Frey
Jonathan Samuel Fuhrman
Karen Elizabeth Gaston
Robert Allen Gelfand
Steven Haym Green
Karen Faye Greif
David Howard Hall
Alvin Joseph Hill, Jr.
Sue Carol Hocker
Stanley Roy Hoffman
Henry Vincent Huang
David Saul Isenberg
Larry E. Johnson
Nelson Daniell Johnson
Gary Stephen Jones
Janet Roberta Kallo
Marilyn Rose Kehry
Michael William Klymkowsky
Mitchell Edwin Kronenberg
Joyce Ellen Lauer
Elwyn Yuan Loh
Kenneth Lawrence Marton
Jeffrey Terrell Mayne
James Stacy McCasland
Galina Dmitriyevna Moller
Robert Francis Murphy
William Thomas Newsome III
Bruce John Nicholson
Charles Edward Novitski
Dominic Ping-Yim Orr
Richard Carl Parker
William Raymond Pearson
Steven E. Petersen
James Posakony
David Eugene Presti
Donald Furner Ready
Mark Reynolds-Gurney
Charles Moen Rice III
Leslie Dawn Robinson
Thomas Dean Sargent
Michael John Savage
James Walter Schilling, Jr.
Margaret Yoshiko Scott
Brian Sarsfield Seed
Diane Marie Shelby
Robert Edward Sheridan
Sandra Lee Shotwell
Mavis Shure
Randall Forrest Smith
Barbara Landale Stitt
Duncan Knight Stuart
William Edward Stumph
Michael Surkes
David Tang
Betty Anne Vermeire
Christopher Mark West
William Lee Wheatley
Barbara Jane Wold
Wilson Wu

Division of Chemistry and Chemical Engineering

John D. Baldeschwieler, *Chairman*
Fred C. Anson, *Executive Officer for Chemistry*
John H. Seinfeld, *Executive Officer for Chemical Engineering*

Professors Emeriti

William N. Lacey, Ph.D. .... *Chemical Engineering*
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*
Don M. Yost, Ph.D. .... *Inorganic Chemistry*

Professors

Fred C. Anson, Ph.D. .... *Chemistry*
John D. Baldeschwieler, Ph.D. .... *Chemistry*
Jesse L. Beauchamp, Ph.D. .... *Chemistry*
Robert G. Bergman, Ph.D. .... *Chemistry*
Sunney I. Chan, Ph.D. .... *Chemical Physics and Biophysical Chemistry*
William H. Corcoran, Ph.D. .... *Chemical Engineering*
Norman Davidson, Ph.D. .... *Chemistry*
Richard E. Dickerson, Ph.D. .... *Physical Chemistry*
David A. Evans, Ph.D. .... *Chemistry*
Sheldon K. Friedlander, Ph.D .... *Chemical and Environmental Health Engineering*
George R. Gavalas, Ph.D. .... *Chemical Engineering*
William A. Goddard III, Ph.D. .... *Theoretical Chemistry*
Harry B. Gray, Ph.D .... *William R. Kenan, Jr. Professor and Professor of Chemistry*
Robert E. Ireland, Ph.D. .... *Organic Chemistry*
Aron Kuppermann, Ph.D. .... *Chemical Physics*
Vincent McKoy, Ph.D. .... *Theoretical Chemistry*
Cornelius J. Pings, Ph.D. .... *Chemical Engineering and Chemical Physics*
Michael A. Raftery, Ph.D. .... *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*

Sherman Fairchild Distinguished Scholars

Rutherford Aris, Ph.D. .... *Chemical Engineering*
Allen J. Bard, Ph.D. .... *Chemistry*
Gerhard Ertl, Dr.rer.nat. .... *Chemical Engineering*
Joshua Jortner, Ph.D. .... *Chemistry*
Geoffrey A. Ozin, Ph.D. .... *Chemistry*
Alexander Rich, M.D. .... *Chemistry*

Standard Oil Company of California Visiting Professorshp

Mark S. Wrighton, Ph.D. .... *Chemistry*

Visiting Professors

Robin M. Hochstrasser, Ph.D. .... *Chemistry*
A. B. P. Lever, Ph.D. .... *Chemistry*
Aaron Lewis, Ph.D. .... *Chemistry*
D. M. Roundhill, D.I.C. .... *Chemistry*

Senior Research Associates Emeriti

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

Visiting Associates

Richard C. Alkire, Ph.D. .... *Chemical Engineering*
Malwina Allen, Ph.D. .... *Chemistry*
Tian Tse Ang, Ph.D. .... *Chemistry*
Richard J. Bing, M.D. .... *Chemical Engineering*
Emilio Bordignon, Ph.D. .... *Chemistry*
Costello L. Brown, Ph.D. .... *Chemistry*
Robert L. Cargill, Ph.D. .... *Chemistry*
George Carlson, Ph.D. .... *Chemistry*
I-Y. Samuel Cheng, Ph.D. .... *Chemistry*
Gyorgy Csanak, Ph.D. .... *Chemistry*
Earl C. Harrison, M.D. .... *Chemical Engineering*
Keiichi Itakura, Ph.D. .... *Chemistry*
Catherine C. Johnson .... *Chemical Engineering*
Yoshiaki Kusuyama, Ph.D. .... *Chemistry*
Ting Fong Lai, Ph.D. .... *Chemistry*
Robert G. Lamb, Ph.D. .... *Chemical Engineering*
Rudolf Lenk, Ph.D. .... *Chemical Engineering*
Thomas N. Margulis, Ph.D. .... *Chemistry*
Rollie J. Myers, Ph.D. .... *Chemistry*
T. E. Ramabhadran, Ph.D. .... *Chemical Engineering*
Michael W. Rathke, Ph.D. .... *Chemistry*
David M. Roundhill, D.I.C. .... *Chemistry*
Harvey J. Schugar, Ph.D. .... *Chemistry*
Robert R. Sharp, Ph.D. .... *Chemistry*
Charles S. Springer, Jr., Ph.D. .... *Chemistry*
Harold J. Suderman, Ph.D. .... *Chemistry*
Vladimir M. Tapilin, Ph.D. .... *Chemical Engineering*
Richard A. Walton, Ph.D. .... *Chemistry*
Hans Wengle, Dr.Ing. .... *Chemical Engineering*

Associate Professors

L. Gary Leal, Ph.D. .... *Chemical Engineering*
Robert M. Stroud, Ph.D. .... *Chemistry*
Robert W. Vaughan, Ph.D. .... *Chemical Engineering*
W. Henry Weinberg, Ph.D. .... *Chemical Engineering*

Visiting Associate Professor

W. Ronald Fawcett, Ph.D. .... *Chemistry*

Research Associates

Richard E. Marsh, Ph.D. .... *Chemistry*
Sten O. Samson, Fil. Dr. .... *Chemistry*
Walter A. Schroeder, Ph.D. .... *Chemistry*

Associate

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

Assistant Professors

John E. Bercaw, Ph.D. .... *Chemistry*
Peter B. Dervan, Ph.D. .... *Chemistry*
Robert R. Gagné, Ph.D. .... *Chemistry*
Ahmed H. Zewail, Ph.D. .... *Chemical Physics*

Senior Research Fellows

H. Hollis Reamer, M.S. .... *Chemical Engineering*
William P. Schaefer, Ph.D. .... *Chemistry*

Lecturer

Thomas J. McMillen, Ph.D. .... *Chemical Engineering*

Research Fellows

William S. Agnew, Ph.D.
Lynne M. Angerer, Ph.D.
William H. Bearden, Ph.D.
Robert A. Bell, Ph.D.
Ricardo Bloch, Ph.D.
John S. Brabson, Ph.D.
Robert E. Botto, Ph.D.
Alan P. Brown, Ph.D.
Paul A. Cain, Ph.D.
Peter J. Card, Ph.D.
James W. Casey, Ph.D.
Richard S. Chadwick, Ph.D.
Purushotham Chalilpoyil, Ph.D.
Peter Chandler, Ph.D.
Yueh-Hsiu Chien, Ph.D.
Claude Cohen, Ph.D.
Maurice Cohen, Ph.D.
Diane Cummins, Ph.D.
Rudolf O. Duthaler, Ph.D.
Helen M. Echols, Ph.D.
James D. Engel, Ph.D.
Arne W. Fliflet, Ph.D.
Hans G. Forster, Ph.D.
Robert S. Gall, Ph.D.

Ronald C. Gamble, Ph.D.
Partha S. Ganguli, Ph.D.
Kenneth M. Gerst, Ph.D.
John F. Hagel, Ph.D.
David J. Hart, Ph.D.
Paul R. Hartig, Ph.D.
Fred Lee Heffron, Ph.D.
Christina M. Henneke, Ph.D.
Jay Hirsh, Ph.D.
David S. Holmes, Ph.D.
Charles F. Hoyng, Ph.D.
Che-hsiung Hsu, Ph.D.
Sylvia Hu, Ph.D.
Michael W. Hunkapiller, Ph.D.
Karl Huthmacher, Ph.D.
Judy C. Johnston, Ph.D.
Richard P. Junghans, Ph.D.
David B. Kaback, Ph.D.
Roger E. Koeppe II, Ph.D.
Monty Krieger, Ph.D.
Yun Ko Lee, Ph.D.
Simon R. Levinson, Ph.D.
Carol D. Linden, Ph.D.
Shlomo Margel, Ph.D.[1]
A. Grant Mauk, Ph.D., M.D.
Marcia R. Mauk, Ph.D.
Lorraine P. McDonnell, Ph.D.
David B. McKay, Ph.D.
Gunter P. Merker, Dr. Ing.
Anne C. Moore, Ph.D.
Gregory A. Parker, Ph.D.
Valery S. Petrosyan, Ph.D.
Chung-Kwong Poon, Ph.D.
Ulrich H. Quast, Ph.D.
LeRoy L. Richer, Ph.D.
Robert M. Richman, Ph.D.
John M. Rosenberg, Ph.D.
Denis E. Ryono, Ph.D.
James D. Satterlee, Ph.D.
Michael I. Schimerlik, Ph.D.
Loren B. Schreiber, Ph.D.
Robert M. Shelby, Ph.D.[1]
Marek Sitarski, Ph.D.
Thomas J. Smith, Ph.D.
Ann Sodja, Ph.D.
Glenn R. Sullivan, Ph.D.
John A. Thich, Ph.D.
Samuel J. Tremont, Ph.D.
Bruno Van den Bosch, Ph.D.
Michael A. Van Hove, Ph.D.
Alexander J. Vega, Ph.D.
William H. Vine, Ph.D., M.D.
Willi Volksen, Ph.D.
Patricia H. Von Dreele, Ph.D.
Henri Wajcman, Ph.D.
William V. Walter, Ph.D.
Marisa S-W. Wang, Ph.D.
Patricia L. Watson, Ph.D.
Ralph A. Whitney, Ph.D.
Karl A. Wilks, Ph.D.
Stephen P. Withrow, Ph.D.
Veit Witzemann, Dr.rer.nat.
James A. Wurzbach, Ph.D.

[1]Chaim Weizmann Research Fellow

Graduate Students 1976-77

Chemical Engineering

Arthur Thomas Andrews
Amir Attar
Samir Ilyas Barudi
Kenneth Edward Bencala
Clarke Berdan II
Russell Leslie Bone
Douglas Glenn Carson
Chi Ming Chan
Paul Chun-Ho Chan
Paul How-Kei Cheong
Ying-Chee Chung
Michael Thomas Duncan
Howard Edwin Evans
Theodore Edwin Farrington, Jr.
Gerald Gendall Fuller
Freddy Morris Gelbard
Gregory Steve Gibson
Dale Edward Ibbotson
Ravi Jain
Nicholas Alexandrou Kaffes
Paul Casey Kikuchi
Annie Ming-Chi Ko
James Gregory Kralik
Donald Leroy Kuehne
Sudarshan Kumar
Seong Hee Lee
Thomas Joe McMillen
James Arthur Mesher

William Kevin Moonan
William Lee Olbricht
Byron Lance O'Steen
David Paul Palmer
Thomas William Peterson
Charunya Phichitkul
Daryl Lynn Roberts
Vega Sankur
John Robert Schlup
Larry Odell Seward
Mark Alan Siddoway
Arthur Wesley Stelson
David Walter Suobank
James Long Taylor
Daniel Paul Teichman
Glenn Ellwood Thomas
Grant Fred Tiefenbruck
Nick Vasilakos
Gerald Wayne Ward
Albert Theodore Watson
Gary Eugene Whatley
Philip Eric Wood
Ajit Prithiviras Yoganathan
Yanis Christos Yortsos

Chemistry

Amy Abe
George Adler
David Andrew Agard
Judith Lee Allison
Robert James Almassy
Paul Adrian Aristoff
Peter Bruce Armentrout
Pamela Rae Auburn
William Walter Bachovchin
David Joseph Baillargeon
Raymond Alan Bair
Joe Timothy Bamberg
Michael McClellan Becker
Jacqueline Gail Berg
D. Wayne Berman
Scott Adams Biller
Steven Gerard Blanchard
David Scott Bomse
Duncan William Brown
Frank Ripley Brown, Jr.
Katherine Ann Brown
Gary Wayne Brudvig
Jonathan Arno Burke
David Maxwell Cannon
Boyd Jay Carter
John Lyman Chambers
Man-Kin Chan
Richard Eugene Cherpeck
Edson Hoi-Kam Cheung
Paula Jean Clendening
Benjamin Norman Conner
Reed Roeder Corderman
Catherine Louise Coyle
William Robert Croasmun
James Hubbard Davis
Nicki Lee Davis
Daniel Richard Dawson
Catherine Boxley Devine
Bradley Scott Dixon
David Marlin Dooley
Horace Rainsford Drew III
Daniel Charles Duan
John Patrick Dwyer
Kenneth Eugene Eigenberg
James Conrad Eisenach
Janet Ruth Elliott
David Keith Erwin
Eric Robert Evitt
James Brian Flanagan
William Paul Fornaciari, Jr.
Ben Sherman Freiser
Jane Elizabeth Frommer
Robert Paul Frueholz
Patricia Margaret George
Alexander Sherwin Gerwer
James William Gleeson
Douglas Edward Godar
Andrew Michael Goetze
Alan Mark Golob
Marvin Mark Goodgame
Neal Bruce Handly
Larry Brook Harding
Richard Randolph Hardy
Brian Garnet Herndier
Albert John Highe
William Dinan Hinsberg
Ronald Vernon Hodges
Frances Anne Houle
Hsiao-ping Hsu
Valerie Wailin Hu
John Mitchell Huggins
Kenneth Murrill Hurst
David Michael Ingle
Gilbert Collier Johnson
Carol Ruth Jones
Melvin Owen Jones

William Davidson Jones II
Robert James Kaiser, Jr.
Keiko Kanamori
Jack Alan Kaye
Mark Howard Keil
Robert James Kinney
Peter Martin Koelsch
Dale Alvin Kooistra
Carl Anthony Koval
Robert Paul Kreh
Brian Kent Lamb
Richard Edward Laura
Theodore Tsan-Tsung Lee
Deborah Ann Levin
Jane Fern Lilienthal
George Clark Lisensky
Thomas P. Lockhart
Charlotte Lowe Ma
Kent Robert Mann
Juan Manuel Manriquez
Patrick Henry Souza Martin
Donald Robert McAlister
Lawrence Ray McGee
Daniel Keith McIntyre
Steven Joshua Milder
James Arthur Miller
Mark Allen Mitchell
Terry William Moody
Kevin William Moore
Corinne Sue Morse
Randall Heywood Morse
Alan Henry Moskowitz
Milton Keith Murphy
Marco Antonio Chaer Nascimento
John Victor Nelson
Stephen Lee Nesbitt
Ann Tryon Nicol
Carol Ann Oken
Barry Duane Olafson
Thomas Howard O'Neill
Thomas Edward Orlowski
Bruce Alan Parkinson
Pamela Jane Peerce
Nils Overgaard Petersen
Anthony Kay Rappe
Jeffrey Allan Reimer
Robert Henry Reiner
Ronald Rianda
Randy Richard Robinson
Michael Jay Ross
John Edward Ruark
Clifford Eugene Sacks
Napapon Sailasuta
Robert D. Sanner
Don Sabatino Santilli
Richard Henry Scheller
Steven Alan Schichman
Robert Allen Scott
Jeffrey Alan Sell
Sarah Anne Sheard
Michael Allen Shippey
Brian Michael Skuse
John Thomas Slankas
Penny Slusser
Terry Alan Smedley
Duane Donald Smith
Steven Andrew Spencer
Clifford Lawrence Spiro
Frank Alan Stackhouse
Amy Elizabeth Stevens
Tom Hall Stevens
David John Strader
Sally Anne Sullivan
Barry Allen Swartz
Terry Ray Taber
James Michael Takacs
Newell Derrill Taylor
Suvit Thaisrivongs
Patricia Ann Thiel
Richard Charles Thomas
Wayne Julius Thompson
Richard Scott Threlkel
Jerry Tobler
Florence Lucy Trentacosti
William Charles Trogler
David Ralph Tyler
Thomas Hallworth Upton
John Henry Van Drie, Jr.
Stephen Perry Walch
Scot Edward Wherland
Mary Ann White
Craig Stephens Wilcox
Ellen D. Williams
Roger M. Williams
Peter Thomas Wolczanski
Rayman Young Wong
Richard Lawrence Woodin
Kathryn Mary Yocum
Ellen Yuan-Chu Yu

Division of Engineering and Applied Science

Robert H. Cannon, Jr., *Chairman*
Roy W. Gould, *Executive Officer for Applied Physics*
Paul C. Jennings, *Executive Officer for Civil Engineering and Applied Mechanics*
Hans W. Liepmann, *Director of the Graduate Aeronautical Laboratories and Executive Officer for Aeronautics*
James J. Morgan, *Executive Officer for Environmental Engineering Science*
John R. Pierce, *Executive Officer for Electrical Engineering*
Gerald B. Whitham, *Executive Officer for Applied Mathematics*

Professors Emeriti

Donald S. Clark, Ph.D. .... *Physical Metallurgy*
Frederick J. Converse, B.S. .... *Soil Mechanics*
Robert L. Daugherty, M.E. .... *Mechanical and Hydraulic Engineering*
Arthur L. Klein, Ph.D. .... *Aeronautics*
Frederick C. Lindvall, Ph.D., D.Sc., D.Eng. .... *Engineering*
William W. Michael, B.S. .... *Civil Engineering*
Ernest E. Sechler, Ph.D. .... *Aeronautics*
Vito A. Vanoni, Ph.D. .... *Hydraulics*

Professors

Allan J. Acosta, Ph.D. .... *Mechanical Engineering*
Charles D. Babcock, Jr., Ph.D. .... *Aeronautics*
Norman H. Brooks, Ph.D. .... *James Irvine Professor of Environmental Engineering Science; Director, Environmental Quality Laboratory*
Robert H. Cannon, Jr., Sc.D. .... *Engineering*
Thomas K. Caughey, Ph.D. .... *Applied Mechanics*
Francis H. Clauser, Ph.D. .... *Clark Blanchard Millikan Professor of Engineering*
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. .... *Jet Propulsion*
Pol E. Duwez, D.Sc.[1] .... *Applied Physics and Materials Science*
Derek H. Fender, Ph.D. .... *Biology and Applied Science*
Joel N. Franklin, Ph.D. .... *Applied Mathematics*
Sheldon K. Friedlander, Ph.D. .... *Chemical and Environmental Health Engineering*
Roy W. Gould, Ph.D. .... *Applied Physics*
George W. Housner, Ph.D. .... *Carl F Braun Professor of Engineering*
Donald E. Hudson, Ph.D.[2] .... *Mechanical Engineering and Applied Mechanics*
Floyd B. Humphrey, Ph.D. .... *Electrical Engineering and Applied Physics*
Wilfred D. Iwan, Ph.D. .... *Applied Mechanics*
Paul C. Jennings, Ph.D. .... *Applied Mechanics*
Herbert B. Keller, Ph.D. .... *Applied Mathematics*
James K. Knowles, Ph.D. .... *Applied Mechanics*
Toshi Kubota, Ph.D. .... *Aeronautics*
Paco A. Lagerstrom, Ph.D. .... *Applied Mathematics*
Robert V. Langmuir, Ph.D. .... *Electrical Engineering*
Lester Lees, M.S. .... *Environmental Engineering and Aeronautics*

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

Hans W. Liepmann, Ph.D. .... *Charles Lee Powell Professor of Fluid Mechanics and Thermodynamics*
Frank E. Marble, Ph.D. .... *Jet Propulsion and Mechanical Engineering*
James W. Mayer, Ph.D. .... *Electrical Engineering*
James O. McCaldin, Ph.D. .... *Applied Science and Electrical Engineering*
Gilbert D. McCann, Ph.D. .... *Applied Science*
Jack E. McKee, Sc.D., D.Eng. .... *Environmental Engineering*
Carver A. Mead, Ph.D. .... *Electrical Engineering*
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*
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.[1] .... *Engineering Science*
Fredric Raichlen, Sc.D. .... *Civil Engineering*
W. Duncan Rannie, Ph.D. .... *Robert H. Goddard Professor of Jet Propulsion*
Anatol Roshko, Ph.D. .... *Aeronautics*
Rolf H. Sabersky, Ph.D. .... *Mechanical Engineering*
Philip G. Saffman, Ph.D. .... *Applied Mathematics*
Ronald F. Scott, Sc.D. .... *Civil Engineering*
Eli Sternberg, Ph.D., D.Sc. .... *Mechanics*
Homer J. Stewart, Ph.D. .... *Aeronautics*
Bradford Sturtevant, Ph.D. .... *Aeronautics*
Ivan E. Sutherland, Ph.D. .... *Computer Science*
Frederick B. Thompson, Ph.D. .... *Applied Science and Philosophy*
Thad Vreeland, Jr., Ph.D. .... *Materials Science*
J. Harold Wayland, Ph.D. .... *Engineering Science*
Gerald B. Whitham, Ph.D. .... *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. .... *Electrical Engineering and Applied Physics*
Edward E. Zukoski, Ph.D. .... *Jet Propulsion*

Sherman Fairchild Distinguished Scholars

George K. Batchelor, Ph.D.[2] .... *Applied Mathematics and Fluid Mechanics*
K. Bertram Broberg, Dr. techn.[2] .... *Solid Mechanics*
A. William Castleman, Ph.D. .... *Environmental Engineering*
Louis N. Howard, Ph.D.[2] .... *Applied Mathematics*
Bela Julesz, Ph.D. .... *Bioinformation Systems*
Albert Rose, Ph.D.[2] .... *Applied Physics*
Alexander Silberberg, Ph.D. .... *Bioengineering*

Visiting Professors

Leon Lukaszewicz, Ph.D.[2] .... *Information Science*
Peter Weiner, Ph.D. .... *Computer Science*

[1]Half-time
[2]In residence 1975-76

Associate Professors

Francis S. Buffington, Sc.D. .... *Materials Science*
Nicholas George, Ph.D. .... *Electrical Engineering*
Wolfgang G. Knauss, Ph.D. .... *Aeronautics*
Ericson John List, Ph.D. .... *Environmental Engineering Science*
Hardy C. Martel, Ph.D. .... *Electrical Engineering*
Thomas C. McGill, Ph.D. .... *Applied Physics*
David F. Welch, I.D. .... *Engineering Design*

Visiting Associate Professor

Alan C. Kay, Ph.D. .... *Computer Science*

Research Associates

Christopher Brennen, Ph.D. .... *Engineering Science*
James E. Broadwell, Ph.D. .... *Aeronautics*
Dan Cohen, Ph.D. .... *Computer Science*
Allen T. Chwang, Ph.D. .... *Engineering Science*
Robert C. Y. Koh, Ph.D. .... *Environmental Engineering Science*

Associate

Martin Goldsmith, Ph.D. .... *Environmental Engineering*

Visiting Associates

Y. V. G. Acharya, D.Sc. .... *Engineering*
Pierre Alais, Doctorat d'État[1] .... *Aeronautics*
Richard F. Baker, Ph.D. .... *Biomedical Engineering*
Richard J. Bing, M.D. .... *Biomedical Engineering*
James A. Boa, Ph.D.[1] .... *Applied Mathematics*
Stephen H. Caine .... *Computer Science*
Bruno Crosignani, Lib.Doc.[1] .... *Electrical Engineering*
Ellis Cumberbatch, Ph.D.[1] .... *Engineering Science*
Kamalaksha Das Gupta, Ph.D. .... *Applied Physics*
Peter S. Eagleson, Sc.D.[1] .... *Civil Engineering*
Gaetano Foti, Ph.D.[1] .... *Applied Physics*
Wallace G. Frasher, M.D. .... *Biomedical Engineering*
E. Kent Gordon, B.S. .... *Electrical Engineering*
Jozsef Gyulai, Ph.D.[1] .... *Applied Physics*
Matsamitsu Hasegawa, Ph.D. .... *Biomedical Engineering*
Robert W. Hellwarth, Ph.D. .... *Applied Physics*
George M. Hidy, D.Eng. .... *Environmental Engineering Science*
Paul Kaminski, Ph.D.[1] .... *Systems Engineering*
Hiroshi Kato, D.Eng. .... *Engineering Science*
Hristo Kapsarov, M.S.[1] .... *Earthquake Engineering*
Edward F. Kennedy, Ph.D.[1] .... *Applied Physics*
Tsutomu Kobayashi, Ph.D. .... *Electrical Engineering*

[1]In residence 1975-76

Nancy Jane Kopell, Ph.D.[1] .... *Applied Mathematics*
Hans H. Kuehl, Ph.D.[1] .... *Electrical Engineering*
Rachmiel Levine, M.D. .... *Biomedical Engineering*
Robert T. Menzies, Ph.D. .... *Electrical Engineering*
John B. Mooney, M.S.[1] .... *Applied Science and Electrical Engineering*
Derek W. Moore, Ph.D. .... *Applied Mathematics*
Milos Novak, Ph.D.[1] .... *Earthquake Engineering*
Thomas E. Ogden, M.D., Ph.D. .... *Biomedical Engineering*
Ruggero Pierantoni, Ph.D. .... *Biomedical Engineering*
Allen Plotkin, Ph.D.[1] .... *Engineering Science*
John M. Poate, Ph.D.[1] .... *Applied Physics*
René Pretorius, D.Sc. .... *Applied Physics*
Robert H. Pudenz, M.D. .... *Biomedical Engineering*
Donald D. Rafuse, Ph.D. .... *Biomedical Engineering*
Simon Ramo, Ph.D. .... *Engineering*
Alexander Rodriguez, Ph.D.[1] .... *Engineering*
Klaus Rohwer, Dr.Ing. .... *Aeronautics*
Joachim Roth, Dr.rer.nat. .... *Applied Physics*
Mei-Chang Shen, Ph.D. .... *Engineering Science and Civil Engineering*
Nobuyuki Shimizu, Ph.D. .... *Earthquake Engineering*
Yehuda J. Sokal, Engr. .... *Earthquake Engineering*
Michael Steinhausen, M.D., Ph.D.[1] .... *Biomedical Engineering*
James M. Varah, Ph.D.[1] .... *Applied Mathematics*
Robert J. Wagner, Ph.D. .... *Applied Physics*
Thomas G. Wheeler, Ph.D.[1] .... *Information Science*
Dean E. Wooldridge, Ph.D. .... *Engineering*
George J. Zimmer, Dipl. Phys.[1] .... *Applied Physics*

Assistant Professors

Paul E. Dimotakis, Ph.D. .... *Aeronautics and Applied Physics*
Richard C. Flagan, Ph.D. .... *Environmental Engineering Science*
Bengt Fornberg, Ph.D. .... *Applied Mathematics*
Thomas J. R. Hughes, Ph.D. .... *Structural Mechanics*
Darryl L. Smith, Ph.D. .... *Applied Physics*

Visiting Assistant Professor

Robert F. Sproull, M.S. .... *Computer Science*

Senior Research Fellows

James R. Fox, Ph.D. .... *Biomedical Engineering*
Abraham Katzir, Ph.D. .... *Electrical Engineering*
Aurora M. Landel, Ph.D. .... *Biomedical Engineering*
Silvanus S. Lau, Ph.D.[2] .... *Applied Physics*
Nicholas R. Moore, Ph.D. .... *Engineering*

[1]In residence 1975-76
[2]Also part-time Lecturer in Materials Science

Instructors

James Long, Ph.D. .... *Electrical Engineering*
Benjamin S. White, Ph.D. .... *Bateman Research Instructor in Applied Mathematics*
Richard R. Willis, M.S.[2] .... *Electrical Engineering*

Lecturers

Robert S. Deverill, B.S. .... *Computer Science*
Richard G. Lipes, Ph.D.[2] .... *Electrical Engineering*
Robert S. Logan, B.S.[2] .... *Applied Science*
Charles B. Ray, M.S. .... *Applied Science*
Lincoln J. Wood, Ph.D. .... *Systems Engineering*

Research Fellows

Abderrazak Amamou, Doctorat d'Etat .... *Applied Physics*
John G. Anderson, Ph.D. .... *Applied Science*
Brian J. Cantwell, Ph.D. .... *Aeronautics*
Anthony Tze-Wai Cheung, Ph.D. .... *Engineering Science*
Patrick Delattre, Ph.D. .... *Environmental Engineering Science*
Eusebius J. Doedel, Ph.D. .... *Applied Mathematics*
William R. Goodin, Ph.D. .... *Environmental Engineering Science*
Avraham Gover, Ph.D. .... *Applied Physics*
Joe M. Harris, Ph.D.[2] .... *Applied Physics*
Steven L. Heisler, Ph.D.[2] .... *Environmental Health Engineering*
Susanne V. Hering, Ph.D. .... *Environmental Health Engineering*
Jacob Keller, Ph.D. .... *Aeronautics*
Doyle D. Knight, Ph.D. .... *Applied Mathematics*
Vijay Kulkarny, Ph.D. .... *Aeronautics*
Hsi-ping Liu, Ph.D. .... *Engineering and Geophysics*
Alexander C. R. Livanos, Ph.D. .... *Applied Physics*
Vasilis Marmarelis, Ph.D.[3] .... *Bioinformation Systems*
Samuel E. Matteson, Ph.D.[4] .... *Applied Physics*
Antonio H. Miguel, Ph.D. .... *Environmental Health Engineering*
Sheung Lip Ng, Ph.D.[2] .... *Mechanical Engineering*
Jean-Herve Prevost, Ph.D.[5] .... *Civil Engineering*
Michael J. Shantz, Ph.D.[3] .... *Bioinformation Systems*
Thomas W. Sigmon, Ph.D.[6] .... *Applied Physics*
Wen F. Tseng, Ph.D. .... *Applied Physics*
Jasenka Vuceta, Ph.D.[2] .... *Environmental Engineering Science*
Patricia A. Wheeler, Ph.D. .... *Environmental Engineering Science*
Marc F. Wittmer, Ph.D. .... *Applied Physics*
Frank Hong-Ye Wu, Ph.D. .... *Hydraulics*

[2]In residence 1975-76
[3]Also part-time Lecturer in Bioinformation Systems
[4]Chaim Weizmann Research Fellow
[5]Also part-time Lecturer in Civil Engineering
[6]Also part-time Lecturer in Applied Physics. In residence 1975-76.

Graduate Students 1976-77

Aeronautics

Adi Rahman Adiwoso
Gabi Ben-Dor
Dale Evan Berg
Luis Paulino Bernal
Robert Edward Breidenthal, Jr.
Herzl Chai
Reazuddin Ahmed Chaudhuri
Eric Roland Christensen
James Eldon Craig
Robert Buck Crombie
Ronald Richard Eskridge
Ari Glezer
Jean-Francois Luc Haas
Jon Stuart Hanson
Alan Douglas Hebb
Luc Jozef Heymans
Hiroshi Higuchi
Davorin Hrovat
Frederick G. Johnson
Keith Koenig
John Harrison Konrad
Ravi Chandar Krishnaswamy
Stelios Kyriakides
Kenneth MacDougall Liechti
Kiran Ramanlal Magiawala
Olivier Maumy
Richard Barron Mintz
Mark Godfrey Mungal
Daniel Mark Nosenchuck
Kiam Thian Oey
Charles Wilcox Pinney
Ibrahim Mohammad Rashed
Fredrick Allan Roberts
Philip Louis Rogers
Edward Kenneth Ruth
William Stapf Sargent
Omer Savas
Piyush Chimanlal Shah
Choon-foo Shih
Ernst Norman Tangren
Stephen Taylor
David Walker Thompson
Bernd Otto Trebitz
Timothy Neal Turner
Aharon Vinkler
Alan James Wadcock
Jack Leroy Wise
Greg Lynn Wojcik
Ronald Willard Zimmerman

Applied Mathematics

Gregory Richard Baker
Edward John Bissett
Evangelos Athanassios Coutsias
Athanassios Fokas
Patrick S. Hagan
Allan Douglas Jepson
David Anthony Leighton
Marianela Lentini-Gil
John Weidman McLean
James Robert Mueller
David Joseph Perozzi
Stephen Bart Sunshine
Randall Gary Williams

Applied Mechanics

Rohan Chandra Abeyaratne
Ahmet Vecdet Arslan
Alexander N. Brooks
Carl Leei Chen
W. Riley Garrott
Nathan Craig Gates
Conrad Earl Hartsell
Christopher Donald Helleur
Lambertus Hesselink
Charles Morton Krousgrill, Jr.
Samuel Charles Levine
Wing Kam Liu
Uy Loi Ly
Jewell Clinton Maxwell, Jr.
Graeme Haynes McVerry
Rodney Allen Stephenson
Joseph David Titlow
Bruce Donald Westermo
Paul Jerome Yoder

Applied Physics

Pinchas Agmon
Randall Kieth Bartman
John Stewart Best
Ronald Lee Boatright
William Matthew Bowser
Scott Charles Burkhart
Douglas Peter Burum
Martin Yu-Wen Chen

Gene Alan Clough
Jean Roger Delayen
Kenneth Robert Elliott
Cheri Lee Erickson
George Fox
Christopher Lee Frenzen
Andrew Keith Gabriel
Timothy Joseph Gallagher
Crockett Lane Grabbe
Glenn Joel Greene
Ronald Leonard Gregg
William Mark Grossman
Gregory Prince Hamill
Mark Allen Hedemann
David Li-shui Quek Hwang
Randall Lynn Kubena
Daniel Bernard Lang
Chien-Ping Lee
Zong-Long Liau
Stephen Aplin Lyon
Gregory Allen Lyzenga
Bruce Edward MacNeal
Robert McNamara
Gordon Stuart Mitchard
Terrence Marshall Morris
Richard Harrison Moyer
Johnson Olufemi Olowolafe
Thomas Eugene Osheroff
David Mort Pepper
Siu Joe Poon
Dale Austen Prouty
Antonio Redondo-Muino
David Martin Scott
Robert Alan Scranton
Mei-Ling Shek
Jeffrey Brian Shellan
Joseph Emmett Shepherd
Emilio Temoche Sovero
Virgil Simon Speriosu
Michael Edward Stoll
Israel Ury
Arthur Ray Williams
Tadashi Yogi

Civil Engineering
Philippe Bardey
James Leslie Beck
Eugene Patrick Berek
William Madison Brown
William Robert Brownlie
Thomas Richard Card
Jing-Chang Chen
Martin Francis Cohen
Michael James Craig
Bernard André Jean-Marie Cuny
Alex Chike Egwuatu
Douglas Allen Foutch
Raul Gonzales
Derek Garard Goring
Medhat Ahmed El-Sayed Haroun
David John Debenham Harper
Mark Joachim Holum
Stephen Joseph Kadysiewski
Philippe Francois Le Guludec
Thierry Lepelletier
Brian Mitsuo Murata
Joseph Charles Prinster
Ioannis John Psycharis
Polihronis-Thomas Dimitrios Spanos
Kozo Tagaya
Albert Chia Ting
Hans Van der Kogel
Catharine L. van Ingen
Steven Jay Wright

Electrical Engineering
Mustafa Abushagur Gyth Abushagur
John Chen Wei Au Yeung
Arthur Raymond Brown
Christopher Ralph Carroll
Craig McClain Cheetham
Weng Cho Chew
Pierre Choubert
Slobodan Cuk
Walter Kamiel De Logi
Mark B. Dolson
Joe Patrick Elmers
Raymond Edward Feeney
Samy Maurice Hanna
Franklin Sai Wai Ho
Chi-Shain Hong
Shi-Ping Hsu
Dwight Lincoln Jaggard
Kochan Ju
Michael Joseph Kavaya
Vijaya Narayan Korwar
James Laurens Latimer
Bruce Stephen Levine
Bartholomew Nicholas Locanthi III
Jacob D. Mark
John Douglas Marshall
Rodney Tak Masumoto
Amelia Marie Maxted
Alan Rolf Mickelson

George Michael Morris
Stephen Taylor Neely
Willie Wing Lau Ng
Fernando Moncada Nocedal
Harry Lawrence Parker
Jonell Polansky
Ajay Kumar Puri
Charles Lee Ramiller
Loman Rensink
Michael John Roberts
James A. Rowson
Tom Peter Sterk
Jebril Ahmed Swedan
James Victor Tierney III
Kadri Vural
Larry Kevin Warne
Vincent Sydney Wong

Engineering Science
James Carl Althoff, Jr.
Ole Lloyd Anderson
Ronald Frederick Ayres
Anthony Francis Barton
Sally Anne Browning
Alain Coriat
Terrance Michael Darcey
Daniel Bruce Diner
Leslie Ann Froisland
Eberhard Erwin Groetsch
William Kevin Hassett
Mark Hersey
Gideon Hess
Li-ho Raymond Hou
Beatriz Valdes Infante
Michael Yih-Hwa Jin
Robert E. Johnson
Arthur Joseph Koblasz
Larry Douglas Koffman
Ross Martin Larkin
Daniel Margoliash
Luis Manuel Vaillard Medina
Robert Lewis Powers
Scott Darrell Roth
Satwindar Singh Sadhal
Thomas Peter Santoro
Helene R. Schember
David Sheby
Dana Lynn Small
Sankaran Srinivas
Kent Allen Stevens
Shriram Mahabal Udupa
Lenora Yee-Ling Valainis
Ramon Varela
Lawrence Allan White
Rick Alan Williams
George Thomas Yates
Kwang-I Yu

Environmental Engineering Science
Fernando Cadena-Cepeda
Glenn Rowan Cass
Stanton Jonathan Cowen
Cliff Ian Davidson
Gregory Gartrell, Jr.
Jan Leslie Hillson
Thomas Russell Holm
Joyce Shin-Chiao Hsiao
James Robert Hunt
Peter Douglas Kirkwood
James Shigeru Kuwabara
Howard Michael Liljestrand
Derek John McKay
Peter H. McMurry
Gregory John McRae
Obiefuna Timothy Nwasike
James Richard Ouimette
James Frederick Pankow
Philip Joseph William Roberts
Stanley Paul Sander
Isi Isaac Saragossi
Windsor Sung
James Robert Young

Mechanical Engineering
Mark Edward Ankrom
David Miner Braisted
Fred M. Dycus, Jr.
Dean Barton Edwards
Edward Maurice Gates
Shawn Anthony Hall
Douglas Kerry Ikema
Scott Stephen Kimbrough
Alfred Barr Mason
Paul Oakley Mason
Tanh Van Nguyen
Olin Perry Norton
Yvon Resplandy
David Carl Sherman
Tadashi Shiraishi
Tad Decatur Simons
Malladi Venkata Subbaiah
William Allan Symington
Dean Dalton Taylor
John Paul Velas
Yau-Ching James Wu

Division of Geological and Planetary Sciences

Barclay Kamb, *Chairman*
Arden L. Albee, *Academic Officer*
Don L. Anderson, *Director, Seismological Laboratory*

Professors Emeriti

Ian Campbell, Ph.D. .... *Geology*
C. Hewitt Dix, Ph.D. .... *Geophysics*
Charles F. Richter, Ph.D. .... *Seismology*

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*
Harrison S. Brown, Ph.D., LL.D., Sc.D., D.Sc. .... *Geochemistry*
Science and Government
Donald S. Burnett, Ph.D. .... *Nuclear Geochemistry*
Samuel Epstein, Ph.D. .... *Geochemistry*
Peter Goldreich, Ph.D. .... *Planetary Science and Astronomy*
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*
Robert P. Sharp, Ph.D. .... *Geology*
Eugene M. Shoemaker, Ph.D., Sc.D. .... *Geology*
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 Scholars

Lynn Margulis, Ph.D. .... *Geology and Biology*
Henry G. Thode, Ph.D. .... *Geochemistry*
Seiya Uyeda, Ph.D. .... *Geophyics*

Visiting Professor

Kevin C. Burke, Ph.D. .... *Geology*

Senior Research Associate

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

Associate Professors

David G. Harkrider, Ph.D. .... *Geophysics*
Donald V. Helmberger, Ph.D. .... *Geophysics*

Research Associates

Richard M. Goldstein, Ph.D. .... *Planetary Science*
Dimitri A. Papanastassiou, Ph.D. .... *Geochemistry*

Visiting Associates

Gary S. Fuis, Ph.D. .... *Geophysics*
Samuel Gulkis, Ph.D. .... *Planetary Science*
Thomas C. Hanks, Ph.D. .... *Geophysics and Earthquake Engineering*
Yoshimitsu Hirao, Ph.D. .... *Geochemistry*
William R. Kelly, Ph.D. .... *Geochemistry*
Robert W. G. Kerrich, Ph.D. .... *Geology*
Hugh H. Kieffer, Ph.D. .... *Planetary Science*
C. Marshall Payne, M.S. .... *Geology*
Richard J. Proctor, M.A. .... *Geology*
I. K. Reddy, Ph.D., ... *Geophysics*
David J. Roddy, Ph.D. .... *Geophysics*
Philip A. Sandberg, Ph.D. .... *Geology*
Yuk L. Yung, Ph.D. .... *Planetary Science*

Assistant Professors

H. Jay Melosh, Ph.D. .... *Planetary Science*
Jean-Bernard H. Minster, Ph.D. .... *Geophysics*
George R. Rossman, Ph.D. .... *Mineralogy*

Visiting Assistant Professor

Alfred J. Ferrari, D.Sc. .... *Planetary Science*

Senior Research Fellows

Glenn L. Berge, Ph.D. .... *Planetary Science and Radio Astronomy*
Hermann F. Engelhardt, Ph.D. .... *Geophysics*
John C. Huneke, M.S. .... *Planetary Science*
James H. Whitcomb, Ph.D. .... *Geophysics*

Lecturer

David T. Burhans, Ph.D. .... *Speech Communication*

Research Fellows

Edmund D. Andrews, Ph.D. .... *Geology*
Bjørn Buchardt-Larsen, Cand. Scient. .... *Geochemistry*
Kiyoshi Fujii, M.S. .... *Geochemistry*

Yoshio Fukao, Ph.D. .... *Geophysics*
Alexander J. Gancarz, Jr., Ph.D. .... *Geochemistry*
Neil R. Goulty, Ph.D. .... *Geophysics*
Mizuho Ishida, Ph.D .... *Geophysics*
Ian N. S. Jackson, Ph.D. .... *Geophysics*
Charles A. Langston, Ph.D. .... *Geophysics*
Karen C. McNally, Ph.D .... *Geophysics*
Arend Meijer, Ph.D. .... *Geochemistry*
Felix Oberli, Ph.D. .... *Geology and Geochemistry*
Christine A. Powell, Ph.D.[1] .... *Geophysics*
Filippo Radicati di Brozdo, Ph.D .... *Geochemistry*
James A. Woodhead, Ph.D. .... *Geology*
Hsueh-Wen Yeh, Ph.D .... *Geochemistry*

[1]Chaim Weizmann Research Fellow

Graduate Students 1976-77

Geology

James Rodney Anderson
Thomas Carl Anderson
Warren Scott Baldridge
Marian Judith Basin
David Wayne Beatty
Timothy Miller Benjamin
Brian Stuart Brock
Michael Welch Burnett
Duane Edwin Champion
Robert Everett Criss
Donald James Depaolo
Charles Brown Douthitt
Raymond Joseph Durkan
Robert F. Dymek
Joel Earl Everson
Edward William Fall
Don Steven Goldman
Robert Theodore Gregory
Lewis Peter Gromet
Stein Bjornar Jacobsen
Raymond Francois Jeanloz
John Hume Jones
Theodore Charles Labotka
Jo Laird
Richard Edwin Lewis
Malcolm Thomas McCulloch
Donald Evans Miser
Jay Dennis Murray
Amy Chihang Ng
Russell Marsh Potter
Robert Edward Powell
James Edward Quick
Bernhard Karl Schaule
Stephen Pritchard Smith
Michael Anthony Stephens
David Ralph Van Alstine
Joana Marija Vizgirda
Josephine Beatrice Way
Stephen Weiner

Geophysics

Lawrence James Burdick
Rhett Giffen Butler
Wai Ying Chung
John Joseph Cipar
Stephen Norfleet Cohn
David Martin Cole
John Edward Ebel
Robert James Geller
Alan Reed Gillespie
Jeffrey Wayne Given
David Milton Hadley
Robert Stuart Hart
Thomas Harrison Heaton
James Alan Hileman
Tai-Lin Hong
Carl Edward Johnson
Richard Paul Keller
Dan Douglas Kosloff
Lyle Dean Meier
George Robert Mellman
Emile Andre Okal
James Christopher Pechmann
Susan Ann Raikes
Jose Antonio Rial
Larry John Ruff
Seth Avram Stein
Gordon Selbie Stewart
Anne Marie Suteau

Planetary Science

Jeff Richard Barnes
Bruce Gordon Bills
Judith Ann Burt
Kevin Vincent Cook
David Joseph Diner
Anthony Robert Dobrovolskis
John Joseph Dvorak
Daniel Dzurisin
William Beall McKinnon
Philip David Nicholson
David Pollard
Carolyn C. Porco
Frederic Peter Schloerb
Maritza Irene Stapanian
Richard John Terrile
Jerry Lawrence Thoss
Carel Andries Theodore Veenhuyzen

Division of the Humanities and Social Sciences

Robert A. Huttenback, *Chairman*

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*
Roger F. Stanton, Ph.D. .... *English*
Alfred Stern, Ph.D. .... *Philosophy*
Ray E. Untereiner, Ph.D., J.D. .... *Economics*

Lecturer Emeritus

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

Professors

John F. Benton, Ph.D. .... *History*
Harrison S. Brown, Ph.D., Sc.D., LL.D., D.Sc. .... *Geochemistry and Science and Government*
J. Kent Clark, Ph.D. .... *English*
Lance E. Davis, Ph.D. .... *Economics*
David C. Elliot, Ph.D. .... *History*
Peter W. Fay, Ph.D. .... *History*
Angus J. S. Fletcher, Ph.D. .... *Doris and Henry Dreyfuss Professor of English and Comparative Literature*
Robert D. Gray, B.S. .... *Economics and Industrial Relations*
David M. Grether, Ph.D. .... *Economics*
Robert A. Huttenback, Ph.D. .... *History*
William T. Jones, Ph.D.[1] .... *Philosophy*
Burton H. Klein, Ph.D. .... *Economics*
Beach Langston, Ph.D. .... *English*
Michael E. Levine, J.D.[1] .... *Luce Professor of Law and Social Change*
Oscar Mandel, Ph.D. .... *English*
George P. Mayhew, Ph.D.[2] .... *English*
Edwin S. Munger, Ph.D. .... *Geography*
Roger G. Noll, Ph.D.[2] .... *Economics*
Robert W. Oliver, Ph.D. .... *Economics*

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

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*
Alan R. Sweezy, Ph.D. .... *Economics*
Frederick B. Thompson, Ph.D. .... *Applied Science and Philosophy*

Sherman Fairchild Distinguished Scholars

Charlotte J. Erickson, Ph.D. .... *Economic History*
Leo E. Rose, Ph.D. .... *Political Science*

Visiting Associates

David A. Hamburg, M.D. .... *Social Science*
H. Stuart Burness, Ph.D. .... *Economics*

Visiting Professor

H. Peter Kahn .... *Andrew W. Mellon Visiting Professor of Fine Arts*

Associate Professors

Robert H. Bates, Ph.D.[2] .... *Political Science*
Louis Breger, Ph.D. .... *Psychology*
Heinz E. Ellersieck, Ph.D. .... *History*
Stuart A. Ende, Ph.D. .... *English*
John Ferejohn, Ph.D. .... *Political Science*
Morris P. Fiorina, Ph.D. .... *Political Science*
Daniel J. Kevles, Ph.D. .... *History*
J. Morgan Kousser, Ph.D. .... *History*
David R. Smith, Ph.D. .... *English*
Robert D. Wayne, M.A. .... *German*

Visiting Associate Professor

David L. McNicol, Ph.D. .... *Economics*

Assistant Professors

Russell Z. Abrams, Ph.D. .... *Philosophy*
Bruce E. Cain, Ph.D. .... *Political Science*
Robert E. Forsythe, Ph.D. .... *Economics*
Holly Jackson, Ph.D. .... *English*
Gary J. Miller, Ph.D. .... *Political Science*
W. David Montgomery, Ph.D. .... *Economics*
Forrest D. Nelson, Ph.D. .... *Economics*
Joyce Penn, Ph.D. .... *English*
Martin H. Rubin, Ph.D. .... *English*
Randolph N. Splitter, Ph.D. .... *English*
Louis L. Wilde, Ph.D. .... *Economics*

Lecturers

Nancy G. Beakel, Ph.D.[1] .... *Psychology*
Irving S. Bengelsdorf, Ph.D.[1] .... *Science Communication*
David J. Britton, D.M.A. .... *Music*
Lee F. Browne, M.S.[1] .... *Education*
Klara Carmely, M.A. .... *German*
John Dyckman, Ph.D.[1] .... *Psychology*
Stirling L. Huntley, Ph.D. .... *Drama*
Edward Hutchings, Jr., B.A.[1] .... *Journalism*
Galina Moller, M.S. .... *Russian*
David W. Morrisroe, M.B.A.[1] .... *Business Economics*
Jon Richard Pariser, M.A. .... *Russian*
Aimée Brown Price, Ph.D. .... *Art History*
Elma Schonbach, B.M. .... *Music*
Annette Smith, Dr. d'Université .... *French*
Robert R. Wark, Ph.D.[1] .... *Art*
Valentina Zaydman, M.A. .... *Russian*

Research Associate

Bozena Henisz-Dostert Thompson, Ph.D. .... *Linguistics*

Senior Research Fellows

Clayton R. Koppes, Ph.D. .... *History*
Tracy Lewis, Ph.D. .... *Economics*

Research Fellow

Lytton W. Stoddard, Ph.D. .... *Economics*

Research Assistant

Doris P. Stover, B.A. .... *Public Affairs*

Graduate Students 1976-77

Social Science
Gul Abdulnabi Agha
Naim Hassan Al-Adhadh
Gerhard Werner Befeld
Brian Robert Binger
Randall Lee Calvert
Nancy Maressa Childs
Linda Rachel Cohen
Elizabeth Hoffman
James Takfay Hong
Robert Mark Isaac
Bryan Creed Jack
Tom Kwan-Yau Lee
Steven Allen Matthews
Darwin Curt Niekerk
Thomas R. Palfrey III
William Paul Rogerson
Phillip A. Sher
Lee Ira Sparling
Matthew L. Spitzer
Kim C. Thomas
Paul Arthur Thomas
Barry Robert Weingast

[1]Part time
[2]Leave of absence

Division of Physics, Mathematics and Astronomy

Maarten Schmidt, *Chairman*
Robert L. Walker, *Executive Officer for Physics*
W. A. J. Luxemburg, *Executive Officer for Mathematics*
W. L. W. Sargent, *Executive Officer for Astronomy*

Professors Emeriti

Carl D. Anderson, Ph.D., Sc.D., LL.D., Nobel Laureate ..... *Physics*
Robert E. Bacher, Ph.D., Sc.D., LL.D. ..... *Physics*
H. F. Bohnenblust, Ph.D. ..... *Mathematics*
Jesse W. M. DuMond, Ph.D., D.H.C. ..... *Physics*
H. Victor Neher, Ph.D., Sc.D. ..... *Physics*
William R. Smythe, Ph.D. ..... *Physics*

Professors

Tom M. Apostol, Ph.D. ..... *Mathematics*
Michael Aschbacher, Ph.D. ..... *Mathematics*
Barry C. Barish, Ph.D. ..... *Physics*
Charles A. Barnes, Ph.D. ..... *Physics*
Felix H. Boehm, Ph.D. ..... *Physics*
Robert F. Christy, Ph.D. ..... *Theoretical Physics*
Donald S. Cohen, Ph.D. ..... *Applied Mathematics*
Marshall H. Cohen, Ph.D. ..... *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*
Richard P. Feynman, Ph.D., Nobel Laureate[1] ..... *Richard Chace Tolman Professor of Theoretical Physics*
William A. Fowler, Ph.D., D.Sc. ..... *Institute Professor of 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*
Peter Goldreich, Ph.D. ..... *Planetary Science and Astronomy*
David L. Goodstein, Ph.D. ..... *Physics and Applied Physics*
Roy W. Gould, Ph.D. ..... *Applied Physics*
Jesse L. Greenstein, Ph.D. ..... *Lee A. DuBridge Professor of Astrophysics*
James E. Gunn, Ph.D. ..... *Astronomy*
Marshall Hall, Jr., Ph.D.[1] ..... *IBM Professor of Mathematics*
Ralph W. Kavanagh, Ph.D. ..... *Physics*
Herbert B. Keller, Ph.D. ..... *Applied Mathematics*
Robert B. Leighton, Ph.D. ..... *Physics*
W. A. J. Luxemburg, Ph.D. ..... *Mathematics*
Jon Mathews, Ph.D. ..... *Theoretical Physics*
James E. Mercereau, Ph.D., D.Sc. ..... *Physics and Applied Physics*

[1]Leave of absence, second and third terms 1976-77

Alan T. Moffet, Ph.D. .... *Radio Astronomy*
Guido Münch, Ph.D.[2] .... *Astronomy*
Gerry Neugebauer, Ph.D. .... *Physics*
J. Beverley Oke, Ph.D. .... *Astronomy*
Jerome Pine, Ph.D. .... *Physics*
Herbert J. Ryser, Ph.D. .... *Mathematics*
Wallace L. W. Sargent, Ph.D. .... *Astronomy*
Maarten Schmidt, Ph.D., Sc.D. .... *Astronomy*
Frank J. Sciulli, Ph.D. .... *Physics*
Edward C. Stone, Jr., Ph.D. .... *Physics*
Kip S. Thorne, Ph.D.[1] .... *Theoretical Physics*
John Todd, B.Sc. .... *Mathematics*
Olga T. Todd, Ph.D. .... *Mathematics*
Alvin V. Tollestrup, Ph.D.[2] .... *Physics*
Thomas A. Tombrello, Jr., Ph.D. .... *Physics*
Rochus E. Vogt, Ph.D. .... *Physics*
Robert L. Walker, Ph.D. .... *Physics*
Ward Whaling, Ph.D. .... *Physics*
Gerald B. Whitham, Ph.D. .... *Applied Mathematics*
Fredrik Zachariasen, Ph.D. .... *Theoretical Physics*
Harold Zirin, Ph.D. .... *Astrophysics*
George Zweig, Ph.D.[2] .... *Theoretical Physics*

Sherman Fairchild Distinguished Scholars

Friedrich L. Bauer, Ph.D. .... *Mathematics*
Curtis Callan, Jr., Ph.D. .... *Physics*
Georgio Careri, Laurea .... *Physics*
Robert M. Solovay, Ph.D. .... *Mathematics*
Robert V. Wagoner, Ph.D. .... *Physics*
Kenneth Wilson, Ph.D. .... *Physics*
Richard M. Wilson, Ph.D. .... *Mathematics*

Visiting Associates

Peter H. G. Aczel, Ph.D. .... *Mathematics*
Lars Brink, Ph.D. .... *Theoretical Physics*
William L. Burke, Ph.D. .... *Physics*
William A. Coles, Ph.D. .... *Radio Astronomy*
Nicholas A. Derzko, Ph.D. .... *Mathematics*
James B. Hartle, Ph.D. .... *Physics*
David Horn, Ph.D. .... *Theoretical Physics*
James Houck, Ph.D. .... *Physics*
Sir Fred Hoyle, D.Sc. .... *Physics*
Robert L. Jaffe, Ph.D. .... *Theoretical Physics*
Michio Kaku, Ph.D. .... *Theoretical Physics*
Konrad Kleinknecht, Ph.D. .... *Physics*
W. Krzeminski, Ph.D. .... *Astrophysics*
David K. Lynch, Ph.D. .... *Physics*
Fernando B. Morinigo, Ph.D. .... *Physics*
Yuval Ne'eman, Ph.D. .... *Theoretical Physics*

[1]Leave of absence, second and third terms 1976-77
[2]Leave of absence, 1976-77

Andre Neveu, Ph.D.	*Theoretical Physics*
James R. Nix, Ph.D.	*Physics*
Kenneth Nordtvedt, Jr., Ph.D.	*Physics*
Jack C. Overley, Ph.D.	*Physics*
Keith Phillips, Ph.D.	*Mathematics*
Stephen S. Pinsky, Ph.D.	*Theoretical Physics*
Christoph Schmid, Ph.D.	*Theoretical Physics*
Leonard Susskind, Ph.D.	*Theoretical Physics*
Zygmunt Switkowski, Ph.D.	*Physics*
Carroll C. Trail, Ph.D.	*Physics*
Roger Ulrich, Ph.D.	*Physics*
Clifford M. Will, Ph.D.	*Physics*
C. Gareth Wynn-Williams, Ph.D.	*Physics*

Associate Professors

Geoffrey Fox, Ph.D.	*Theoretical Physics*
Ricardo Gomez, Ph.D.	*Physics*
Alexander S. Kechris, Ph.D.	*Mathematics*
Gary Lorden, Ph.D.	*Mathematics*
Charles W. Peck, Ph.D.	*Physics*
David B. Wales, Ph.D.[1]	*Mathematics*

Visiting Associate Professors

John Castor, Ph.D.	*Astronomy*
Gary M. Seitz, Ph.D.	*Mathematics*

Research Associates

Eric E. Becklin, Ph.D.	*Physics*
John H. Schwarz, Ph.D.	*Theoretical Physics*
George A. Seielstad, Ph.D.	*Radio Astronomy*
Gordon J. Stanley, Dipl.	*Radio Astronomy*
Petr Vogel, Ph.D.	*Physics*

Assistant Professors

Colin Bennett, Ph.D.	*Mathematics*
Roger D. Blandford, Ph.D.	*Theoretical Astrophysics*
Glennys Farrar, Ph.D.	*Theoretical Physics*
Alexander S. Kechris, Ph.D.	*Mathematics*
Hershy H. Kisilevsky, Ph.D.	*Mathematics*
Steven E. Koonin, Ph.D.[2]	*Theoretical Physics*
Arnold J. Sierk, Ph.D.	*Physics*
Peter G. Wannier, Ph.D.	*Radio Astronomy*
Michael Werner, Ph.D.	*Physics*

[1]Leave of absence, second and third terms, 1976-77
[2]Leave of absence, 1976-77

Visiting Assistant Professor

Henricus C. A. van Tilborg, M.S. .... *Mathematics*

Senior Research Fellows

Glenn L. Berge, Ph.D. .... *Planetary Science and Radio Astronomy*
G. John Dick, Ph.D. .... *Physics*
Richard D. Field, Ph.D. .... *Theoretical Physics*
Brosl Hasslacher, Ph.D. .... *Theoretical Physics*
Gillian Knapp, Ph.D. .... *Radio Astronomy*
Richard A. Mewaldt, Ph.D. .... *Physics*
Ronald L. Moore, Ph.D. .... *Astrophysics*
Harris A. Notarys, Ph.D. .... *Physics*
Richard J. Powers, Ph.D. .... *Physics*
Pierre Ramond, Ph.D.[1] .... *Theoretical Physics*
I-Juliana Sackmann, Ph.D. .... *Physics*
John A. Scheid, Ph.D. .... *Physics*
Paul R. Stevens, Ph.D. .... *Theoretical Physics*

Instructors

Frederick K. Dashiell, Jr., Ph.D.[2] .... *Mathematics*
Richard M. Foote, Ph.D.[2] .... *Mathematics*
Kenneth Holladay, Ph.D.[2] .... *Mathematics*
John S. Schlipf, Ph.D.[2] .... *Mathematics*
Israel Zibman, Ph.D.[2] .... *Mathematics*

Lecturer

Albert R. Hibbs, Ph.D. .... *Physics*

Research Fellows

William M. Adams, Ph.D. .... *Astrophysics*
Daniel N. Baker, Ph.D. .... *Physics*
Arie Bodek, Ph.D.[3] .... *Physics*
Carl Bromberg, Ph.D. .... *Physics*
Nim-Kwan Cheung, Ph.D. .... *Physics*
Charles Filleux, Ph.D. .... *Physics*
Frank A. Hagen, Ph.D. .... *Physics*
Eduardo J. Hardy, Ph.D. .... *Astronomy*
Mark R. Hartoog, Ph.D. .... *Astronomy*
Stephen P. Hatchett II, Ph.D. .... *Physics*
John A. Herb, Ph.D. .... *Physics*
Gordon Hurford, Ph.D. .... *Astronomy*
Vincent Icke, Ph.D. .... *Astrophysics*
Stephen L. Knapp, Ph.D. .... *Astronomy*
Paul S. Linsay, Ph.D. .... *Physics*
Kwok-Yung Lo, Ph.D. .... *Radio Astronomy*

[1]Robert Andrews Millikan Senior Research Fellow
[2]Harry Bateman Research Instructor, 1976-77
[3]Robert Andrews Millikan Research Fellow

Roscoe E. Marrs, Ph.D. .... *Physics*
Kenneth Marsh, Ph.D. .... *Astronomy*
Jonathan D. Melvin, Ph.D.[1] .... *Physics*
David R. Mikkelsen, Ph.D. .... *Physics*
Philippe Miné, Ph.D. .... *Physics*
Mark R. Morris, Ph.D. .... *Radio Astronomy*
Michael J. Newman, Ph.D. .... *Physics*
Douglas Richstone, Ph.D. .... *Astronomy*
Craig L. Sarazin, Ph.D.[2] .... *Physics*
Jonathan Schonfeld, Ph.D. .... *Theoretical Physics*
Michael Shaevitz, Ph.D. .... *Physics*
James R. Smith, Ph.D. .... *Physics*
Jack Sulentic, Ph.D. .... *Astronomy*
Keith Taylor, Ph.D. .... *Astronomy*
Scott Tremaine, Ph.D.[1] .... *Theoretical Physics*
Ian R. Tuohy, Ph.D. .... *Physics*
Jean L. Vuilleumier, Dr.Sc.Nat. .... *Physics*
Althea Wilkinson, Ph.D. .... *Astronomy*
Peter N. Wilkinson, Ph.D. .... *Radio Astronomy*
Robert J. Zinn, Ph.D. .... *Astronomy*

[1]Richard Chace Tolman Research Fellow
[2]Robert Andrews Millikan Research Fellow

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*
Barbara A. Zimmerman, *Computing Analyst*

Graduate Students 1976-77

Applied Mathematics
Benito Chen-Charpentier
Dwight William Decker
Lee Don Dobbs
Elliot Fischer
Arthur Ira Metz
John Charles Neu
Rodolfo Ruben Rosales
John Steven Sheffield
Henry Clark Simpson
Roque Kwok-hung Szeto
Gerald Allen Wedekind

Astronomy
Charles Roger Alcock
Kirk Daniel Borne
Menachem Cimerman
Jonathan Hart Elias
Richard Frederick Green
John Greg Hoessel
John Peter Huchra
Stephen Matthew Kent
Charles King
Barry James Labonte
Roger Paul Linfield
Jorge Hershel Melnick
Douglas Mark Rabin
Russell Ormond Redman
Jonathon Daniel Romney
Anneila Isabel Sargent
Donald P. Schneider
William Lawrence Sebok
David Frank Sholle
Richard Alan Wade
Howard Kwong Chew Yee
Peter John Young

Mathematics

Richard Paul Anstee
Stuart Lynch Blackburn
John Roll Bloom
Anselm Cyril Blumer
Neville Ray Campbell
Leslie J. Deutsch
Brent Lee Ellerbroek
Gregory Bruce Ennis
Michael David Huffman
Ilias George Kastanas
Donald Eugene Keenan
Hong-Chuan Lin
William Robert Love
David Jason Penney
Jeffrey Lee Rackusin
Arthur Leonard Rubin
Helene Marian Shapiro
Eric Paul Verheiden, Jr.
Michael Franz Yoder
Demetrious G. Zaferis

Physics

Victor Renos Akylas
Alan Axelrod
Alan Voltz Barnes
Frank Edward Barnes
Bertrand Charles Barrois
Steven Van Walter Beckwith
Gary Bedrosian
Howard Louis Berg
Robert Eugene Blair
John Richard Bond
Richard Laurence Brenner
Kay Wyatt Brown
Larry James Carson
Carlton Morris Caves
Yia-Chung Chang
Pei Chuang Chen
Arthur Er-Terg Chiou
Albert Pak-Ming Choi
Yam Ki Chu
Christopher Alan Cole
Walter Richardson Cook
Barbara Hope Cooper
Nicholas Albert Copping
France Anne Cordova
David Philip Crewther
Thomas Lynn Curtright
Vaughn Omer Davidson
Brian Ronald Davis
Murray Scott Daw
Dean Alan Deeds
Nathan Myron Denkin
Deepak Dhar
Eva Maria Dohrn
Mark F. Dumke
Daniel Bent Eldred
David James Ennis
Richard Alan Flammang
Bradley Arnold Flanders
James Dean Franson
George Michael Fuller
Ian Gatley
Cornelis Adolf Gehrels
James Lawrence Gimlett
Matthew Leigh Ginsberg
Richard Henry Goldberg
Thomas Russell Greenlee
Jeffrey Mark Greif
Joseph Edward Griffith
Yekta Gursel
Alan Andrew Hahn
Jeffrey John Hamilton
Steward Russell Hartman
Robert Lee Hatch
Lowell Eugene Hazelton
Raymond David Herrmann
Christopher Thaddeus Hill
Yupai Hsu
Andrew Thompson Hunter
Darrell Richard Jackson
Sarbmeet Singh Kanwal
Rosemary Gillian Kennett
Jaisam Kim
Arieh Konigl
Sandor Janos Kovacs, Jr.
Keith E. Krombel
Mauri Eugene Krouse
Daniel Sai Wah Kwoh
Heemin Kwon
Warren Yiu-Cho Lai
James Roy Lee
Typhoon Lee
Sally Amanda Lewis
Michael Murdock Lowry
Douglas A. MacDonald
John Kevin Markey
Max Marshall
Michael Charles McNab
Charles Kenneth Meins, Jr.

Frank Smith Merritt
Boris Z. Moroz
James Marshall Mosher
Daniel Nadeau
Frank Joseph Nagy
Daniel Edward Novoseller
Gordon Cecil Osbourn
Dee-Son Pan
Richard Allan Partridge
Jim David Povlis
William Charles Priedhorsky
David Benjamin Reiss
Charles Edward Riedhauser
Leo Carl Rosenfeld
William Armstrong Russell
Conrad Nobushige Sato
Joel Nathan Schulman
Lucy Elizabeth Seiberling
Kristen Sellgren
Chun-Ching Shih
Eric Jonathan Siskind
Stephen Avery Slutz
John David Spalding
Srinivas Sridhar
Stuart Reh Stampke
John Stager Stemple
Timothy Sullivan
Eugene Szedenits, Jr.
Peter Taborek
Anthony Emerson Terrano
Stephen Trentalange
John Reinhold Valainis
Howard Andrew Walter
Keh-chung Wang
Michael Ben Weimer
Martha Riherd Weller
Robert Allen Weller
Mark Edward Wiedenbeck
Gregory Mark Wilkinson
Harold Stevenson Wilson
Daniel Paul Wilt
Jack Leach Wisdom
Shiu-Chin Alice Wu
Gong Ping Yeh
Pochi Albert Yeh
Huan-Chun Yen
Kar Woo Yung
Cosmas Kyriacoulis Zachos
Mark Edward Zimmermann
James Frederick Zumberge
John Lehrer Zyskind

Owens Valley Radio Observatory
Staff Members

Alan T. Moffet, *Director*

Glenn L. Berge, Ph.D.
Marshall H. Cohen, Ph.D.
Martin S. Ewing, Ph.D.
Jesse L. Greenstein, Ph.D.
Gillian R. Knapp, Ph.D.
Robert B. Leighton, Ph.D.
Alan T. Moffet, Ph.D.
Duane O. Muhleman, Ph.D.
Richard B. Read, Ph.D.
Bruce H. Rule, B.S.
Maarten Schmidt, Ph.D.
George A. Seielstad, Ph.D.
Gordon J. Stanley, Dipl.
Melvyn C. H. Wright, Ph.D.

Sherman Fairchild Distinguished Scholars 1975-76

George K. Batchelor, Ph.D.
Head of Department of Applied Mathematics and Theoretical Physics, University of Cambridge
Knut Bertram Broberg, Dr.techn.
Professor, Strength of Materials Department, Lund Institute of Technology
Alexander Rich, M.D.
Sedgwick Professor of Biophysics, Massachusetts Institute of Technology
Robert V. Wagoner, Ph.D.
Associate Professor of Physics, Stanford University
Richard M. Wilson, Ph.D.
Professor of Mathematics, The Ohio State University

1976-77

Rutherford Aris, Ph.D., D.Sc.
Professor of Chemical Engineering, University of Minnesota
Allen J. Bard, Ph.D.
Professor of Chemistry, University of Texas
Freidrich L. Bauer, Ph.D.
Professor, Co-Director of the Mathematics Institute and Computing Center, University of Munich
Curtis G. Callan, Ph.D.
Professor of Physics, Princeton University
Giorgio Careri, Laurea
Professor, Department of Physics, University of Rome
A. Welford Castleman, Jr., Ph.D.
Group Leader, Brookhaven National Laboratory
Terry Cole, Ph.D.
Engineering and Research Staff, Ford Motor Company; *Adjunct Professor of Physics,* University of Minnesota
Charlotte Joanne Erickson, Ph.D.
Reader in Economic History, The London School of Economics, University of London
Gerhard Ertl, Dr.rer.nat.
Professor and Director, Institute of Physical Chemistry, University of Munich
John R. S. Fincham, Ph.D., Sc.D.
Professor and Head, Department of Genetics, University of Leeds
Joshua Jortner, Ph.D.
Heinemann Professor of Chemistry, Tel-Aviv University
Bela Julesz, Ph.D.
Head, Sensory and Perceptual Processes, Bell Laboratories
Lynn Margulis, Ph.D.
Associate Professor of Biology, Boston University
Geoffrey A. Ozin, Ph.D.
Associate Professor of Chemistry, University of Toronto
Leo E. Rose, Ph.D.
Editor, *Asian Survey*
Alexander Silberberg, Ph.D.
Professor of Polymer Science, Weizmann Institute of Science
Robert M. Solovay, Ph.D.
Senior Research Staff Member, International Business Machines T. J. Watson Research Center
Henry George Thode, Ph.D.
Professor of Chemistry, McMaster University
Seiya Uyeda, Ph.D.
Professor of Geophysics, University of Tokyo
Kenneth Geddes Wilson, Ph.D.
Professor of Physics, Cornell University

Athletics and Physical Education

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

Full-time Staff

Thomas Gutman, M.S.
E. Leroy Neal, M.A.
Edward T. Preisler, B.A.
Edwin Spencer, B.S.

Part-time Staff

David E. Beck
Rebecca Bobele, B.A.
Dean G. Bond, B.A.
Donald R. Cameron, B.Sc.
Harold G. Cassriel, B.S.
John L. Lamb
Tsutomu Ohshima, B.A.
Hudson L. Scott, M.S.

Athletic Council

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

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Kiku Matsumoto, *Deputy Director*

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Edward C. Stone
Felix Strumwasser
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Frederick B. Thompson
John Todd
Robert L. Walker
James A. Westphal
Barbara Zimmerman

Environmental Quality Laboratory

Norman H. Brooks, *Director*
Martin Goldsmith, *Deputy Director*

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Samuel Epstein, Ph.D., Professor of Geochemistry
John Ferejohn, Ph.D., Associate Professor of Political Science
Sheldon K. Friedlander, Ph.D., Professor of Chemical and Environmental Health Engineering
Martin Goldsmith, Ph.D., Associate in Environmental Engineering
Arie J. Haagen-Smit, Ph.D., Professor of Bio-organic Chemistry, Emeritus
Burton H. Klein, Ph.D., Professor of Economics
Lester Lees, M.S., Professor of Environmental Engineering and Aeronautics
E. John List, Ph.D., Associate Professor of Environmental Engineering Science
W. David Montgomery, Ph.D., Assistant Professor of Economics
James J. Morgan, Ph.D., Professor of Environmental Engineering Science; Executive Officer for Environmental Engineering Science
Roger G. Noll, Ph.D.[1], Professor of Economics
James P. Quirk, Ph.D., Professor of Economics
John H. Seinfeld, Ph.D., Professor of Chemical Engineering; Executive Officer for Chemical Engineering
Fredrick H. Shair, Ph.D., Professor of Chemical Engineering

Staff Associates

H. Stuart Burness, Ph.D., Visiting Associate in Economics
Richard C. Flagan, Ph.D., Assistant Professor of Environmental Engineering Science
William R. Goodin, Ph.D., Research Fellow in Environmental Engineering Science
Robert C. Y. Koh, Ph.D., Research Associate in Environmental Engineering Science
James E. Krier, J.D., Visiting Associate [Professor of Law, University of California (Los Angeles)]
Tracy R. Lewis, Ph.D., Senior Research Fellow in Economics
Lytton W. Stoddard, Ph.D., Research Fellow in Economics
Brent D. Taylor, Ph.D., Senior Research Engineer

Graduate Research Assistants (1975-76)

Glen R. Cass
Nancy Childs
Linda Cohen
William K. Faisst
Bryan Jack
Arthur R. Jensen
Gregory John McRae
Darwin Niekerk
Windsor Sung
Paul Thomas

[1]Leave of absence

Hale Observatories

Operated jointly with the Carnegie Institution of Washington

Horace W. Babcock, *Director*
J. Beverley Oke, *Associate Director*

Observatory Committee

Horace W. Babcock, *Chairman*
James E. Gunn
J. Beverley Oke
George W. Preston
Allan R. Sandage
Wallace L. W. Sargent
Maarten Schmidt
Arthur H. Vaughan, Jr.

Staff Members

Halton C. Arp, Ph.D.
Horace W. Babcock, Ph.D., Sc.D.
Eric E. Becklin, Ph.D.
Jesse L. Greenstein, Ph.D.
James E. Gunn, Ph.D.
Robert F. Howard, Ph.D.
Jerome Kristian, Ph.D.
Robert B. Leighton, Ph.D.
Guido Münch, Ph.D.
Gerry Neugebauer, Ph.D.
J. Beverley Oke, Ph.D.
S. Eric Persson, Ph.D.
George W. Preston, Ph.D.
Allan R. Sandage,
Ph.D., Sc.D., D.Sc., LL.D.
Wallace L. W. Sargent, Ph.D.
Maarten Schmidt, Ph.D., Sc.D.
Leonard Searle, Ph.D.
Stephen A. Shectman, Ph.D.
Arthur H. Vaughan, Jr., Ph.D.
James A. Westphal, B.S.
Harold Zirin, Ph.D.

Staff Associates

Robert J. Brucato, Ph.D.
Michael W. Werner, Ph.D.

Senior Research Fellow

Ronald Moore, Ph.D.

Research Fellows

William M. Adams, Ph.D.
A. G. de Bruyn, Ph.D.
Eduardo J. Hardy, Ph.D.
Mark R. Hartoog, Ph.D.
Gordon J. Hurford, Ph.D.
Stephen L. Knapp, Ph.D.
Kenneth A. Marsh, Ph.D.
Douglas Richstone, Ph.D.
Jack Sulentic, Ph.D.
Trinh X. Thuan, Ph.D.
Althea Wilkinson, Ph.D.
Robert J. Zinn, Ph.D.

Health Center

Gregory Ketabgian, M.D. .... *Director of Health Services*
Nancy G. Beakel, Ph.D. .... *Institute Psychologist*
Marlene Coleman, M.D. .... *Attending Physician*
John Dyckman, Ph.D. .... *Institute Psychologist*
Judson James, M.D. .... *Attending Physician*
Warren Jones, M.D. .... *Consulting Psychiatrist*
Jack Lindheimer, M.D. .... *Consulting Psychiatrist*
Nerses Matossian, M.D. .... *Attending Physician*

Industrial Relations Center

Robert D. Gray, B.S., *Director, Industrial Relations Center; Professor of Economics and Industrial Relations*
Robert M. Sloane, M.S., *Lecturer in Industrial Relations*

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Administered by Caltech for the National Aeronautics and Space Administration

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

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G. Edward Danielson, Jr., *Executive Secretary*

Dr. Philip H. Abelson
President, Carnegie Institution of Washington, and Editor, SCIENCE
Mr. Norton Belknap
Vice President, Corporate Planning, Exxon Corporation
Mr. Benjamin Biaggini
Caltech Trustee, and President and Chief Executive Officer of Southern Pacific Company
Dr. Eugene G. Fubini
E. G. Fubini Consultants, Ltd.
Dr. Harry B. Gray
William R. Kenan, Jr. Professor and Professor of Chemistry, Caltech
Dr. James J. Morgan
Professor of Environmental Engineering and Executive Officer of the Department of Environmental Engineering Science, Caltech
Dr. Roger G. Noll
Professor of Economics, Caltech
Dr. Bernard M. Oliver
Vice President, Research and Development, Hewlett-Packard Company
Dr. Ray D. Owen
Professor of Biology, Dean of Students, and Vice President of Student Affairs, Caltech
Dr. Allen Peterson
Professor of Electrical Engineering and Co-Director, Stanford Center for Radar Astronomy, Stanford University
Dr. John R. Pierce
Professor of Engineering and Executive Officer of the Department of Electrical Engineering, Caltech
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Caltech Trustee and Vice Chairman, TRW, Inc.
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Caltech Trustee
Dr. Robert P. Sharp
Professor of Geology, Caltech
Dr. Rochus E. Vogt
Professor of Physics, Caltech
Mr. William E. Zisch, *Chairman*
Caltech Trustee and Vice Chairman of the Board, Science Applications, Inc.

Institute Libraries

Johanna E. Tallman, *Director*

Members of the Professional Staff
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Judith R. Goodstein
Dana L. Roth

Representatives for the Departmental Libraries

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Tom M. Apostol, Ph.D.
Felix H. Boehm, Ph.D.
Charles J. Brokaw, Ph.D.
Norman H. Brooks, Ph.D.
Francis S. Buffington, Ph.D.
Marshall Cohen, Ph.D.
Donald E. Coles, Ph.D.
George R. Gavalas, Ph.D.
Robert D. Gray, B.S.
Donald Helmberger, Ph.D.
Paco A. Lagerstrom, Ph.D.
Gilbert D. McCann, Ph.D.
Edwin S. Munger, Ph.D.
Charles H. Papas, Ph.D.
Rolf H. Sabersky, Ph.D.
Walter A. Schroeder, Ph.D.
Leonard Searle, Ph.D.

Musical Activities

Olaf Frodsham .... *Director of Choral Music*
Monica Roegler .... *Assistant Director of Choral Music*
William Bing .... *Jazz Band Director*
Marc Blake .... *Chamber Orchestra Director*
James Rötter .... *Wind Ensemble Director*
James Boyk .... *Interpretive Music Class*
Alice and Eleonore Schoenfeld .... *Chamber Music Master Classes*

OFFICERS AND FACULTY

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

Russell Z. Abrams, Ph.D., *Assistant Professor of Philosophy*
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B.S., California Institute, 1941; M.S., 1946; Ph.D., 1949. Lecturer in Mechanical Engineering, 1949-50; Assistant Professor, 1950-55; Associate Professor, 1955-61; Professor, 1961-63; Professor of Materials Science, 1963-; Acting Associate Dean of Students, 1968-69; Associate Dean, 1969-74.

Lincoln Jackson Wood, Ph.D., *Lecturer in Systems Engineering* (PT)
B.S., Cornell University, 1968; M.S., Stanford University, 1969; Ph.D., 1972. Research Scientist, Hughes Aircraft Company, 1974-. Bechtel Instructor in Engineering, California Institute 1972-74; Lecturer, 1975-76.

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

James Alan Woodhead, Ph.D., *Research Fellow in Geology*
B.S., California Institute, 1969; M.A., Princeton University, 1972; Ph.D., 1976. Research Fellow, California Institute, 1976-77.

Dean Everett Wooldridge, Ph.D., *Visiting Associate in Engineering*
B.A., University of Oklahoma, 1932; M.S., 1933; Ph.D., California Institute, 1936. Director, Thompson Ramo Wooldridge, Inc., 1958-. Lecturer in Electrical Engineering, California Institute, 1947-49; Research Associate in Engineering, 1950-52; 1962-73; Visiting Associate, 1973-.

Frank Hong-Ye Wu, Ph.D., *Research Fellow in Hydraulics*
B.S., National Taiwan University, 1969; M.S., Stanford University, 1972; Ph.D., 1976. California Institute, 1976-77.

Jung-Rung Wu, Ph.D., *Senior Research Fellow in Biology*
B.S., National Taiwan University, 1962; Ph.D., University of Texas (Austin), 1969. Research Fellow, California Institute, 1969-72; Senior Research Fellow, 1974-.

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

Oliver Reynolds Wulf, Ph.D., *Senior Research Associate in Physical Chemistry, Emeritus*
B.S., Worcester Polytechnic Institute, 1920; M.S., American University, 1922; Ph.D., California Institute, 1926. Research Associate, 1945-67; Research Associate Emeritus, 1967-74; Senior Research Associate Emeritus, 1974-.

James A. Wurzbach, Ph.D., *Research Fellow in Chemistry*
B.S., The University of Michigan, 1969; Ph.D., University of California, 1975. California Institute, 1975-76.

Charles Gareth Wynn-Williams, Ph.D., *Visiting Associate in Physics*
B.A., Trinity College, University of Cambridge, 1966; M.A., 1970; Ph.D., 1971. Demonstrator in Physics, 1973-. Research Fellow, California Institute, 1971-73; Visiting Associate, 1975-76.

Amnon Yariv, Ph.D., *Professor of Electrical Engineering and Applied Physics*
B.S., University of California, 1954; M.S., 1956; Ph.D., 1958. Associate Professor of Electrical Engineering, California Institute, 1964-66; Professor, 1966-74; Professor of Electrical Engineering and Applied Physics, 1974-.

Hsueh-Wen Yeh, Ph.D., *Research Fellow in Geochemistry*
B.S.E., National Cheng Kung University (Taiwan), 1967; Ph.D., Case Western Reserve University, 1974. California Institute, 1975-.

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

Nobuyuki Yonekura, D.Sc., *Visiting Associate in Geology*
B.Sc., University of Tokyo, 1962; M.Sc., 1964; D.Sc., 1975. Research Associate, 1965-. California Institute, 1976.

Don M. Yost, Ph.D., *Professor of Inorganic Chemistry, Emeritus*
B.S., University of California, 1923; Ph.D., California Institute, 1926. Instructor, 1927-29; Assistant Professor, 1929-35; Associate Professor, 1935-41; Professor, 1941-64; Professor Emeritus, 1964-.

Yuk Ling Yung, Ph.D., *Visiting Associate in Planetary Science*
B.S., University of California, 1969; Ph.D., Harvard University, 1974. Research Associate and Lecturer, 1975-. California Institute, 1976.

Fredrik Zachariasen, Ph.D., *Professor of Theoretical Physics*
B.S., University of Chicago, 1951; Ph.D., California Institute, 1956. Assistant Professor, 1960-62; Associate Professor, 1962-66; Professor, 1966-.

Eran Zaidel, Ph.D., *Research Fellow in Biology*
A.B., Columbia College, 1967; M.S., California Institute, 1968; Ph.D., 1973. Research Fellow, 1973-.

Valentina Zaydman, M.A., *Lecturer in Russian*
M.A., Moscow State University, 1971. California Institute, 1974-.

Ahmed H. Zewail, Ph.D., *Assistant Professor of Chemical Physics*
B.Sc., Alexandria University (Egypt), 1967; Ph.D., University of Pennsylvania, 1974. California Institute, 1976-.

Israel B. Zibman, Ph.D., *Bateman Research Instructor in Mathematics*
B.A., M.A., Brandeis University, 1973; Ph.D., Princeton University, 1976. California Institute, 1976-77.

George J. Zimmer, Dipl., *Visiting Associate in Applied Physics*
Dipl., Eotvos University (Budapest), 1962; Scientist, Institute of Hungarian Academy of Sciences. California Institute, 1974; 1975.

Robert J. Zinn, Ph.D., *Research Fellow in Astronomy*
B.S., Case Institute of Technology, 1968; Ph.D., Yale University, 1974. Carnegie Fellow, Hale Observatories, 1974-. California Institute, 1975-76.

Harold Zirin, Ph.D., *Professor of Astrophysics; Chief Astronomer of Big Bear Solar Observatory*
A.B., Harvard College, 1950; A.M., Harvard University, 1951; Ph.D., 1953. Visiting Associate, California Institute, 1963; Professor, 1964-. Staff Member, Hale Observatories, 1964-. Chief Astronomer, Big Bear Solar Observatory, 1970-.

Edward Edom Zukoski, Ph.D., *Professor of Jet Propulsion*
B.S., Harvard College, 1950; M.S., California Institute, 1951; Ph.D., 1954. Research Engineer, Jet Propulsion Laboratory, 1950-57; Lecturer, California Institute, 1956-57; Assistant Professor, 1957-60; Associate Professor, 1960-66; Professor, 1966-.

George Zweig, Ph.D., *Professor of Theoretical Physics* (LOA)
B.S., The University of Michigan, 1959; Ph.D., California Institute, 1964. Research Fellow in Physics, 1963; Assistant Professor, 1964-66; Associate Professor, 1966-67; Professor of Theoretical Physics, 1967-.

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

Section II

GENERAL INFORMATION

The California Institute of Technology is an independent, privately supported and privately controlled institution, officially classed as a university, carrying on undergraduate and graduate instruction and research, principally in the various fields of science and engineering. It is fully accredited by the Western Association of Schools and Colleges.

Including its off-campus facilities, it is also one of the world's major research centers. According to *World* magazine: "In a number of countries today, there is at least one magnificently equipped scientific research institution that is proudly referred to as the nation's 'center of excellence.' Caltech, though, in the words of a senior Dutch astrophysicist, 'may well have become the center of scientific excellence for the entire world.' "

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

The Undergraduate Program

The primary purpose of the undergraduate school of the California Institute of Technology, as stated by the Trustees, is "to provide a collegiate education which will best train the creative type of scientist or engineer so urgently needed in our educational, governmental, and industrial development." It is believed that this purpose is attained at the Institute because of the contacts of its relatively small group of students with the members of its relatively large research staff. Advancement in understanding is best acquired by intimate association with creative workers who are, through research and reflection, extending the boundaries of knowledge.

Caltech offers a four-year undergraduate course with options available in various fields of science, engineering, applied science, and certain humanities subjects, all leading to the degree of Bachelor of Science. The curriculum is planned so that interchange between options is not too difficult to the end of the second year. During the first year, the work of all undergraduates is almost identical, but there is opportunity for some differentiation between the various options during the second year.

The undergraduate options are: applied mathematics, applied physics, astronomy, biology, chemical engineering, chemistry, economics, engineering and applied science, geochemistry, geology, geophysics and planetary science, history, independent studies program, literature, mathematics, physics, and social science.

The science courses afford an intensive training in physics, chemistry, and mathematics, with further specialization in a chosen field of science during the third and fourth years.

The courses in engineering and applied science are of a general fundamental character, with a minimum of specialization in the separate branches. There is an unusually thorough training in the basic sciences of physics, chemistry, and mathematics, as well as in the professional subjects common to all branches of engineering. The major concentration in a chosen field occurs during the fourth year.

Students electing a humanities or social science option will pursue the same curriculum as all other students during the freshman year, and will continue with the regular sophomore courses in mathematics and physics. During the last two years, they specialize in a chosen field of humanities or social science but will continue substantial work in science and engineering subjects.

The undergraduate options in science, engineering, and applied science themselves contain a large proportion of humanistic and cultural studies — with 20 percent, or more, of the time during the entire four years being devoted to such subjects. The purpose of this requirement is to provide a combination of fundamental scientific training with a broad human outlook and to enlarge the student's mental horizon beyond the limits of his immediate professional interest.

Caltech also encourages a reasonable participation in extracurricular activities, largely managed by the students themselves. These include student publications, dramatics, music, and public affairs. All undergraduates are required to take three terms of physical education prior to graduation and may also participate in a program of intercollegiate and intramural sports.

Dean of Students and Professor of Biology Ray D. Owen (center) relaxes with students and faculty members at the 1975 Freshman Camp. The camp has been held each fall for several years on Catalina Island, a 26-mile boat trip from Los Angeles harbor, and very far indeed from the pressures of campus life.

In short, every effort is made to provide the undergraduate student with a well-rounded, integrated program which will not only give him sound training in his professional field, but which will also develop character, breadth of view, general culture, and physical well-being.

The Graduate Program

In the graduate school Caltech offers courses leading to the degree of Master of Science, which normally involves one year of graduate work; the Engineer's degree in certain branches of engineering, with a minimum of two years; and the degree of Doctor of Philosophy. In all the graduate work, research is strongly emphasized, not only because of its importance in contributing to the advancement of science and thus to the intellectual and material welfare of mankind, but also because research activities add vitality to the educational work of Caltech.

The graduate options are: aeronautics, applied mathematics, applied mechanics, applied physics, astronomy, biology, chemical engineering, chemistry, civil engineering, electrical engineering, engineering science, environmental engineering science, geological and planetary sciences, materials science, mathematics, mechanical engineering, physics, and social science.

Graduate students constitute a comparatively large portion (almost 50 percent) of the total student body. Engaged as they are in research problems of varying degrees of complexity, and taught by faculty members who are also actively engaged in research, they contribute materially to the general atmosphere of intellectual curiosity and creative activity which is engendered on the Institute campus.

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 in engineering and science in which it offers undergraduate and graduate study, believing that it is better to provide thoroughly for a limited number of curricula than to risk diffusion of personnel, facilities, and funds in attempting to cover a wide variety of fields. Second, and in line with this policy of conservation of resources, the student body is strictly limited to that number which can be satisfactorily provided for. Admission is granted after a careful study of the merits of each applicant, including the results of entrance examinations, school records, and interviews by members of the Caltech staff. These procedures result, it is believed, in a body of stuents of exceptional ability. A high standard of scholarship is also maintained, as is appropriate for students of such competence.

HISTORICAL SKETCH

The California Institute of Technology, as it has been called since 1920, developed from a local school of arts and crafts, founded in Pasadena in 1891 by the Honorable Amos G. Throop and named, after him, Throop Polytechnic Institute. It enjoyed the loyal support of the citizens of Pasadena, and by 1908 the board of trustees had as members Dr. Norman Bridge, Arthur H. Fleming, Henry M. Robinson, J. A. Culbertson, C. W. Gates, and Dr. George Ellery Hale. It was the dedication, by these men, of their time, their brains, and their fortunes that transformed a modest vocational school into a university capable of attracting to its faculty some of the most eminent of the world's scholars and scientists.

George Ellery Hale, astronomer and first director of the Mount Wilson Observatory, foresaw the development in Pasadena of a distinguished institution of engineering and scientific research. Hale well knew that a prime necessity was modern well-equipped laboratories, but he stressed to his fellow trustees that the aim was not machines, but men. "We must not forget," he wrote in 1907, "that the greatest engineer is not the man who is trained merely to understand machines and apply formulas, but is the man who, while knowing these things, has not failed to develop his breadth of view and the highest qualities of his imagination. No creative work, whether in engineering or in art, in literature or in science, has been the work of a man devoid of the imaginative faculty."

The realization of these aims meant specializing, so the trustees decided in 1907 to separate the elementary department, the normal school, and the academy, leaving only a college of technology which conferred Bachelor of Science degrees in electrical, mechanical, and civil engineering.

In 1910 Throop Polytechnic Institute moved from its crowded quarters in the center of Pasadena to a new campus of twenty-two acres on the southeastern edge of town, the gift of Arthur H. Fleming and his daughter Marjorie. The president, Dr. James A. B. Scherer, and his faculty of 16 members, opened the doors to 31 students that September. When, on March 21, 1911, Theodore Roosevelt delivered an address at Throop Institute, he declared, "I want to see institutions like Throop turn out perhaps ninety-nine of every hundred students as men who are to do given pieces of industrial work better than any one else can do them; I want to see those men do the kind of work that is now being done on the Panama Canal and on the great irrigation projects in the interior of this country — and the one-hundredth man I want to see with cultural scientific training."

It would have surprised Roosevelt to know that within a decade the little Institute, known from 1913 as Throop College of Technology, would have again raised its sights, leaving to others the training of more efficient technicians and concentrating its own efforts on Roosevelt's "hundredth man." On November 29, 1921, the trustees declared it to be the express policy of the Institute to pursue scientific researches of the greatest importance and at the same time "to continue to conduct thorough courses 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 800 undergraduates, 700 graduate students, and 650 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

Arthur Amos Noyes came to Throop College of Technology (the predecessor of Caltech) as director of chemical research in 1919. He was one of three men who founded the modern California Institute of Technology. In this photograph taken in the early 1920s, Noyes has breakfast at a table that apparently was used for chemistry experiments as well as meals.

departments except when the work done in them would be at the same high level as that in physics and chemistry. In 1925 a gift of $25,000 from the Carnegie Corporation of New York made possible the opening of a department of instruction and research in geology. A seismological laboratory was constructed, and Professors John P. Buwalda and Chester Stock came from the University of California to lead the work in the new division.

In 1928 the California Institute began its program of research and instruction in biology. Thomas Hunt Morgan became the first chairman of the new Division of Biology and a member of Caltech's Executive Council. Under Morgan's direction the work in biology developed rapidly, especially in genetics and biochemistry. Morgan received the Nobel Prize in 1933.

The Guggenheim Graduate School of Aeronautics was founded at Caltech in the summer of 1926 and a laboratory was built in 1929, but courses in theoretical aerodynamics had been given at the Institute for many years by Professors Harry Bateman and P. S. Epstein. As early as 1917 Throop Institute had had a wind tunnel in which, the catalog proudly boasted, constant velocities of 4 to 40 miles an hour could be maintained, "the controls being very sensitive." The new program, under the leadership of Theodore von Kármán, included graduate study and research at the level of the other scientific work at the Institute, and GALCIT (Guggenheim Aeronautical Laboratory at the California Institute of Technology) was soon a world-famous research center in aeronautics.

In 1928 George Ellery Hale and his associates at the Mount Wilson Observatory developed a proposal for a 200-inch telescope and attracted the interest of the General Education Board in providing $6,000,000 for its construction. The Board proposed that the gift be made to the California Institute of Technology, and Caltech agreed to be responsible for the construction and operation. The huge instrument was erected on Palomar Mountain, and the Mount Wilson and Palomar Observatories are now operated jointly as the Hale Observatories through an agreement between Caltech and the Carnegie Institution of Washington. Teaching and research in astronomy and astrophysics thus became a part of the Caltech program.

Although the emphasis upon the humanities or liberal arts as an important part of the education of every scientist and engineer was traditional even in the Throop College days, a reiterated insistence upon this principle was made when Hale, Noyes, and Millikan created the modern Caltech. In 1924, when a five-year engineering course leading to the M.S. degree was offered, the humanities requirement was included. In 1925 William Bennett Munro, chairman of the Division of History, Government and Economics at Harvard, joined the Institute staff, and soon became a member of the Executive Council. Students were required to spend between 20 and 25 percent of their undergraduate years in the Division of the Humanities — mainly in literature and history, with some economics. In the fifties the relation of science to society became increasingly important, and in 1966 the division changed its name to the Division of the Humanities and Social Sciences. Studies of our modern society were undertaken by processes of formal analysis based on the social and political sciences. Undergraduate options in literature, history, economics, and social science are now offered.

For the five years beginning with the summer of 1940, Caltech devoted an increasingly large part of its personnel and facilities to the furthering of 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 conducted the Ranger, Surveyor, Mariner, and Viking programs of lunar and planetary exploration for NASA. The Laboratory also operates the NASA worldwide deep-space tracking network and conducts a program of supporting research in space science and engineering.

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

DuBridge was also committed to the concept of a small, select institution offering excellence in education. Facts and figures are only part of the story, but the statistical record of change during the DuBridge administration indicates how he held to that concept. The 30-acre campus of 1946 grew to 90 acres; the $17 million endowment grew to over $100 million; the faculty of 260 became 550; the number of campus buildings increased from 20 to 64; and the budget went from something under $8 million to $30 million. But enrollment remained relatively constant. In 1946 the total number of students, graduate and undergraduate, was 1,391. In 1968, the year DuBridge left, it was 1,492.

Dr. Harold Brown came to Caltech as president in 1969. A physicist who received his Ph.D. from Columbia in 1949, he succeeded Dr. Edward Teller as director of the University of California's Lawrence Radiation Laboratory in Livermore in 1960. President Lyndon Johnson named Brown Secretary of the Air Force in 1965, and he came to the Institute from that office.

As Caltech has developed in effectiveness and in prestige, it has attracted a steady flow of gifts for buildings, for endowment, and for current operations. The gifts invested in plant now total $119,000,000 and those invested in endowment about $160,000,000. Very substantial grants and contracts from the federal government support many research activities.

Today Caltech has about 13,000 alumni scattered all over the world, many eminent in their fields of engineering and science. Eight of them have received Nobel Prizes: Carl D. Anderson (B.S. '27, Ph.D. '30), Edwin M. McMillan (B.S. '28, M.S. '29) Linus Pauling (Ph.D. '25), William Shockley (B.S. '32), Donald A. Glaser (Ph.D. '50), Charles H. Townes (Ph.D. '39), L. James Rainwater (B.S. '39), and Howard Temin (Ph.D. '60).

BUILDINGS AND FACILITIES

Gates and Crellin Laboratories of Chemistry: first unit, 1917; second unit, 1927; third unit, 1937. The first two units were the gift of Messrs. C. W. Gates and P. G. Gates of Pasadena; the third unit was the gift of Mr. and Mrs. E. W. Crellin of Pasadena. 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, the Huntington Library and Art Gallery, and the Hale Observatories; 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 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.

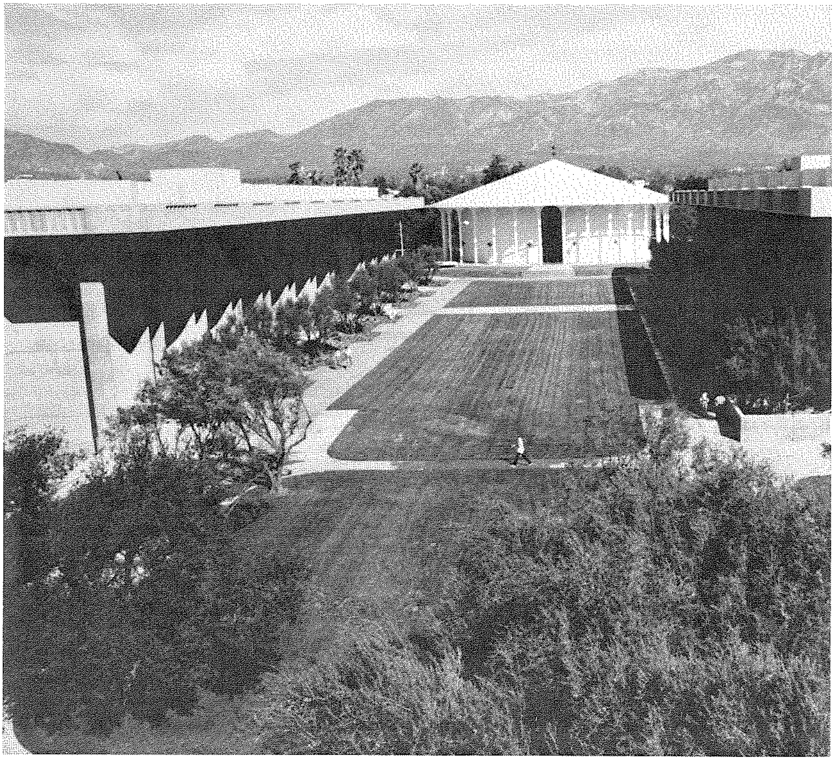
Karman Laboratory of Fluid Mechanics and Jet Propulsion, 1961. The gift of the Aerojet-General Corporation, named in honor of Dr. Theodore von Kármán, professor of aeronautics at the Institute, 1929-1949.

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.

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, chairman of the Board of Trustees from 1964-1974, and is now chairman emeritus.



In this view of the campus, looking north toward the San Gabriel mountains, the Mabel and Arnold Beckman Laboratories of Behavioral Biology are at left, Beckman Auditorium is in the center, and the Donald E. Baxter, M.D., Hall of the Humanities and Social Sciences is at right. The open area in the center is known as the Court of Man; commencement exercises are held there each June.

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 an anonymous donor, and named in honor of

Arthur Amos Noyes, director of the Gates and Crellin Laboratories of Chemistry and chairman of the Division of Chemistry and Chemical Engineering, 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.

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.

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.

Students and faculty in many different disciplines make use of the facilities of Kerckhoff Marine Laboratory at Corona del Mar.

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 Detroit, Michigan.

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

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

Palomar Observatory, San Diego County, 1948. Owned by the Institute and, with the Mount Wilson Observatory, operated jointly as the Hale Observatories by Caltech and the Carnegie Institution of Washington.

Owens Valley Radio Observatory, near Bishop, 1958.

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

LIBRARIES

The Robert A. Millikan Memorial Library houses the general administrative activities of the Institute's library system as well as the following divisional collections: biology, chemistry, engineering, humanities and social sciences, mathematics, and physics.

Millikan Memorial, completed in 1967, is a nine-story building with 63,000 feet of floor space. It has an eventual capacity of about 300,000 volumes and provides seats for about 250 students. Book collections have been distributed throughout the building in such a way that each major subject has its own area and retains its identity and its close relationship with its parent academic division. Library administrative services are concentrated on the second floor; here also are the catalog of campus libraries and general reference and information services. The first floor contains reserve book services and the rare books room. The various divisional collections are on floors four through nine. The basement contains reproduction 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, astrophysics, chemical engineering, earthquake engineering, electrical engineering, Environmental Quality Laboratory, geology, hydraulics and environmental engineering, information and computer science, management, and public affairs. The libraries collectively subscribe to about 5,000 journals and serials and contain about 292,000 volumes.

THE INDUSTRIAL RELATIONS CENTER

The objectives of the Industrial Relations Center are to increase and disseminate a knowledge and an understanding of the philosophies, principles, policies, and procedures of employer-employee relations influencing the motivation, development, utilization, compensation, and supervision of rank-and-file, professional, and managerial personnel.

Representatives of many organizations in both the private and public sectors receive training in the field of management in general and in the specialized field of personnel administration. Special attention is given to programs for technical supervisors and managers who function in engineering and research laboratories. Other series are designed for the first- and second-line supervisors of non-exempt employees. The courses are presented on a number of bases: on-campus or off-campus; full-time or part-time; for representatives of a variety of companies or for representatives of a specific company. These courses do not carry academic credit.

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

The office, library, and conference rooms of the Center are located on campus at 383 South Hill Avenue. Detailed information about the specific services of the Center and the fees involved can be secured from the Director of the Industrial Relations Center.

THE WILLIS H. BOOTH COMPUTING CENTER

The Computing Center offers a comprehensive integrated set of facilities for the research and educational use of all divisions of the Institute.

These include an IBM 370/158 computer and a PDP-10 computer which, in addition to servicing batch processing functions, provide for a variety of user communication modes through 40 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 at Caltech brings some of the world's great intellectual leaders to the campus 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.

It is possible to have 15 to 20 Scholars in residence on the campus at any one time. They will not all be scientists and engineers, though they will all be people who have exhibited an interest in science and technology; and in applying knowledge from these fields to meeting human needs. Appointments are for one year, but may be lengthened or shortened to accommodate the needs of the Scholar and the Institute.

The emphasis in the program is to give faculty and students exposure to Fairchild Scholars in all academic Divisions — through teaching, seminars, and lectures — and to establish a new forum for the exchange of ideas among Fairchild Scholars, Caltech faculty, students, and industry about new directions and ideas in science and engineering.

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 Laboratory, as well as the various disciplines making up the broad field known as Aeronautics.

Areas of Study and Research

Aeronautics has evolved at Caltech from a field of basic research and engineering, as related to the development of the airplane, to a wide discipline encompassing a broad spectrum of basic as well as applied problems. Starting from a need to gain a better understanding of fluid dynamics and structural mechanics, research at GALCIT has traditionally been guided through a host of 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 with the knowledge that they will be 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 of investigation are related to a variety of modern technological problems and, in addition, to the traditional aeronautical problems of drag, wing stall, and jet mixing. Current areas of activity in addition to those just mentioned 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 at GALCIT includes studies on 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 which 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, non-linear acoustics and hydroacoustics.

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 on page 134 under the separate heading of Jet Propulsion. Students in aeronautics are able to pursue studies and research leading to graduate degrees in aeronautics utilizing facilities, courses, and research supervision by the faculty of the Jet Propulsion Center.

Physical Facilities

The Graduate Aeronautical Laboratories contain a diversity of experimental facilities in support of the above programs. Low-speed wind tunnels include the Merrill Wind Tunnel, which can be operated by a single student, the GALCIT 10-ft. Wind Tunnel, and many special-purpose flow facilities. Both a High-Speed Water Tunnel (100 feet per second) and a Free-Surface Water Tunnel are housed in the Hydrodynamics Laboratory; they are used for studies of hydrofoils, cavitation, and acoustics. A smaller water channel for studies of wave motion and flow visualization is also available. For investigations of high-speed flows there is a hypersonic wind tunnel and a supersonic wind tunnel, each with two different working sections. Shock tubes, plasma tunnels, and other special facilities are available for the study of extreme temperatures, shock waves, acoustics, and cryogenic flow.

The solid mechanics laboratories contain standard as well as special testing machines for research in aircraft and spacecraft structures and materials under static and dynamic loads. Fatigue machines and photoelastic equipment are available. Special apparatus, including laser equipment and a line of high-speed cameras, offering recording at rates from still to 250,000 frames per second, is available for study of elastic waves, dynamic buckling, and the mechanics of static and dynamic fracture.

Electronic instrumentation up to the present state-of-the-art is being developed and used. A portable, computer-controlled data acquisition system is used extensively by the several research groups.

Applied Mathematics

It is the broad aim of the applied mathematics program at Caltech to stimulate and explore the interplay between mathematics and the various non-mathematical disciplines. On the one hand there is an active group of pure mathematicians devoting themselves mainly to the more abstract and foundational branches of mathematics, and on the other hand there is wide diversity of research in physics, engineering, biology, chemistry, geophysics, and economics. Ideas travel in both directions, bringing mathematical tools to bear for synthesis and solution of practical problems in various fields and, of equal importance, generating new mathematical ideas and points of view which arise from physical problems. The research and educational program reflects this aim in its organization.

This program is a joint effort of the Division of Physics, Mathematics and Astronomy and the Division of Engineering and Applied Science. Students majoring in applied mathematics are enrolled in either division and the professors of applied mathematics are also in these two divisions. Further, professors from other divisions take part supervising research and offering courses of special interest. Close contact is maintained with experimental programs in fluid and solid mechanics. The present graduate program is one leading mainly to the Ph.D. degree. The curriculum consists of two types of courses: those which survey the methods used in applied mathematics, and those which have a special applied mathematics flavor and represent active research interests of the members of the faculty. Among the latter have been wave motion, perturbation theory, 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. In addition to the connections mentioned above, special notice should be taken of the existence of computer science and bioinformation systems groups 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 group primarily interested in applied mathematics consists of approximately 25 students and 8 professors. Also, each year many distinguished visitors come either to present lectures or remain in residence for large parts of the academic year.

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, stochastic processes, variational methods, applications of group theory, and other related branches of analysis.

Applied Mechanics

Areas of Research

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

Research studies in these areas which illustrate current interests include: linear and nonlinear vibrations, structural dynamics and design for earthquake and blast loads, linear and nonlinear problems in static and dynamic elasticity, plasticity and viscoelasticity, wave propagation in elastic and viscoelastic media, diffraction of elastic waves by cavities and inclusions, boundary layer problems in plates and shells, stratified flow, unsteady cavity flow, oscillatory flow of blood in very small tubes, and the mechanical properties of biological tissues under large deformations.

Research Facilities

In addition to the regular facilities of the Division of Engineering and Applied Science, such as the extensive digital computing facilities of the Computing Center, and the special facilities for studies in solid and fluid mechanics of the Graduate Aeronautical Laboratories, certain special facilities have grown up in connection with applied mechanics activities. The Dynamics Laboratory is equipped with a good selection of modern laboratory apparatus and instrumentation for experimental research in shock and vibration, and the Earthquake Engineering Research Laboratory contains specialized equipment for the analysis of complex transient loading problems, and for the recording and analysis of strong-motion earthquakes. Other specialized laboratories include the Heat Transfer Laboratory which contains a forced convection heat transfer loop, and the Hemorheology Laboratory with equipment for quantitative study of blood flow in living microvessels and related model systems and of the mechanical properties of biological tissues.

Applied Physics

An interdivisional program in applied physics for both undergraduate and graduate study was initiated in 1970. Like applied mathematics, applied physics at Caltech is in a fortunate position: The comparatively small size of Caltech coupled with great strength in both the pure sciences and engineering make it possible to draw on a faculty having wide interest in the application of modern physics to technology, without losing close interaction with "pure subjects." At present, members of four divisions, Engineering and Applied Science, Physics, Mathematics and Astronomy, Chemistry and Chemical Engineering, and Geological and Planetary Sciences, participate in instruction and research in applied physics leading to a B.S. degree as well as to M.S. and Ph.D. degrees.

The program is designed for students who are deeply interested in physics but at the same time are fascinated by the interrelation of physical problems and technological development, i.e., students who like to work with problems in physics which originate from or result in applications. A sharp division between "pure" and "applied" physics or between applied physics and 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 on the study of matter in bulk than the "pure" physicist. Since it is expected that a comparatively large portion of the student body will be interested in experimental research, a special effort has been made to set up challenging laboratory courses.

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

Areas of Research

Research activities cover a broad spectrum, ranging from cryogenics to plasmas, from rarefied gas flow to high pressures and shock waves in solids, from neutron transport to planetary science. There is research in progress in the physics of solids, including solid-state electronics, ferromagnetic materials, quantum electronics, and superconductivity; in the physics of fluids, including plasmas and magnetohydrodynamics, liquids and superfluids; and in the physics of electromagnetic radiation, including linear and nonlinear laser optics and electromagnetic theory.

Astronomy

The astronomical observatories at Palomar, Mount Wilson, Big Bear, and the Owens Valley Radio Observatory together constitute a unique and unprecedented concentration of scientific facilities in astronomy. Outstanding scientific talent is present in various fields of astronomy and in the related fields of physics. The California Institute of Technology recognized the advantages in the creation of a great astronomical center in which a scientific program could be pursued under favorable circumstances, with a variety of instruments, which would also draw young men and women of ability to graduate studies, where they might familiarize themselves with powerful tools of exploration. The joint scientific staff of astronomers at Caltech and at the Carnegie Institution of Washington comprise the Hale Observatories. Caltech owns the Palomar and Big Bear Solar Observatories, and the Carnegie Institution the Mount Wilson Observatory, but the equipment and facilities of both observatories are made available for the astronomical investigations of the combined staff and students. The research program is paralleled by undergraduate and graduate training in astronomy and astrophysics by members of the Institute faculty and Hale Observatories, the Radio Observatory, and the Solar Observatory at Big Bear Lake.

The radio astronomy group works in close collaboration with the optical astronomers in Pasadena; the program of graduate study in the two fields is essentially the same, except for specialized advanced courses. Work in physics and geology is expanding in the field of astronomical research in space and in the ground-based study of the planetary system. There will be close cooperation between these groups and the students and astronomers interested in planetary physics and space science.

As a result of the cooperation possible over a broad range of astronomy, astrophysics, and radio astronomy, unsurpassed opportunities exist at the California Institute for advanced study and research. The instructional program is connected with a broad and thorough preparation in physics, mathematics, and other relevant subjects, as well as instruction in astronomy, solar physics, space and planetary physics, radio astronomy, astrophysics, and observations with large telescopes.

Areas of Research

Both observational and theoretical astrophysics are actively pursued at Caltech. Topics of current interest in optical astronomy include 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.

In addition, active research in infrared and planetary astronomy is done in cooperation with groups in physics and geology.

The research in radio astronomy covers the physical properties of galactic and extragalactic radio sources including quasars, radio galaxies, supernova remnants, pulsars, and the planets. The properties of the interstellar medium in our own and other nearby galaxies are investigated in spectroscopic studies of the 21-cm hydrogen line and various molecular spectral lines.

Theoretical astrophysics is pursued not only in the astronomy department, but in physics and geology as well, and at Caltech includes work on supernovae, pulsars, stellar structure and evolution, stellar atmospheres, interstellar and intergalactic matter, the physics of radio sources, nucleosynthesis, relativity, and cosmology.

Physical Facilities

The Rockefeller Boards provided in 1928 for the construction by the Institute of an astronomical observatory on Palomar Mountain, equipped with a 200-inch reflecting telescope, 48-inch and 18-inch Schmidt wide-angle telescopes, and other auxiliary instruments, together with an astrophysical laboratory on the Institute campus. This observatory is supplemented by the facilities of the Mount Wilson Observatory of the Carnegie Institution of Washington, which, while not a part of Caltech, is located even closer to Pasadena than is Palomar Mountain. Some graduate student thesis research is carried out at Mount Wilson. The increased light-collecting power of the 200-inch telescope permits further studies of the size, structure, and motion of the galactic system; of the distance, motion, radiation, composition, and evolution of the stars; the interstellar gas; the distance, motion, and nature of remote galaxies and quasi-stellar radio sources; and of many phenomena bearing directly on the constitution of matter. The 48-inch Schmidt has made possible a complete survey of the sky, as well as an attack upon such problems as the structure of clusters of galaxies, the luminosity function of galaxies, extended gaseous nebulae, and the stellar content of the Milky Way. These two unique instruments at Palomar supplement each other as well as the telescopes on Mount Wilson; the one reaches as far as possible into space in a given direction, while the other photographs upon a single plate an entire cluster of distant galaxies, or a star cloud in our own galaxy.

A new multi-purpose solar equatorial telescope has been installed at a new observing station at Big Bear Lake. The work of this facility is coordinated with work with the two solar coelostats in Pasadena (20-inch and 36-inch apertures) and the 60-foot and 150-foot towers on Mount Wilson. The unique atmospheric conditions in this area make possible investigations of the fine structure of the solar atmosphere. Emphasis is on high-resolution spectroscopy, magnetography, and cinematography.

A new 60-inch telescope has been completed for photoelectric observations, image-tube spectroscopy and photography at Palomar. An astro-electronics laboratory is continuously developing sophisticated data-handling systems.

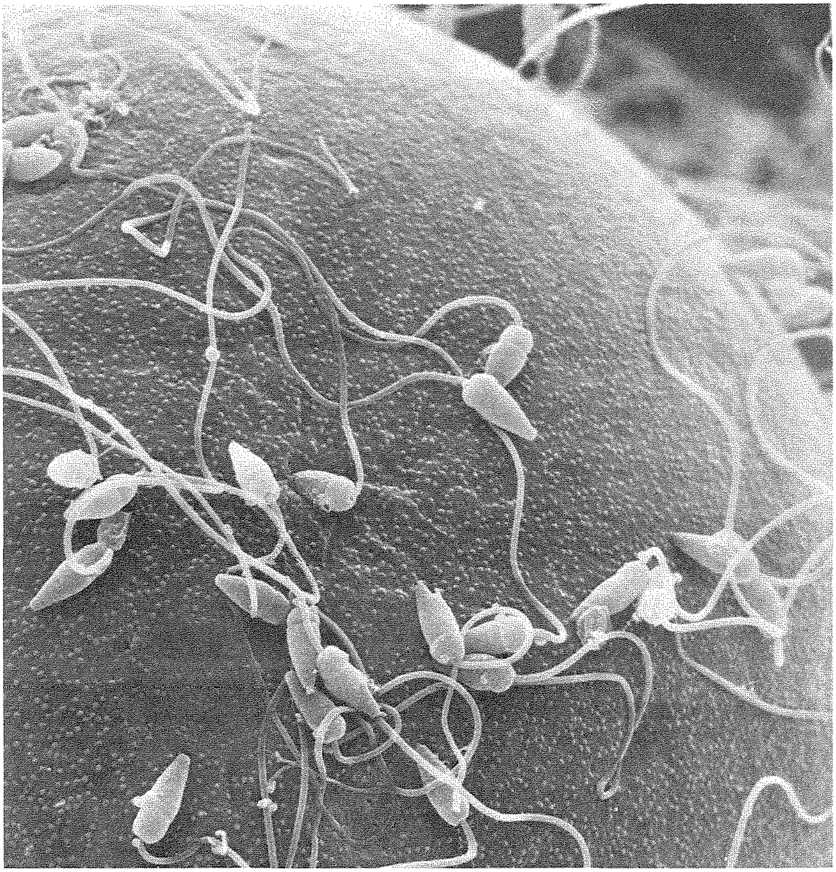
Special apparatus for the far infrared has been fitted to various telescopes to study very cool stars and planets.

The Owens Valley Radio Observatory is in 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. It is expected that two more similar antennas will be 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;



Electron micrograph of sea urchin (Lytechinus) *sperm on the surface of the egg (magnification 5,000 x). Courtesy Professor Jean-Paul Revel.*

and the nature and interactions of nerve activity, brain function, and behavior. Qualified experimental biologists will find opportunities for challenging work in basic research as well as in medicine, agriculture, and the chemical or pharmaceutical industries.

Because of the eminent position of the California Institute of Technology in both the physical and biological sciences and the current expansion of our programs in the study of behavior and experimental psychology, students at the Institute have an unusual opportunity to be introduced to modern biology.

Areas of Research

Research (and graduate work leading to the Ph.D. degree) is chiefly in the following fields: biochemistry, biophysics, cell biology, developmental biology, experimental psychology, genetics, immunology, neurobiology, neurophysiology, psychobiology, and virology. Most of these fields are approached at the molecular as well as higher levels of organization. The disciplines of biochemistry and biophysics encompass the area of molecular biology. There is extensive interaction with related programs in chemical biology within the Division of Chemistry and Chemical Engineering.

The programs in cell and developmental biology are based upon approaches derived from biochemistry, biophysics and genetics which offer new possibilities for expanded insight into long-standing problems.

Neurobiology, experimental psychology, and behavioral biology are receiving increasing emphasis within the Division. A comprehensive program of research 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 level. The constant-temperature equipment includes rooms for the culturing of the Institute's valuable collection of mutant types of Drosophila and Neurospora and complete facilities for tissue culture.

Adjacent to these laboratories is the Campbell Plant Research Laboratory for botanical investigations.

About 50 miles from Pasadena, at Corona del Mar, is the William G. Kerckhoff Marine Laboratory. The building houses several laboratories for teaching and research in marine physiology and developmental biology. It is equipped with its own shop, has boats and tackle for collecting marine animals, and running seawater aquaria for keeping them. The proximity of the marine station to Pasadena makes it possible to supply the biological laboratories with living material for research and teaching. The fauna at Corona del Mar and at nearby Laguna Beach is exceptionally rich and varied, and is easily accessible.

The Biological Systems Laboratory in the Booth Computing Center houses the joint research program of the biology and engineering divisions dealing with data processing systems and systems theory as they relate to the nervous system and sensory perception.

Chemical Engineering

The research and teaching interests of the chemical engineering faculty are directed towards 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, and the behavior of materials under conditions of unusual temperature and pressure. There is strong emphasis on the fundamentals of heterogeneous catalysis and their applications 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 biomedical engineering, air pollution, fluid mechanics, liquid-state physics, polymers, plasma chemistry, energy conversion and combustion, heterogeneous catalysis and surface chemistry, solid-state chemistry, optimal control and estimation theory, and the physics and chemistry of two-phase systems.

1. Energy: Coal conversion to synthetic fuels by pyrolysis and gasification. Coal and fuel oil desulfurization by selective oxidation. Petroleum reservoir engineering and recovery methods.
2. 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. Design of novel gas cleaning systems. Chemistry and particulate mechanics in flowing water systems.
3. Polymers: Mechanical and ultimate properties of filled elastomers, block copolymers and dialysis membranes. Behavior of elastomers under pressure. Physics of elastomer networks.
4. Biomedical: Transport in tissues, artificial organs, and the cardiovascular system. Pulmonary bioengineering. Gas sterilization.
5. Heterogeneous catalysis and surface chemistry: Adsorption and catalytic reactions on well-characterized surfaces utilizing low-energy electron diffraction, Auger-electron spectroscopy, x-ray and uv-photoelectron spectroscopies, inelastic electron-tunneling spectroscopy, and mass spectroscopy. Theoretical modeling of solids, solid surfaces, and gas-surface interactions.
6. Solid-state and surface chemistry: Investigations using multiple-pulsed nuclear magnetic resonance techniques. Studies of effects of high pressure on chemical and electronic properties.
7. Liquid-state physics: Studies of forces and configurations at the molecular level in simple systems. Determination of structure by x-ray diffraction. Other studies of local order by optical, magnetic, and ultrasonic experiments. Statistical mechanics.
8. Plasma chemistry and engineering: Diffusion. Homogeneous and heterogeneous reactions.
9. Fluid mechanics: Rheology and transport properties of suspensions and emulsions. Mechanics of non-Newtonian fluids. Mass transfer from bubbles and drops. Numerical simulation of fluid motion.
10. Optimal control and estimation theory with applications to chemical reactors and to petroleum reservoir engineering.

Physical Facilities

Chemical engineering is primarily 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, and biochemical and biophysical chemistry. Active interaction exists between chemistry and other disciplines at Caltech, especially 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.

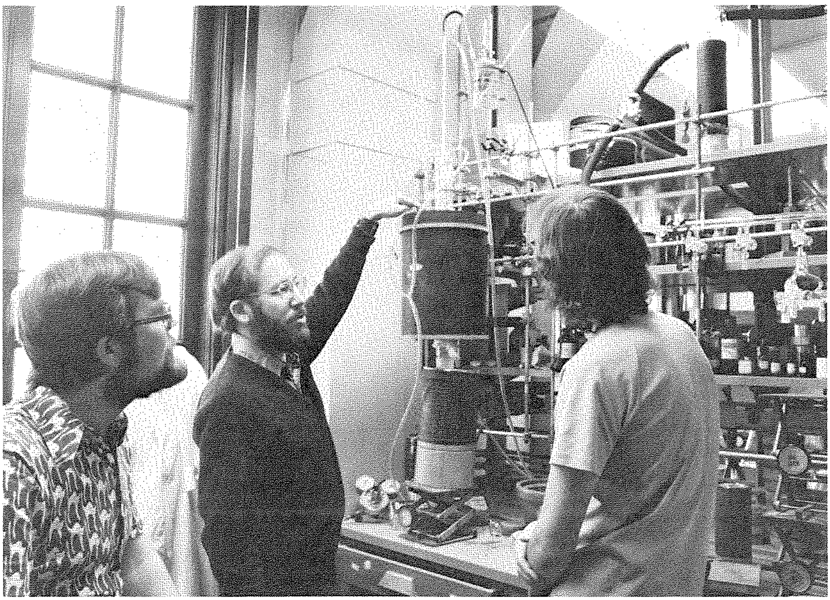
Areas of Research

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, 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, both in 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 in both 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, and nitrogen fixation. Micellar catalysis as well as 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 as well as systematic characterization of 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

Professor Robert G. Bergman and two members of his research group discuss techniques for studying the high-temperature reactions of organic compounds.



molecules required for the testing of structural theories, as well as efforts directed at the development of new, synthetically useful chemical reactions.

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, as well as 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 effort 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 being developed towards facilitating detailed understanding of reacting systems.

Physical Facilities

The laboratories of chemistry consist of four units providing space for about 225 graduate students and postdoctoral research fellows. Crellin Laboratory and an adjoining annex house several research groups and the divisional administrative offices. The Norman W. Church Laboratory for Chemical Biology is shared with the Division of Biology. The Arthur Amos Noyes Laboratory of Chemical Physics is the largest of the chemistry 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. It deals with the function and safety of such public facilities as buildings, bridges, pipelines, dams, rivers, power plants, and harbors; and is concerned with the protection of the public against natural hazards of earthquakes, winds, floods, landslides, water waves, and fires.

Advances of recent years in technology and the escalation of urban problems have broadened the applications of civil engineering and increased the scope of research in that field. New problems have presented special challenges to the civil engineer well trained in the fundamentals of his profession. For this reason, in the advanced study of civil engineering at the Institute, emphasis is placed on the application of basic scientific principles and mathematics to the solution of engineering problems.

Areas of Research

Graduate work leading to advanced degrees is chiefly in the following fields: structural engineering and applied mechanics; earthquake engineering; soil mechanics and foundation engineering; hydraulics, which includes hydrodynamics, hydraulic engineering, hydrology and coastal engineering; and environmental engineering (see also Environmental Engineering Science). In recent years, graduate students and members of the staff have pursued a variety of research programs including analysis of structures subjected to earthquakes and other dynamic loadings; the use of digital computers for structural analysis; soil deformation under stress; lunar soils studies; permafrost; investigation of laws of sediment transportation and dispersion in bodies of water; turbulent mixing in density stratified flows; wave-induced harbor oscillations; tsunamis; design criteria for various hydraulic structures; aerosol filtration; radioactive waste disposal; water reclamation; and ocean outfalls for thermal discharges or sewage effluents.

Students whose interests are in environmental problems may enroll for graduate degrees in either civil engineering or environmental engineering science.

Physical Facilities

Civil engineering activities are housed in two buildings, the Franklin Thomas Laboratory which contains the soil mechanics laboratory, the earthquake engineering laboratory, and 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.

Electrical Engineering

Electrical engineering at the Institute comprises physical electronics, electronic circuits, and communication. Closely allied with the applied physics option, it offers students the opportunity for study in the more technological aspects of a wide variety of subjects including plasma dynamics, electromagnetic radiation, quantum electronics, modern optics, new solid-state materials and devices, 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. The transport of charge carriers in semiconductors is studied by experiments on single injection, double injection, Hall effect and noise, with particular attention given to very high purity germanium and silicon. Another field of study is the formation of contacts to semiconductors. Closely related to this effort are investigations on the metallurgy of thin evaporated layers, using conventional tools and experimentation as well as ion implantation and ion backscattering. The properties, limitations, and ranges of application of these two techniques are the subject of additional investigations performed in part at the 3 MeV Van de Graaff accelerator in the Kellogg Radiation Laboratory.

The Quantum Electronics Laboratory is engaged in research in the area of generation and control of coherent radiation and in the study of related physical phenomena. Research projects now in progress include: super-radiance in extremely high gain lasers, generation and control of ultrashort pulses, tunable optical parametric oscillation, integrated optical circuits, injection lasers, nonlinear optics, infrared fluorescence applied to pollution monitoring, speckle, optical data processing, pattern recognition, and holography. Up-to-date facilities for carrying out these experiments are available.

Research in the Magnetics Laboratory involves studies of the dynamic processes in magnetic materials that are important to the modern digital computer devices. Imaging of the dynamic domain structures in "magnetic bubble" garnet material using high speed photographic methods pioneered in this laboratory have provided a new dimension to the understanding of bubble dynamics. Investigations of the transient shape of bubbles translating, expanding, and collapsing, as well as their wall structure, are performed using a laser illuminated sampling optical microscope. Ferromagnetic resonance and fast reversal studies in thin films of ferromagnetic metals and garnets are used to explore surface pinning 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 Energy Processing Laboratory deals with modern problems in analysis, design, and synthesis of electronic circuits as applied to conversion, control and regulation of electric energy. Applications of new and current devices and analysis techniques for a better understanding of existing devices are emphasized. Projects now in progress include analysis and design of multiple-loop power converters, and optimization of pulse-width controlled regulators.

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 and hearing.

Energy

Tomorrow's energy will be provided through engineering advances on many fronts. Caltech scientists and Caltech engineers — and their students — will be instrumental in many of them. Already under way are projects in better fuels, in cleaner, more efficient combustion, in low-drag cars and trucks, in geothermal energy, in improving air quality, in gas lasers and in fusion, in windmills, in solar cells that are affordable, in power plants and structures that are immune to earthquakes, and in environmental protection that is engineered — that leaves nothing to chance.

Energy at Caltech is broader than any one division. Exciting energy-related projects and programs of instruction are to be found within each of the Divisions of Engineering and Applied Science, Chemistry and Chemical Engineering, and Geological and Planetary Sciences, where the scientific and technological ingredients are most active. The problems of conventional and novel power stations, automotive engines, nuclear and fusion power are covered widely within the Division of Engineering and Applied Science, where the fundamentals of fluid dynamics, combustion, heat transfer, materials science, and electromagnetism have been highly developed. Graduate programs in these areas are described further on page 228, and suggested undergraduate preparation on page 186. The technology of coal gasification, fuel desulfurization, production of particulates, and trace pollutants is an active concern of the Division of Chemistry and Chemical Engineering, and is described further on pages 177, 179, 217, and 219, while the fundamentals of earth resources and geothermal energy are pursued in the Division of Geological and Planetary Sciences, and are described on pages 126 and 236. Investigations in conversion, control, and regulation of electric energy are conducted in the Energy Processing Laboratory.

This broad academic and research activity offers the student an extensive selection of formal course work and access to a large number of growing and productive research centers.

Engineering Science

Advanced programs of study leading to the degree of Master of Science and Doctor of Philosophy in Engineering Science are offered by the Division of Engineering and Applied Science. The need for these programs has developed as the traditional 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 which underlie the current development of technology. Its scope contains a broad range of subjects. Fields of study may include such topics as fluid mechanics with applications to geophysical and biomechanical problems, physics of fluids, structure and properties of solids, dynamics of deformable solids, rheology of biological fluids, 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.

Computer Science

Areas of Research

Computer science at Caltech spans a range from computer hardware design to the theory of computation, including software design and analysis, theory of algorithms, operating systems, computer languages, information retrieval, mathematical linguistics, graphics and man-machine interaction. Students participate in projects involving design and testing of digital integrated circuits, assembly of them into computer systems, design and writing of system software and problems of application programming. We are particularly interested in the freedoms and limitations imposed on computer system designers by their ability to express themselves in precise computer languages and by the existing and projected properties of digital integrated systems.

Bioinformation Systems

Areas of Research

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

Therefore, this program, in addition to extensive research on animals ranging from 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 are 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 which serve both the research and educational needs of the discipline. Of particular importance is a specially equipped computer interactive classroom and student laboratory for both research on man-machine interactions and computer interactive education and for direct applications to education.

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, circulatory dynamics and hydromechanics 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.

Circulatory Dynamics. Studies on blood flow in microscopic blood vessels as well as transport and exchange of substances from the blood to the surrounding tissue are carried out in the Laboratory of Hemorheology and Microcirculation. State-of-the-art methods for quantitative study of molecular transport from the microcirculation to the surrounding tissue have been developed and are being used to study basic mechanisms, the effect of pharmacologic agents, and certain diseases on such transport processes. Close collaboration is maintained with nearby medical research groups.

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 subject of intracellular movements, diffusion of macromolecules, transport of muco-ciliary 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 optics), a high-speed-cine-photomicrographic facility, and an automatic image processing unit for quantitative measurements of flows about moving micro-organisms. 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. Further geophysical interests in this area contain various studies of rotating and stratified flows.

Environmental Engineering Science

This interdisciplinary graduate program is concerned with protection and control of man's environment. Research and instruction stress basic studies which aim to answer such questions as: How can we improve the air quality in the great basins in which lie our urban and industrial centers? How can we insure 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; biomedical transport processes; 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 bacteria by polymers; gas-to-particle conversion processes in urban atmospheres; oceanic farming as a potential energy source; kinetics of sulfide oxidations in aqueous solutions; dilution of turbulent jets; natural temperature variations in coastal waters; and fine particulate formation in combustion.

Physical Facilities

The facilities in the W. M. Keck Laboratory of Environmental Health Engineering include the modern instrumentation used in air and water pollution analyses. The Air Quality Laboratory is a specially designed facility located on the roof of the Keck Laboratory and is equipped with a 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 is 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), carbon 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: flumes for studies in diffusion, turbulence, sediment transport, and stratified flow; a wave tank and wave basin; water tunnel; and outfall model basin.

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 (EQL) is an interdisciplinary center for the study of policy questions of environmental protection and control. 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, the faculty and students who participate in EQL activities are also associated with the appropriate academic divisions. EQL research projects are often closely related to individual research activities in the academic divisions, and seek to provide the framework for a comprehensive view of environmental control problems and alternative solutions.

Environmental policy questions frequently involve the tradeoffs among diverse impacts on all environmental media (air, water and land) and society's needs and resources. The siting of a power plant or a refinery is one example; another is the final disposal of residuals (such as sewage sludge). Furthermore, some pollutants, such as heavy metals, have pathways through several media, and cannot be understood or controlled without considering the environment as a whole. In order to understand these interactions, EQL works on a range of problems covering air, water and land resources.

Areas of current or recent work include:

(a) *Environmental impacts of energy systems* (geothermal energy; alternative automobile engines; electric vehicles; energy conservation; freight traffic misallocation due to regulation).

(b) *Air pollution control strategies for the South Coast Air Basin of California* (sulfates; oxidants; numerical modeling; regulatory and legislative alternatives).

(c) *Water resources management and water pollution control* (sediment management for streams and coastlines in Southern California; uses of the Colorado River; regulation of thermal discharges from power plants).

(d) *Regulation of hazardous materials* (decision-making in the face of strong uncertainties; disposal of radioactive wastes).

(e) *Options for residuals disposal and recycling.*

Students who desire to work in EQL apply through an appropriate degree program, such as Environmental Engineering Science, Social Science, Chemical Engineering, or Geological Sciences.

Geological and Planetary Sciences

In the Division of Geological and Planetary Sciences, study of the earth and planets is pursued with the aim of understanding their origin, constitution, and development, and the impact of the resulting physical and chemical environments on the history of life, and on man. The approach to these problems is made with strong reliance on the basic sciences; close contact and interaction with the other divisions of the Institute is cultivated. Programs of study and research are pursued in geology, geobiology, geochemistry, geophysics, and planetary science.

The geographical position and geologic setting of the Institute are favorable for year-round field access to a wide variety of earth problems and materials. Current advances in understanding the dynamic motions of the earth's crust and the structure of the interior have opened up new opportunities for research into the processes responsible for the earth's development and activity. Seismic activity in the southern California area presents stimulus and research material for the study of earthquakes, which are of great practical concern and are intimately related to the earth's development on a global scale. Human records of seismic activity are put into long-term perspective by studies of surface and bedrock geology, which reveal the history of motion on fault systems. Major events in the chemical and physical evolution of the earth can be identified by studying the structure and chemistry of rocks formed or modified in these events, and their absolute chronology can be established by measurements of radioactive isotopes. Stable isotopes can indicate the temperature conditions both of deep-seated events and of the habitat of ancient life, whose chemical and structural evolution responded to the changing environment provided by the developing earth. The earliest history of the earth can be approached via the history of the moon, which is being revealed by studies of lunar samples obtained in the Apollo missions. Further breadth in our understanding of the earth and its place in the cosmos is being gained by comparative study of the other planets — their atmospheres, surfaces, and internal structures.

Professor of Geology and Geophysics Gerald Wasserburg demonstrates the technique for picking up a tiny piece of moon rock, breathing out of the side of his mouth so he won't blow it away. The containers in the picture, placed one inside the other for protection, held a small portion of a rock sample taken by the Soviet Luna 20 mission in 1972, and given to Caltech's "Lunatic Asylum" for study and analysis.

Physical Facilities

The Arms and Mudd Laboratories are modern five-story buildings specifically designed for instruction and laboratory research in geology and geochemistry. They also house the division library; paleontologic, rock, and mineral collections; spectrographic, x-ray and electron microprobe facilities, and other facilities required for comprehensive studies in the earth sciences. Extensive facilities are available for the application of techniques of nuclear chemistry to problems in the earth sciences. These facilities include chemical laboratories for trace-element studies and mass spectrometric and counting facilities for isotopic work. Available equipment includes mass spectrometers, emission counters, and extensive mineral separation facilities, in addition to the usual geological and chemical items.

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

Favorable opportunity for study of dynamic aspects of paleontology and evolution as revealed by morphology, ecology, and biogeochemistry is provided by the combination of personnel, reference collections, and modern geochemical tools and techniques. Biologic principles and processes, past and present, of significance to geology may be interpreted from experimentation and studies at the Kerckhoff Marine Laboratory at Corona del Mar, operated under the auspices of the Division of Biology.

The Seeley G. Mudd Building of Geophysics and Planetary Science has just been completed on the campus adjacent to the Arms and Mudd Laboratories. It 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 seventeen 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 heat flow in geological materials and 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.

Optical and infrared observations of the moon and planets are being carried out at the Hale Observatories; special, moderate-sized telescopes designed specifically for planetary work are available. A wealth of photographic information on the surface of Mars and Mercury is available from the Mariner missions. Radio and radar observations of the planets are made at the Owens Valley Radio Observatory and the JPL radar facility.

The Humanities and Social Sciences

Throughout its history the Institute has placed a strong emphasis upon the humanities as an important and necessary part of the education of scientists and engineers. In recent years increased attention has been paid to the social sciences. At the undergraduate level all students are required to devote a substantial portion (between one-fifth and one-fourth) of their curriculum to humanistic and social science studies. These studies are normally undertaken in regular courses, but a limited number of interested students may be permitted after their freshman year to enter a tutorial program involving instruction on a one-to-one basis.

The Institute offers undergraduate options in literature, history, economics, and social science leading to the B.S. degree. Students electing one of these options will take the regular courses prescribed for all freshmen in their first year and the required courses in mathematics and physics in the sophomore year. In the last two years, students in these options will take further work in science, mathematics, or engineering courses as well as the advanced work in their humanities or social science option.

At the graduate level, the Division of the Humanities and Social Sciences offers a Ph.D. and M.S. program in social science. Humanities courses are required for the Master of Science degree in civil engineering and astronomy, and are recommended in other options. At the doctoral level, a Ph.D. minor may be taken in economics, philosophy, history, or English, with a Ph.D. major in any branch of science or engineering.

The purpose of the humanities and social science options at Caltech is to produce a special kind of student — one who has an exceptionally strong background in science or engineering, yet who is well prepared for graduate work in humanities and social science, professional schools, business, or government service.

Dabney Hall of the Humanities was given to the Institute in 1928 by Mr. and Mrs. Joseph B. Dabney. At the same time a special fund of $400,000 for the support of instruction in humanistic fields was subscribed by several friends of the Institute. In 1937 Mr. Edward S. Harkness gave the Institute an additional endowment of $750,000 for the same purpose.

In April 1971, the division moved most of its activities to the Donald E. Baxter, M.D., Hall of the Humanities and Social Sciences, a gift of Mrs. Donald E. Baxter.

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

Independent Studies Program

Independent Studies is an educational alternative for undergraduates whose goals cannot be satisfied within 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 192)

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; 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 containing the books and periodicals most frequently consulted by the students and faculty. The main mathematics library with its outstanding collection of journals is housed nearby in the Robert A. Millikan Memorial Library.

The Willis H. Booth Computing Center central computing facility described on page 109 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 which have to do with fluid flow, heat and mass transport, combustion, power, propulsion, structural integrity, mechanical design, optimization, and systems analysis. Projects in which mechanical engineers play a large role include the space missions, nuclear and fossil-fuel power plants, transportation systems, airplane propulsion engines, and low-pollution vehicles. At the Institute, many of the basic disciplines are offered which are required for applications such as the above. They are described in the following paragraphs under the headings of Design, Mechanics, Thermal and Fluids Engineering, Nuclear Energy, and Jet Propulsion.

Design

Engineering design is regarded as an interdisciplinary activity providing an opportunity for putting theory into practice and bringing together on a common ground some of the more specialized branches of engineering. Emphasis is placed on the imaginative practical approach in the solution of real problems involving various disciplines. System design in the broad sense, automatic control, problem modeling, and the appropriate use of analog and digital techniques in optimization are general areas of interest.

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 those working in the design area at the Jet Propulsion Laboratory, as well as those in industry, is maintained through seminars, visits, and a free exchange of ideas on current design problems.

Mechanics

Studies in the broad field of mechanics may be undertaken in either the Applied Mechanics option or the Mechanical Engineering option. In general, work pursued within the Mechanical Engineering option will have a more physical orientation. The specific areas available for advanced study closely parallel the research interests of the faculty and presently include: linear and nonlinear problems in static and dynamic elasticity, plasticity and viscoelasticity, wave propagation in solids, load transfer problems, modeling of dynamic systems, linear and nonlinear vibrations, random vibrations, stability, structural dynamics, and design for earthquake loads.

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, granular media, and fluids near the critical point as well as studies in cavitation, fluid machines, 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 which 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 of instruction includes appropriate material from both these fields as well as courses specifically concerned with propulsion problems. The experimental facilities of the Jet Propulsion Center are located in the Karman Laboratory of Fluid Mechanics and Jet Propulsion. Some of the special facilities of the Jet Propulsion Laboratory have also been utilized 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. The experimental high-energy physics group performs various types of elementary particle experiments at the major accelerator centers. At present three experimental programs are in progress at the Fermi National Accelerator Laboratory near Chicago: one to study neutrino interactions at high energies, another to measure pion charge-exchange scattering and other related reactions, and a third developing and using a multiparticle spectrometer to investigate quasi-two-body and multiparticle reactions. Other experiments are planned or under way at the Stanford Linear Accelerator Center, one a second multiparticle spectrometer program, and the other the preparation of a major detector for use in studying neutral particles emitted in e^+e^- reactions in the colliding beam storage ring SPEAR.

A phenomenology group is studying the systematics of elementary particle reactions and their theoretical interpretations. It also collaborates closely with the experimentalists in the above program.

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. The 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.

Nuclear Structure at Intermediate Energies. This laboratory is engaged in the study of problems in nuclear and atomic structure. Tests of the space and time symmetries of the

Professor of Physics Gordon P. Garmire examines an x-ray telescope with the largest mirror of its kind. The mirror is being polished at Caltech. The x-ray telescope will be flown above the earth's atmosphere on a sounding rocket. There it will study binary x-ray stars and clusters of galaxies.

nuclear forces are conducted with the use of nuclear orientation at cryogenic temperatures. Experiments with muonic and pionic atoms are being conducted at the Los Alamos Meson Physics Facility.

Space Physics. There is an active observational program in infrared, x-ray, and gamma-ray astronomy. The astrophysical aspects of cosmic radiation are investigated with detectors flown in balloons and in spacecraft, and a variety of related theoretical problems are being studied. Observational and theoretical studies of magnetic fields, velocity fields, and active regions on the sun are carried out. Planetary and interplanetary magnetic fields are being studied with data from magnetometers carried by spacecraft.

Low Temperature. 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 10-meter antenna and receivers for millimeter waves are under construction.

Theoretical Physics. The principal areas under theoretical investigation are the nature of elementary particles and their high-energy interactions, various problems in the area of general relativity and cosmology, the physics of the interplanetary and interstellar media, the origin and transport of cosmic rays, problems of stellar structure and stellar evolution, the synthesis of elements in stars, and the nature of quasi-stellar radio sources and pulsars.

Physical Facilities

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

Undergraduate Research

Each division offers the opportunity for qualified students early in their careers to engage in research under the supervision of a faculty member. Most options offer undergraduate research courses in order to encourage participation in research, and students should consult listings and descriptions of research opportunities given by the various options. Students are encouraged to undertake research of such scope and caliber as to merit the preparation of a Bachelor's Thesis. In most cases, a minimum of 54 units, distributed over at least four terms, counting the summer months as a term, is required of students preparing a Bachelor's Thesis. With the approval of the faculty, graduation "with honor" may be granted a student on the basis of a meritorious Bachelor's Thesis or its equivalent.

Members of the Caltech soccer team work out on their home field.

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 elective officers, and has wide power to arrange its own social events and preserve its own traditions. The immediate supervision of the activities of each house is the responsibility of the house Resident Associate, generally a graduate student or younger faculty member. All houses are under the general supervision and control of a member of the faculty known as the Master of Student Houses.

Entering freshmen will receive housing contracts from the Master of Student Houses Office in June.

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. There is representation of each of the undergraduate houses on the Interhouse Committee, which determines matters of general policy for all seven houses. While each sponsors independent activities, there is at least one joint dance held each year. The program of intramural sports is also carried on jointly. At present it includes football, softball, swimming, basketball, tennis, track, and volleyball.

Interhouse Scholarship Trophy. A trophy for annual competition in scholarship among the seven student houses has been provided by an anonymous donor. With the approval of the donor the trophy has been designated as a memorial to the late Colonel E. Goldsworthy, who was Master of Student Houses, and it commemorates his interest and efforts in the field of undergraduate scholarship.

Faculty-Student Relations. Faculty-student coordination and cooperation with regard to campus affairs is secured through the presence of students on faculty committees and by means of other less formal mechanisms.

Freshman Advisers. Each member of the freshman class is assigned to a faculty adviser. The adviser interests himself in the freshman's progress and provides advice on any questions or problems which the freshman may have.

Option Advisers. Each member of the three undergraduate upper classes is assigned to an option adviser, a faculty member in the option in which the student is enrolled. The adviser interests himself in the student's selection of optional courses, progress toward 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.

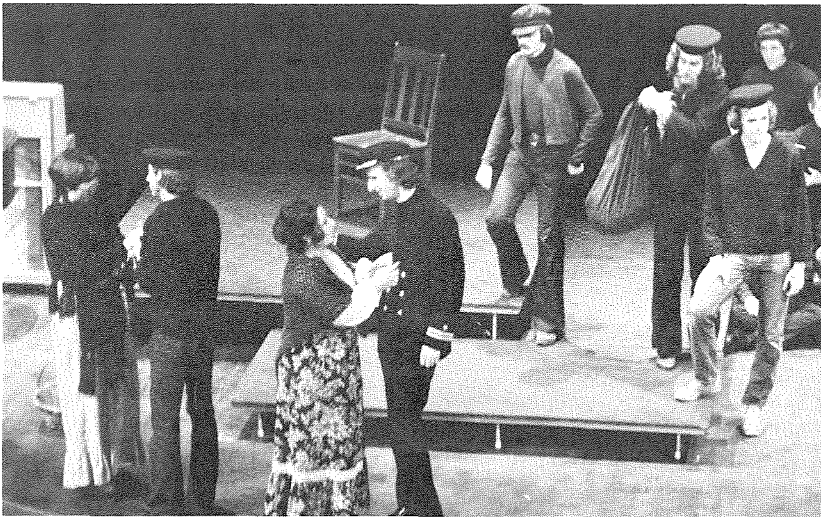
Athletics. The California Institute maintains a well-rounded program of athletics and, as a member of the Southern California Intercollegiate Athletic Conference, schedules contests in nine sports with the other members of the Conference — Occidental, Pomona, Redlands, Whittier, and Claremont-Harvey Mudd — as well as many other neighboring colleges. In addition, the Caltech Sailing Club sails a fleet of Institute dinghies based at Los Angeles Harbor.

The California Institute Athletic Field of approximately 23 acres includes a football field, a standard track, a baseball field, and championship tennis courts. The Scott Brown Gymnasium and the Alumni Swimming Pool provide attractive modern facilities for intercollegiate, intramural, or recreational competition in badminton, basketball, volleyball, swimming, and water polo. Funds for the pool were contributed by the alumni of the California Institute; construction of the gymnasium was made possible through a bequest of Scott Brown.

The Institute sponsors an increasingly important program of intramural athletics. There is spirited competition among the seven houses for the possession of the three trophies. The Interhouse Trophy is awarded annually to the group securing the greatest number of points in intramural competition during the year. The Varsity and Freshman Rating Trophy is presented to the group having the greatest number of students participating in intercollegiate athletics. The third trophy, "Discobolus," is a bronze replica of Myron's famous statue of the discus thrower. It is a challenge trophy, subject to competition in any sport, and it remains in the possession of one group only so long as that group can defeat the challengers from other groups.

ASCIT. Despite the outward appearance on campus of political quiescence, the student body government (officially known as the "Associated Students of the California Institute of Technology, Inc.," or "ASCIT") plays a significant role in bringing change to campus life. Some of ASCIT's more notable and recent efforts brought about the student-directed (and smog-oriented) ASCIT Research Project, the student-run coffeehouse (which provides a respite from the pressures of Caltech), and student representation on faculty committees. It should be noted that few student governments are superior to ASCIT in their working relationship with faculty and administration.

A member of the corporation (i.e., a dues-paying student-body member) is entitled to participate fully in campus politics: to vote, to lobby, and to hold corporate office.



The 1976 Glee Club Home Concert was an all-American program in honor of the nation's bicentennial. The first half included performances by the men's and women's sections of the Glee Club, as well as by the Apollo Singers (a small men's group), a barbershop quartet, and the Chamber Singers, a select group of mixed voices. The photograph above is a scene from the second half, a staged version of a delightful folk opera, "The Lowland Sea."

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

Honor System. The Honor System is the fundamental principle of conduct for all students. More than merely a code applying to conduct in examinations, it extends to all phases of campus life. It is the code of behavior governing all scholastic and many extracurricular activities, relations among students, and relations between students and faculty. The Honor System is the outstanding tradition of the student body, which accepts full responsibility for its operation. The Board of Control, which is composed of elected representatives from each of the seven houses, is charged with interpreting the Honor System for undergraduates, while the Graduate Review Board performs the same function for graduate students. If any violations should occur, the appropriate board investigates them and recommends disciplinary measures to the deans.

Student Body Publications. The publications of the student body include a weekly paper, the *California Tech;* an annual; a literary magazine; and a student handbook, which gives a survey of student activities and organizations and serves as a campus directory. These publications are staffed entirely by students. Through them ample opportunity is provided for any student who is interested in obtaining valuable experience not only in creative writing, 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, and a chamber orchestra. A series of chamber music concerts is given on Sunday evenings in the lounge of Dabney Hall. There are other musical programs in Beckman and Ramo Auditoriums. The Musicale is an organization which encourages interest in and appreciation for classical recordings.

Student Societies and Clubs. There are at the Institute over seventy societies and clubs covering a range wide enough to satisfy the most varied interests. The American Chemical Society, the American Institute of Chemical Engineers, and the American Society of Mechanical Engineers all maintain active student branches.

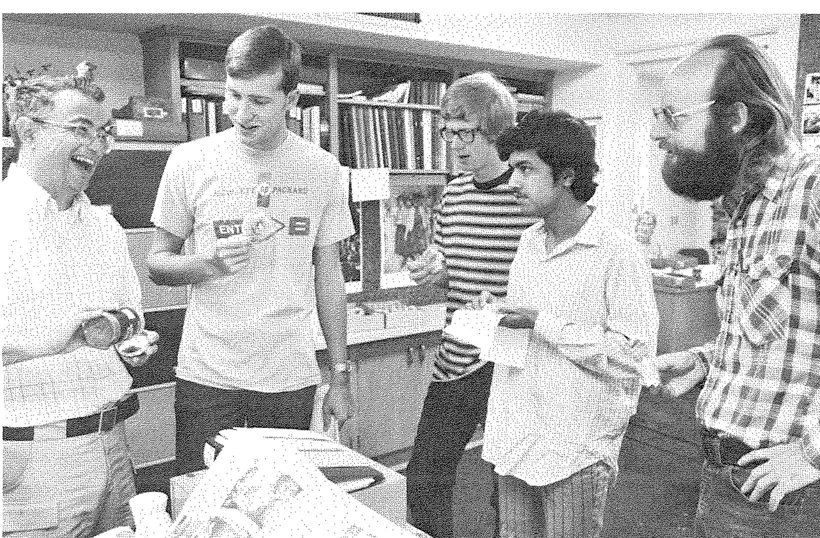
The Institute has a chapter (California Beta) of Tau Beta Pi, the national scholarship honor society of engineering colleges. Each year the Tau Beta Pi chapter elects to membership students from the highest ranking eighth of the junior class and the highest fifth of the senior class.

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. The Caltech Y is one of the major centers of campus activities. The range of programs planned by students and faculty through the Y includes discussion and action programs on social and political issues, educational programs on international problems, personal growth experiences, community services projects, and social events. These programs take the form of guest speakers, Olive Walk talks, retreats and conferences, student house discussions, courses and study groups, dinner in faculty homes, trips, workshops, and work projects. In addition, the Y provides several campus services

Students and faculty gather in the office of James Mayer, Professor of Electrical Engineering and Master of Student Houses, left, for the Master's Doughnut Hour, an informal drop-in event available to all students each Friday.



including a used-book exchange, an emergency loan fund, a record library, and individual and group support services to students and student organizations.

Public Events. Beckman and Ramo Auditoriums serve as the home of the professional performing arts program on the Caltech campus. Each year, over 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 Student Body Musical, the Caltech Glee Club Christmas and Spring Concerts, and the Caltech Wind Ensemble Hunter Mead Memorial Concert. Student tickets, often providing discounts of more than 50 percent, are available 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. Prior to initial registration, each applicant is required to submit a Report of Medical History and Physical Examination on a form which will be sent at the time of notification of admission. Students who have been on leave of absence 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 emergency care, on-the-job injuries and inoculations.)

During the summer, a special health fee of $35 is charged to student trainees and 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 an annual fee of $65, in a plan which 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 student services, facilities, programs, and activities are administered, in a nondiscriminatory manner without regard to race, religion, color, sex, or national or ethnic origin, and fully in accordance with the existing laws and regulations, including Title IX of the Education Amendments of 1972, which specifically prohibits discrimination on the basis of sex.

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 — apppointed, 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 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 1975 of the future plans of those students who had graduated at the commencement ceremony June 13, 1975.

Of those receiving the B.S. degree, about whom we have definite information, 66% had been accepted for admission to graduate school for further education, 15% had accepted employment, 1% were in military service, and 18% were still seeking employment or graduate school admission. The median salary of those accepting employment was $1,000 per month. At the M.S. level, 56% were continuing in graduate school, 36% were employed at a median salary of $1,300, 3% were in military, and 5% were still seeking. Of those receiving the Ph.D. degree, 1% were continuing in school, 92% were employed at a median salary of $1,650 per month, 4% were in military service, and 3% were still looking.

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 students retain all rights in inventions made by them 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 students with the use of Institute facilities are to be retained by the students.
3. The student agrees 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. The student agrees 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 which 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, William P. Schaefer, is responsible for maintaining all of these records, except for those involving Financial Aid. They are available to Dr. Schaefer, 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 William P. Schaefer, Director of Financial Aid, and are available to him and his staff, to the Dean of Graduate Studies and his 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 which 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 the Dean of Graduate Studies or their deputies, as appropriate. A mutually covenient 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 alter-

An intent student sends a message using equipment owned by Caltech's Amateur Radio Club – Station W6UE, one of the oldest groups of its kind in Southern California. The club is one of many that tie in with members' technical interests and abilities.

nates, 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, 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 home town and 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.

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 220 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. 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. No application will be considered until this fee is paid. 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.

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, for which see page 146.)

Transcripts of records covering three years of high school should be submitted as soon as possible following the application. Students should arrange for a supplementary 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 Test must be taken, and that the choice lies only among Physics, Chemistry, Biology, and English — of which two must be taken. No substitution of other tests can be permitted. 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.* No exception can be made to the rule that all applicants must take these tests.

Full information regarding the examinations of the College Entrance Examination Board is contained in the *Bulletin of Information* which may be obtained without charge at most high schools, or by writing to the appropriate address given below. The tests are given at a large number of centers, but if any applicant is located more than 75 miles from a test center, he can make special arrangements to take the tests nearer home.

Applicants who wish to take the examinations in the western United States or Canada, or in Mexico, Australia, or the Pacific Islands should address their inquiries by mail to College Entrance Examination Board, P.O. Box 1025, Berkeley, California 94701. Check the *Bulletin of Information* for the exact dividing line.

Candidates applying for examination in other areas should write to College Entrance Examination Board, P.O. Box 592, Princeton, New Jersey 08540.

All applications to take examinations in the United States should reach the appropriate office of the Board at least four weeks in advance of the test date. Examinations to be taken abroad need to arrive at least six weeks in advance. Please note that requests to take the examinations and all questions referring exclusively to the examinations are to be sent to the College Entrance Examination Board at the appropriate address as given above and not to the California Institute.

Personal Interviews and Recommendation Forms

Accompanying the Institute's acknowledgment of receipt of the application form will be 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; but if a personal interview cannot be held, this in no way prejudices an applicant's chances of admission. The applicant has no responsibility with regard to the personal interview unless and until 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 applicant 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. Checks or money orders should be made payable to the California Institute of Technology.

Deferral of Entrance

The Institute will consider requests from newly admitted freshmen for a year's deferral of entrance for such purposes as studying abroad, working, or maturing. It is possible that not all requests will be granted: the seriousness and appropriateness of the purpose and the number of requests received will be determining factors.

Students who wish to request a year's deferral of entrance must (1) pay the registration fee by May 1 in the normal manner; (2) make a written request stating the purpose of postponement and the plans for using the extra year.

Early Decision Plan

The Institute will consider a few outstanding candidates who wish to make the California Institute their first choice under an early decision plan. Such candidates must have taken the required College Board tests by the end of their junior year or at the following 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 a scholarship, 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 which are taught at the college level and cover the material of a college course. The College Entrance Examination Board gives each year in May a set of Advanced Placement examinations covering this advanced work. The regulations governing Advanced Placement at the California Institute in the subjects concerned are as follows:

Chemistry. Students with a particularly strong background in chemistry may elect to take Chemistry 2, Advanced Placement in Chemistry (or, in exceptional cases, Chemistry 41, Chemistry of Covalent Compounds), rather than Chemistry I, General and Quantitative Chemistry. It is assumed that such students have reasonable competence in the following areas: 1) *elementary* theories of atomic structure and electronic theories of valence, 2) chemical stoichiometry, and 3) computations based upon equilibrium relationships. Admission to Chemistry 2 is based on an interview with the instructor.

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

Literature and History. Students who score high in advanced placement literature or history may be excused from freshman humanities if the Division of the Humanities and Social Sciences rules favorably upon their examination papers. Such students, if an excuse has been granted, may (if they wish) register immediately for upperclass humanities and/or social science courses.

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 freshmen and deadline for application see pages 161-163. In computing need the California Institute includes tuition, board and lodging, books and supplies, incidental fees and dues, and about $500 for 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 this figure. The figure for the expenses of those who live at home or with relatives or friends to whom they pay nothing for board and lodging is approximately $500 less. Further information on tuition and other costs, and on loans and the deferred payment plan is given on pages 165-166.

New Student Orientation

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

The orientation takes place during three days immediately following freshman registration for the fall term. A large number of faculty members and upperclass student leaders participate to help introduce the new student to the Caltech community. The orientation period provides an opportunity for the new student to become acquainted with the campus, the Honor System governing personal conduct, and other aspects of life at Caltech. In addition, he 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 limited number of students who have made satisfactory records at other institutions of collegiate rank and who do satisfactorily on the transfer entrance examinations. Transfer students are not normally admitted to the senior year. In general only students whose grades, especially those in mathematics and science, are above average are permitted to take the entrance examinations.

No application fee is charged in the case of transfer students, but only those whose records are good will be permitted to take the tests. Applicants should not come to the Institute expecting to be admitted to the examinations without first receiving definite permission to take them.

Students will be allowed to apply for transfer admission only if they have completed elsewhere essentially the equivalent of the courses required of students at the Institute.

This means that applicants for transfer into the sophomore class must have completed at least one full year of calculus and one full year of physics at the college level. For transfer to the junior class, two years of each of these subjects is required, plus a one-year course in college chemistry. Those who have pursued college work elsewhere but have not had the substantial equivalent of the freshman courses in mathematics and physics — and in addition chemistry for those wishing to major in chemistry or chemical engineering — will be classified as freshmen and should apply according to the instructions on pages 145-148. They may, however, receive credit for pertinent subjects which have been completed in a satisfactory manner.

An applicant for admission as a transfer student must write to the Office of Admissions of the California Institute of Technology stating his 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. 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. In the preliminary letter, the applicant must describe the content of the physics, mathematics, and chemistry courses completed thus far, and give course numbers, titles, and descriptions for all courses, which are not recorded on the college transcripts, that will have been completed before transferring to the Institute. After this letter has been received and the transcripts have been evaluated by the Admissions Office, an application blank will be sent, provided the grades and subjects on the transcripts meet the transfer requirements.

Please note that an application blank is not sent until the preliminary letter and transcripts have been received and evaluated. Transcripts are held in the files until such a letter is received.

Application blanks must be on file in the Admissions Office by April 1. Transcripts should, therefore, be sent no later than March 15. Applicants living in foreign countries must have applications and transcripts on file by March 1 at the latest; information with regard to acceptance or rejection for all candidates is sent before June 20. Candidates who are admitted to the Institute must send a second transcript of their work showing final grades received for any work in progress during the spring.

All transfer applicants must arrange to have sent in their scores on the Scholastic Aptitude Test (SAT) of the College Entrance Examination Board. If they have taken the SAT in previous years, these scores will be acceptable; but applicants must instruct the College Board (see address on page 146) to send the scores to the Institute. If the SAT has not been taken previously, it must be taken by the April series at the latest. College Board Achievement Tests are not required of transfer applicants. Before their admission to the upper classes of the Institute, all students are required to take entrance examinations in mathematics and physics covering the work for which they desire credit. In addition, an examination in chemistry is required for those desiring to major in chemistry or chemical engineering.

Two examinations of a comprehensive character are offered in mathematics and physics. One examination in each subject covers the work of the first year; the other examination, that of the first and second years. Representative examination papers will be sent to approved applicants upon request. The Institute courses for which those admitted will receive credit will be determined by the Committee on Admission to Upper Classes and the departments concerned, on the basis of the applicants' previous records and the result 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 do not have the equivalent laboratory work elsewhere.

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

Examinations for admission to upper classes are given in the first two weeks in May. No other examinations for admission to upper classes will be given.

Applicants residing at a distance may take the examinations under the supervision of their local college authorities, provided definite arrangements are made well in advance.

Students whose native language is not English will be required to take the Test of English as a Foreign Language (TOEFL). This test is a College Entrance Examination Board test and is given all over the world, including the United States, four times a year. This test must be taken by the 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 Instititute 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 average, 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 138). Admission is conditional upon a satisfactory report on the physical examination.

Transfer students are required to pay a registration fee of $10 upon notification of admission to the Institute. In the event of subsequent cancellation of application, the registration fee is *not* refundable unless cancellation is initiated by the Institute.

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 which they are attending. After two full years' residence at the Institute and after satisfactorily completing all the remaining work required for a bachelor's degree in engineering, they will be awarded a Bachelor of Arts degree by the college from which they transferred and a Bachelor of Science degree by the California Institute. Application for admission at the freshman level under this plan should be made to the liberal arts college.

The colleges with which these arrangements exist are:

Bowdoin College, Brunswick, Maine
Grinnell College, Grinnell, Iowa
Occidental College, Los Angeles, California
Ohio Wesleyan University, Delaware, Ohio
Pomona College, Claremont, California
Reed College, Portland, Oregon
Wesleyan University, Middletown, Connecticut
Whitman College, Walla Walla, Washington

Exchange Programs

Exchange programs exist with Occidental College and Scripps College permitting California Institute students to receive credit for courses taken at these two colleges. Occidental College students and Scripps College students also may receive credit for courses taken at the Institute. Tuition payments are not required but the student may have to pay any special fees. The student must obtain approval from the instructor of the exchange course. Exchange courses taken by Caltech students must have prior approval by the student's option, by the division providing courses most similar to the proposed course, and by the Registrar. Freshmen at the California Institute ordinarily cannot participate in this exchange.

In addition, through the office of the Dean of Students, informal exchange programs are conducted with several colleges and universities throughout the country. Under 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

Arrangements have been made with the University of Southern California to provide two-, three-, and four-year Air Force Reserve Officers Training Corps programs to qualified Caltech students. Academic units earned in these programs will be counted as elective credits towards graduation, and successful completion of the AFROTC program will lead to a commission as a second lieutenant in the Air Force Reserve. Four-year scholarships will be available but must be applied for before December 31 in the calendar year prior to entering college. Three-and two-year scholarships will be available to those already in college. All scholarship recipients receive full tuition, required fees and books, and $100 a month. All pilot-qualified male students are to receive 36½ hours of flying training during their final year in the program. 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 Office of the Registrar 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.

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 signed by the approving signatures and returned to the Registrar's Office. A student may not at any time withdraw from a course which is required for graduation in his 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.

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 $40 per lecture hour, per term. Auditing fees for non-academic staff members may be covered by the Institute Tuition Support Plan. Auditing cards may be obtained in the Registrar's Office.

Regularly enrolled students and faculty members of the Institute staff are not charged for auditing. Auditing cards are not required, but the instructor's consent is necessary in all cases. No grades for auditors are reported to the Registrar's Office, and no official record is kept of the work done.

SCHOLASTIC REQUIREMENTS; GRADING

General Regulation

Every student is expected to satisfy the requirements in each of the courses he 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. The grade of "H" is given for satisfactory completion of freshman honors work. 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 as described on page 155. This rule regarding exceptions applies whether the student is repeating a course failed at an earlier time or taking the course for the first time. In addition, grades of A+ and A−, B+ and B−, C+ and C−, and D+ may be used for undergraduates only.

The grade "E" indicates deficiencies that may be made up without actually repeating the subject. If the course has been graded with letter grades, a grade of "D" is given when the work is completed; a grade of "P" is given if the student is a freshman, or if the course was taken on a Pass-Fail basis.

The grade "I" is given only in case of sickness or other emergency which justifies non-completion of the work at the usual time. An incomplete will be recorded only if the reasons for giving it are stated on the instructor's final grade report and only if, in the opinion of the appropriate committee (Undergraduate Academic Standards and Honors for undergraduates, and Graduate Study for graduate students), the reasons justify an incomplete. If, in the opinion of the committee, the incomplete is not justified, a condition will be recorded. The Undergraduate Academic Standards and Honors Committee has authorized the Dean of Students or the Associate Dean of Students to 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 automatically unless the instructor of the course recommends otherwise.

"Failed" means that no credit will be recorded for the course. The units, however, count in computing the student's grade-point average. He 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: Grades of "P" may be given for courses numbered 200 or greater, and for other courses which do not lend themselves to more specific grading. All courses which do not have a formal course structure (e.g., research and reading courses) must use Pass-Fail grades except where the option requests permission of the Faculty Board to give letter grades. All students in a given course are to be graded using the same system (either all P-F, or all letter grades), unless the instructor offers the course on a letter-graded basis and a student chooses to take it on a P-F basis by filing a Pass-Fail Course Selection Card.

Each term a sophomore, junior, or senior may select one elective course, not specifically required for graduation in his or her option, to be graded on a Pass-Fail basis, subject to such requirements as may be imposed by the option. The following additional provisions apply:

(a) Any instructor may, at his or her discretion, specify prior to pre-registration that his or her course is not available on a Pass-Fail basis.

(b) Registration may be changed from Pass-Fail to regular grades and vice versa until the last day for dropping courses each term.

(c) The total number of Pass-Fail units in regularly scheduled courses (that is, courses other than research and reading courses) in the sophomore, junior, and senior years, which a student may offer for graduation, may not exceed 81.

To elect to take a course *Pass-Fail,* a student must submit a completely filled-out Pass-Fail Course Selection Card to the Office of the Registrar prior to the last day for dropping classes that term.

Scholastic Requirements

All undergraduates are required to meet certain scholastic standards as outlined below. *Ineligibility for Registration.* Undergraduates who register for programs which make it appear that they are no longer candidates for a B.S. degree may be refused further registration by the Undergraduate Academic Standards and Honors Committee. Freshmen who 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 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. Other freshmen may, at the end of the year, be referred to the Committee by the Dean or the Associate Dean of Students and the student's adviser. If it is the opinion of the Committee on Undergraduate Academic Standards and Honors that any freshman referred to it is unprepared for the work of the sophomore year, he or she may be declared ineligible to register for academic reasons.

Freshmen whose records are to be reviewed at any meeting of the Committee will be notified in advance and invited to meet with the Committee to discuss their performance; freshmen so notified should also plan to submit a written statement to the Committee in advance of its meeting.

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.

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. 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, provided permission is obtained, 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. Until they are readmitted to their option, students may not take courses in that option beyond the level they had reached when they were refused permission to continue work. Students may remain without an option for no more than one year.*

Term Examinations will be held in all subjects unless the instructor in charge of any subject shall arrange otherwise. No student will be exempt from these examinations. Permission to take a term examination at other than the scheduled time will be given only in the case of sickness or other emergency and upon the approval of the instructor in charge and of one of the deans. When conflicts exist in a student's examination schedule, it is the student's responsibility to report the conflict to the instructor in charge of one of the conflicting examinations and make arrangements to take the examination at another time.

Graduation Requirement. To qualify for graduation a student must complete the prescribed work in one of the options with a passing grade in each required subject and with a grade-point average of 1.9. A grade of "F" in an elective course need not be made up, provided the student has received passing grades in enough other accepted units to satisfy the minimum total requirements of 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. At least 90 of the units taken must be in subjects in professional courses. A full year of residence is interpreted as meaning the equivalent of registration for three terms of not less than 36 units each.

Requirement for a Second Bachelor of Science Degree. Students who wish to receive a second degree of Bachelor of Science in another option are required to have one additional year of residence (three terms of study involving at least 36 units per term) beyond the first Bachelor of Science degree.

Honor Standing. At the close of each academic year the Committee on Undergraduate Academic Standards and Honors awards Honor Standing to 20 to 30 students in the sophomore and junior classes, based on the scholastic records of the students.

Graduation with Honor. With the approval of the faculty, graduation *with honor* may be granted 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.

Excess 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 option adviser and the approval of the Undergraduate Academic Standards and Honors Committee. Petitions to carry excess units will not be accepted later than the last day for adding classes in any term.

Registration for fewer than 36 units must be approved by the Undergraduate Academic Standards and Honors Committee. Petitions to register for fewer than 36 units must be filed with the Registrar one week prior to the last day for adding classes in any term. 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. Such approval will not be given to any students 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

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, or science to be pursued in subsquent years. Upon the selection of an option, a freshman will be assigned an adviser in that option, whose approval must then be obtained for pre-registration for the following year.

An undergraduate may be allowed to major in two options, 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.

Change of Option. Students wishing, or required, to change options must first obtain a Change of Option petition from the Registrar's Office. The completed petition must be signed by the Option Representative for the new option who will assign a new adviser, and then the petition must be filed in the Registrar's Office.

Leave of Absence. Leave of absence involving non-registration for one or more terms must be sought by written petition. A leave 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.

Candidacy for the Bachelor's Degree. A student must file with the Registrar a declaration of his candidacy for the degree of Bachelor of Science on or before the first Monday of November preceding the date at which he 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 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 prior to the date on which the transcripts are to be mailed.

PHYSICAL EDUCATION

Prior to graduation each undergraduate is required to successfully complete three terms of physical education. This requirement may be satisfied entirely or in part by participation in intercollegiate athletics, successful completion of a physical education class, or successful completion of a student-designed program of physical fitness. Further explanation of each aspect of the program appears below.

Participation as a bona fide member of an intercollegiate team for the period covered by a sport in a given term satisfies the requirement for that term. Students dropping from an intercollegiate team prior to the end of the term or the season must enroll in a physical education class immediately, if they wish to receive credit for physical education.

A broad program of instruction is provided each term. Enrollment in the classes is conducted in the gymnasium and pool on the day of General Registration. A swimming test is required of those planning to enroll in scuba diving or sailing. Standards for evaluation of student performance will be clearly defined at the beginning of each class. Participation in intramural sports will count towards the 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 accomplishment of prestated objectives. It is assumed that students proposing their own program of physical fitness are competent in the activities proposed.

UNDERGRADUATE EXPENSES

For freshmen applying for admission, there is a $10 Application Fee, not refundable, but applicable upon registration to the Tuition Fee.

For freshmen and transfer students, there is a $10 Registration Fee payable upon notification of admission, and not refundable. 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 1976-77

General:	
General Deposit	$ 25.00[1]
Tuition	3,648.00
Student Body Dues, including *The California Tech*	22.00[2]
Assessment for *Big T*	12.00[2]
	$3,707.00
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	$1,328.00[3]
Dues	45.00
Meals not covered by board contract are available at Chandler Dining Hall (approx.)	575.00
Books and Supplies (approx.)	200.00
	$2,148.00

[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.

[3]There are a few single rooms available which will rent for an additional $65 per year. Room contracts are on a term basis for all students.

The following is a list of undergraduate student expenses at the California Institute of Technology for the Academic Year 1976-77 together with the dates on which the various fees are due. Charges are subject to change at the discretion of the Institute.

	First Term	*Fee*
September 22, 1976	General Deposit	$ 25.00
(Freshmen)	Tuition	1,216.00
September 27, 1976	Associated Student Body Dues	8.00
(All Others)	Assessment for *Big T*	4.00
	Room and Board	491.00
	Student House Dues	15.00
	Second Term	
January 3, 1977	Tuition	$1,216.00
	Associated Student Body Dues	7.00
	Assessment for *Big T*	4.00
	Room and Board	430.00
	Student House Dues	15.00
	Third Term	
March 28, 1977	Tuition	$1,216.00
	Associated Student Body Dues	7.00
	Assessment for *Big T*	4.00
	Room and Board	407.00
	Student House Dues	15.00

Tuition Fees for fewer than normal number of units:

Over 35 units	Full Tuition
Per unit per term	$ 34.00
Minimum tuition per term	340.00
Audit Fee (p. 153) $40.00 per unit per term	

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 Student Accounts office. The days in attendance are the number of days counted from the first day of the term to:

1. The date the request is made to the Dean of Students for *Withdrawals.*
2. The date the petition is presented to the Office of the Registrar for *Leave of Absence.*
3. The date that registration for the reduced units is approved by the Undergraduate Academic Standards and Honors Committee or the date that drop cards are filed in the Registrar's Office, whichever is later, for *reduction in units.*

Room contracts are charged on a term basis for all students. Premature termination of a room contract will be granted only with the approval of the Master of Student Houses.

Associated Student Body Dues. As a service to the Associated Students, ASCIT dues of $22 per year and an assessment of $12 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 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.

Winnett Student Center. Winnett Student Center facilities are reserved for the use of Caltech students and their guests. A contribution of fifty cents a year is made by each member of the Associated Student Body ($1 by graduate students wishing to use the facilities) to help defray the expenses of the game room.

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

Application for rooms in the Student Houses may be made by addressing the Master of Student Houses, 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 delinquent may be refused registration for the term following that in which the delinquency occurs. Students who have not made satisfactory arrangements regarding bills due and other indebtedness to the Institute by the date of graduation will be refused graduation. Transcripts cannot be released until all bills due have been paid or satisfactory arrangements are made with the business office for payment.

FINANCIAL AID

1. Scholarship Grants for Entering Students

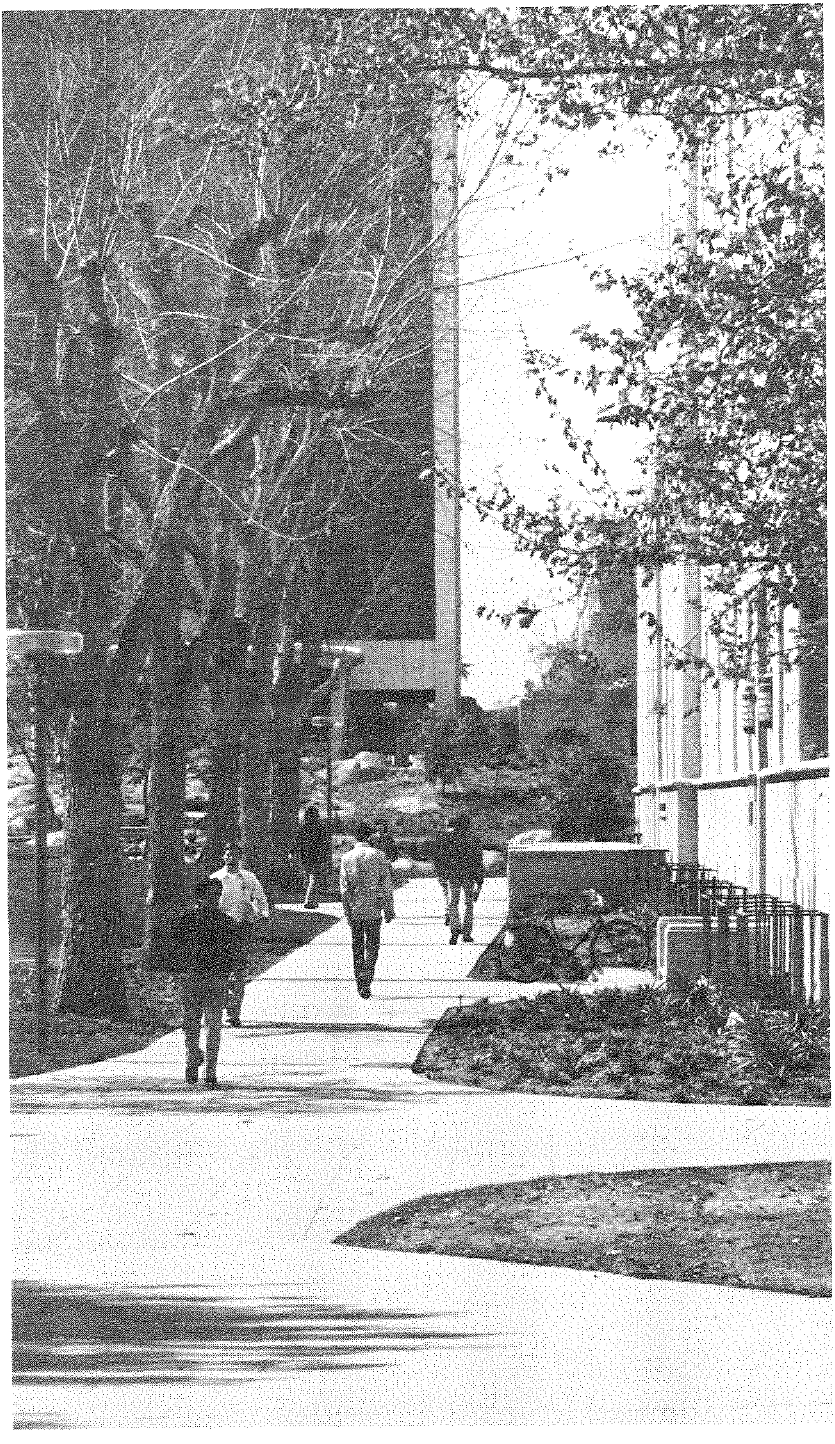
Freshman grants are awarded by the Freshman Admissions Committee to candidates who have been admitted to the Institute and have submitted a *Financial Aid Form*. Grants to transfer students are awarded on the same basis by the Upperclass Admissions Committee. Financial aid is awarded to the extent of available funds where financial need is demonstrated.

Applications by entering students for financial aid must be made on a form called the *Financial Aid Form.* This form may be obtained in nearly all cases at the school the applicant is attending. If the school does not have a supply, the student should write to the College Scholarship Service at one of the College Entrance Examination Board offices, the addresses of which are given on page 146. The form is published by the College Scholarship Service of the College Board and is to be returned directly to the appropriate office of the College Board (see page 146) and not to Caltech.

Financial Aid Forms must be sent to the appropriate College Board office not later than February 1 of the year in which admission is desired for freshman applicants, and by April 1 for transfer applicants. All applicants who have submitted this form by the above dates are considered for financial aid. *It is not necessary to apply for any particular award by name.*

State and National Financial Aid Awards

Candidates for freshman financial aid are urged to make exhaustive inquiry of their school advisers and to watch their school bulletin boards for announcements of scholarship contests. The State of California, for example, awards scholarships annually to residents of the state who wish to attend a college within the state. Residents of the State



of California who request financial aid will be penalized in consideration for Caltech grants if they do not apply for California State Scholarships, provided their test scores indicate that they would have won a State award had they applied. Among the nation-wide awards are the National Merit Scholarships and the Westinghouse Talent Search Awards. Applicants in need of financial assistance should enter any such contest for which they are eligible, in addition to applying for California Institute Financial Aid. While duplicate awards will not be given beyond the actual extent of need, the more sources to which a candidate applies the greater are his chances of receiving financial assistance.

Regulations and Renewals

Recipients of financial aid are expected to maintain a satisfactory standing in their academic work. If the recipient fails to maintain such an academic standing, or if, in the opinion of the Scholarships and Financial Aid Committee, the recipient in any way fails to justify the confidence placed in him, the Committee may cancel the award. Recipients of grants which run for more than one year are expected to pass all courses in their freshman year and thereafter to maintain at least a 2.5 grade-point average. The amount of the award may be increased or decreased at the beginning of any year if the financial need has changed. Freshmen who receive awards for the freshman year only will be considered for aid in subsequent years on the basis of need according to the regulations in the following paragraph.

2. Upperclass Financial Aid Grants

Sophomores, juniors, and seniors are considered for financial aid if need is demonstrated and if they have completed the preceding academic year with a satisfactory academic record. When individual grants exceed full tuition and other expenses exclusive of room and board, the excess is given in the form of a credit against room and board in the Student Houses. A student who expects to finish the academic year satisfactorily and who wishes to apply for financial aid for the next year should obtain a form from the Admissions Office in March. This form is to be filled out by parents (or guardian) and the student and returned to the Admissions Office by May 1. No one will be considered for financial aid unless a proper form completely filled out and signed by parents (or guardian) is submitted by the appropriate date. If the parents should no longer be responsible for the student's support (in the student's opinion), an explanatory note may be attached to the form, but the form must be filled out.

It is expected that students to whom awards are made will carry a full academic load and will maintain a high standard of scholarship and conduct. Failure to do so at any time during the school year may result in the termination of the award.

3. Financial Aid Funds

Funds for freshman and upperclass financial aid are provided from the following special scholarships awarded periodically. It is not necessary to apply for any particular financial aid award by name. Applicants for admission who have a Parents' Confidential Statement on file will be considered for the best award to which their relative need and academic standing entitle them.

Agbabian Associates Scholarship
Alumni Scholarships
ARCS Foundation (Achievement Rewards for College Scientists) of Los Angeles
R. C. Baker Foundation Scholarship in Engineering
Edwin J. Beinecke, Sr., Memorial Scholarship
Berry Holding Company Scholarship Fund
Bing Scholarship

Bookstore Scholarship Fund
C F Braun & Co Scholarship — preference to engineering students
The Carnation Scholarship Fund
Converse Davis Dixon Associates Scholarship
Cyprus Mines Corporation Scholarship
Robert S. and Nellie V. H. Dutton Scholarships
Albert A. Erkel Scholarship
General Motors Corporation Scholarship
The Gnome Club Scholarship
Goodyear Scholarship
Robert E. Gross-Lockheed Aircraft Corporation Scholarship
Hillman, Biddison & Loevenguth Scholarship
Johnson & Nielsen Inc. Scholarship
Earle M. Jorgensen Scholarships
Clarence F. Kiech Scholarships
JPL/Caltech Management Club Scholarships
George H. Mayr Foundation Scholarships
James M. Montgomery, Consulting Engineers, Inc. Scholarship
Moore & Taber Scholarship
La Verne Noyes Scholarship
Pasadena Optimist Club Scholarship Endowment Fund
Lois F. Spalding Scholarships
Waltmar Foundation Scholarships.

In addition, financial aid is provided, without a named designation as to the source of funds, from a financial aid pool to which the following donors have contributed.

Ethel Hazen Allen Scholarship for needy Canadian undergraduates, Roland L. Andreau Scholarship Fund, Edward C. Barrett Scholarship honoring the former Secretary of Caltech for 41 years, Louis D. Beaumont Foundation Scholarships, Meridan Hunt Bennett Scholarship and Fellowships, Knowlton R. Birge Scholarship, Robert Roe Blacker and Nellie Canfield Blacker Scholarship, Mary Huntington Carr Scholarship, Chisholm Scholarship provided by Mr. William Duncan Chisholm, Dorothy Hixon Clark Scholarships, Class of 1927 Scholarship, Earl S. Condon Scholarship Fund, Matthew M. Corbett Scholarship Fund, Crellin Scholarships provided by Mrs. Amy H. Crellin, Dabney Scholarships, Leo P. Delsasso Memorial Scholarship Fund, Drake Scholarships, L. L. Fentress Fund Scholarship, Robert C. Gillis Scholarship Fund, Florence A. Hampton Scholarship Fund, Harriet Harvey and Walter Humphry Scholarships, Robert Haufe Memorial Scholarship, Gene B. Heywood Scholarship Fund, The Holly Scholarship, Vaino A. Hoover Student Aid Fund, Albert Hall Hughey Scholarships, Henry Kirshner Scholarship, Robert J. Kieckhefer Scholarship Fund, John C. Lewis Memorial Student Aid Fund, Peter Madsen Undergraduate Scholarship Fund, Anna and James McDonald Scholarship, William C. McDuffie Scholarship, Robert L. Minckler Scholarships honoring former Chairman of Caltech's Board of Trustees, David Lindley Murray Educational Fund, Frances W. Noble Scholarship, Edgar H. Pflager Scholarship Fund, Charlotte Palmer Phillips Foundation Scholarship, Harry Leslie Remington Memorial Scholarship Fund, Elbert G. Richardson Scholarships and Fellowships, Riley Scholarship Fund, Frederick Roeser Loan, Scholarship, and Research Fund, William E. Ross Memorial Student Fund, Frank Schaak Fund, Scholarship Endowment Fund, Harold O. Springer Scholarship Fund, Standard Oil Company of California Scholarships, Elizabeth Thompson Stone Scholarship, William W. Stout Scholarship Endowment Fund, Claudia Wheat Scholarship Fund, Alice Colby Wheeler Scholarship, Brayton Wilbur-Thomas G. Franck Scholarship.

4. Student Aid Loan Funds

Loans. Loans are available to members of all undergraduate classes, including entering freshmen, who need such aid to continue their education. They are made upon application, subject to the approval of the Faculty Committee on Scholarships and Financial Aid and the extent of available funds. There are three sources of loan funds which are described below.

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 Financial Aid Office 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 (after taxes) out of salaries earned in the United States.

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

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. Brown and Leroy G. Brown Memorial, Glenn L. Converse Memorial, Wilbur D. Crater Memorial, Olive Cleveland, 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, John E. Sherborne Memorial, Richard W. Shoemaker, Albert H. Stone, United States Steel Foundation, 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, nor is any repayment of principal required until nine months after termination of formal education. At the time repayment commences, interest is charged at the rate of 3 percent per annum on the unpaid balance.

For loans to graduate students under the NDSL Program see page 253.

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 Federally Insured Student Loan (FISL) Program the maximum loan amount is $2,500 per academic year with an aggregate maximum of $7,500. Further information on this program, including application forms, may be obtained from the Financial Aid Office.

Deferred Payment Plan. In addition to loans there is available a bank plan under which any student in good standing may defer up to $1,500 of college bills each year to a total of

$6,000 and may pay the deferred portion in installments after the graduation of his or her class. Interest on the amount deferred is charged at 1 percent over the bank's commercial prime rate at the time of inception of the plan, and is payable quarterly. The interest is the only payment made under this plan during the undergraduate years. On November 1 following his class's graduation, the student begins repayment on the deferred portion at the rate of $85 a month including interest. For those who go on to graduate school more favorable repayment arrangements may be made for the duration of graduate work. If student status is discontinued, the repayment schedule of $85 per month will begin after a grace period of 120 days.

Loans and the Deferred Payment Plan may be used in combination, but the total that may be borrowed or deferred may not exceed $2,500 in any one year (maximum of $7,500).

Entirely aside from loans and the Deferred Payment Plan, the following organizations offer plans for scheduled payments of education expenses:

1. EFI-Fund Management Corporation, Suite 3200, Prudential Plaza, Chicago, Illinois 60601. 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 $20 participation fee per year.

2. The Insured Tuition Payment Plan, offered by the Richard C. Knight Insurance Agency, Inc., 53 Beacon Street, Boston, Massachusetts 02108, offers two payment programs. Both programs include insurance protection which covers the balance of the cost of the entire education program in the event of the death or disability of the insured parent. They offer a Prepayment 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 $.50 per month service charge and a monthly insurance premium charge. Interest at the current rate of 5 percent per year is paid on the amount held for disbursement to the Institute. The second plan offered is an Extended Repayment Plan which 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.

3. The Tuition Plan Inc., Concord, New Hampshire 03301, offers a Deferred Monthly Payment Plan (Loan Program) to cover tuition and fees 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 13 percent to 18 percent) and insurance premiums (if coverage is desired). The maximum number of months allowed for repayment is 72. A Prepayment Program is available which provides a prepaid program of monthly budgeted expenses in advance of each school term. Insurance is available to insurable parents (if coverage is desired).

Student Employment

Students who desire part-time or summer employment will receive assistance from the Placement Office. The requirements of the course at the Institute are so exacting, however, that under ordinary circumstances, students who are entirely or largely self-supporting through employment should not expect to complete a regular course program in the usual time. It is highly inadvisable for freshman students to attempt to earn a major part of their expenses.

College Work Study Program. This federally funded program is designed to pay partial salaries to 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 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 research fellows. Students, both graduate and undergraduate, desiring part-time employment during the school year or during vacations, should register with the Placement Office. Assistance will be given whenever possible in securing employment for summer vacations. Alumni who are unemployed, or desire a change in position, should register with the Placement Office.

The Placement Service maintains a Student Information Center which provides information in the form of brochures, catalogs, and announcements concerned with employment opportunities, admissions to colleges and universities, and fellowships and scholarships offered by universities, foundations, and industry. The brochures show employment opportunities offered by all types of organizations. The Director of Placements is available for consultation and guidance on placement problems.

The Placement Office makes 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.

PRIZES

The Frederic W. Hinrichs, Jr., Memorial Award

The Board of Trustees of the California Institute of Technology established the Frederic W. Hinrichs, Jr., Memorial Award in memory of the man who served for more than twenty years as dean and professor at the Institute. In remembrance of his honor, courage, and kindness, the award bearing his name is made annually to the senior who, in the judgment of the undergraduate deans, throughout his undergraduate years at the Institute has made the greatest contribution to the student body and whose qualities of character, leadership, and responsibility have been outstanding. At the discretion of the deans, more than one award or none may be made in any year. The award, presented at commencement without prior notification, consists of a cash award and a certificate.

The Mary A. Earle McKinney Prize in English

The Mary A. Earle McKinney Prize in English was established in 1946 by Samuel P. McKinney, M.D., of Los Angeles. Its purpose is to promote proficiency in writing. The terms under which it is given are decided each year by the English faculty. It may be awarded for essays submitted in connection with regular English classes, or awarded on the basis of a special essay contest. The prize consists of cash awards and valuable books.

The Don Shepard Award

Relatives and friends of Don Shepard, class of 1950, have provided an award in his memory. The award is presented to a student, the basic costs of whose education have already been met but who would find it difficult, without additional help, to engage in extracurricular activities and in the cultural opportunities afforded by the community. The recipients, upperclassmen, are selected on the basis of their capacity to take advantage of and to profit from these opportunities rather than on the basis of their scholastic standing.

The Eric Temple Bell Undergraduate Mathematics Research Prize

In 1963 the Department of Mathematics established an Undergraduate Mathematics Research Prize honoring the memory of Professor Eric Temple Bell and his long and illustrious career as a research mathematician, teacher, author, and scholar. His writings on the lives and achievements of the great mathematicians continue to inspire many hundreds of students at the California Institute and elsewhere. A prize of $150 is awarded annually to one or more juniors or seniors for outstanding original research in mathematics, the winners being selected by members of the mathematics faculty. The funds for this prize come from winnings accumulated over the years by Caltech undergraduate teams competing in the William Lowell Putnam Mathematics Contest, an annual nationwide competition.

The George W. Green Memorial Prize

The George W. Green Memorial Prize was established in 1963 based on contributions given in memory of George W. Green, who for fifteen years served on the staff of the Caltech business office and was from 1956-1962 Vice President for Business Affairs. The prize of $500 is awarded annually to an undergraduate student, in any class, selected by the division chairmen and the deans on the basis of original research, an original paper or essay in any field, or other evidence of creative scholarship beyond the normal requirements of specific courses.

The Donald S. Clark Alumni Awards

From funds contributed by the Caltech Alumni Association, annual awards may be made to a sophomore and a junior in recognition of service to the campus community and good academic performance. Preference is given to students in the Division of Engineering and Applied Science and to those in Chemical Engineering. The awards honor the work of Professor Clark, class of 1929, both in the field of engineering and in his service to the Alumni Association.

The Haren Lee Fisher Memorial Award in Junior Physics

Mr. and Mrs. Colman Fisher have established the Haren Lee Fisher Memorial Award in Junior Physics in memory of their son, who was killed in an automobile accident in May of 1967, in his junior year at Caltech. The General Electric Foundation also contributed to the fund under the matching plan of their Corporate Alumnus Program. A prize of $150 will be awarded annually to a junior physics major, to be selected by a physics faculty committee as demonstrating the greatest promise of future contributions to physics.

The Jack E. Froehlich Memorial Award

The family and friends of the late Jack E. Froehlich, who did his undergraduate and graduate work at the California Institute and was later the project manager for Explorer I for the Jet Propulsion Laboratory, have established a prize fund which will provide a gift of money to a junior in the upper five percent of his class who shows outstanding promise for a creative professional career.

The Sigma XI Award

In accordance with the aim of The Society of the Sigma XI to encourage original investigation in pure and applied science, the Institute Chapter of the Society annually awards a prize of $500, funded from membership dues, to a senior selected for an outstanding piece of original scientific research.

The following two prizes are 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.

Honeywell Award

The Honeywell Award was established in 1961 by the Minneapolis-Honeywell Regulator Company to recognize and reward distinguished individual performance and leadership in undergraduate engineering and science, with preference toward engineering. A prize of $200 and a silver tray are awarded annually to an outstanding junior. In addition, his or her name is engraved on a plaque that is permanently mounted in the Franklin Thomas Laboratory of Engineering and that bears the names of the previous winners.

UNDERGRADUATE OPTIONS AND COURSE SCHEDULES

To qualify for a Bachelor of Science degree at the California Institute of Technology, students must obtain passing grades in each of the required courses listed below, and they must satisfy the additional requirements listed under the undergraduate options. They must also register for programs so that they make normal progress toward their B.S. degree (see Scholastic Requirements, Ineligibility for Registration).

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 presentations of petitions.)

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)	27
5. Freshman Chemistry (Ch 1 abc)	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 Science Courses	54
11. Physical Education	9

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 (units as arranged), Bi 9 (3 units), Ch 3 bc (3 or 6 units per term), ChE 10 (3 units), E 5 (6 units), EE 10 (6 units), Ge 1 (3 units), Ph 3 (6 units), Ph 4 (6 units).

Humanities and Social Sciences 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 and must complete satisfactorily three terms thereof (thereby satisfying the minimum humanities requirement) unless excused by virtue of doing exceptionally well on the essay portion of an English or history college board advanced placement test or by demonstrating outstanding ability in the first or second terms. Freshman humanities courses are numbered 10 or below in this catalog. They require 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 all or part of 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	Kinematics, Particle Mechanics and Electric Forces (4-0-5)	9	9	9
Ch 1 abc	General and Quantitative Chemistry (3-0-3)	6	6	6
Ch 3 a	Experimental Chemical Science (0-6-0)	6	.	.
HSS	Introductory courses in the humanities and social sciences. A wide choice of alternatives will be available to students; the Registrar will announce the offerings for each term	9	9	9
	Freshman Laboratory Courses[1]	x	x	x
	Additional Electives[2]	x	x	x
PE 1 abc	Physical Education[3]	3	3	3

x — Except for the minimum laboratory unit requirement, the number of units chosen here is optional. If the student chooses no electives except physical education and takes the minimum permissible laboratory courses, the total unit load will be 42 for two terms and 39 for one term. A total load including electives of more than 51 units per term is considered a heavy load. A load in excess of 58 units requires formal approval of a petition for overload.

[1]The additional 9 units of laboratory work must be chosen from APh 9 — 6 units per term; Bi 1 — units as arranged; Bi 9 — 3 units; Ch 3 bc — 3 or 6 units per term; ChE 10 — 3 units; E 5 — 6 units; EE 10 — 6 units; Ge 1 — 3 units; Ph 3 — 6 units; Ph 4 — 6 units.

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

[3]Three terms (9 units) of PE are required for the B.S. degree. Students need not elect to take the required PE in the freshman year. It may be taken in any 3 terms prior to graduation.

Applied Mathematics Option

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

Option Requirements

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
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	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Humanities Electives[1]	9	9	9
	Electives	9	9	9
		45	45	45

Third Year

		1st	2nd	3rd
AMa 95 abc or Ma 108 abc	Introductory Methods of Applied Mathematics (4-0-8) Advanced Calculus (4-0-8)	12	12	12
	Humanities Electives[1]	9	9	9
	Electives	27	27	27
		48	48	48

Fourth Year

		1st	2nd	3rd
AMa 101abc	Methods of Applied Mathematics (3-0-6)	9	9	9
	Humanities Electives[1]	9	9	9
	Electives[2]	27	27	27
		45	45	45

[1]See Institute Requirements for specific rules regarding humanities.
[2]See items 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 a broad spectrum of fields which overlap, it is not possible to draw a definite dividing line between them. Realizing this, the applied physics option draws its faculty from the Divisions of Physics, 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 benefit.

Attention is called to the fact that any student who has a grade-point average less than 1.9 at the end of the academic year in the subjects listed under Applied Physics may be refused permission to continue work of this option. A fuller statement of this regulation will be found on page 156.

Option Requirements

1. Any three of the following: APh 24, Ph 3, Ph 5, Ph 6, Ph 7
2. APh 50 abc
3. AMa 95 abc
4. One term of APh 91
5. One term of one of the following: APh 91, APh 154, Ph 77, EE 91, Ch 26, ChE 126, MS 130, MS 131, MS 132
6. 54 additional units of APh courses numbered over 100, Ph 106, Ph 125, or Ch 125. None of these courses shall be elected by the student to be taken on a pass-fail basis. Note that APh 100 does not satisfy this requirement.
7. 27 additional units of science or engineering electives
8. 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	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
	Humanities Electives[1]	9	9	9
	Laboratory Electives[2]	6	6	6
APh 17 abc	Statistical Thermodynamics (3-0-6)	9	9	9
	Other Electives[3]	9	9	9
		51	51	51

[1]See Institute Requirements for specific rules regarding humanities.
[2]See item 1 Option Requirements.
[3]See items 6 and 7, Option Requirements.

Third Year

APh 50 abc	Applied Physics (3-0-6)	9	9	9
APh 110 abc	Topics in Applied Physics	2	2	2
AMa 95 abc	Engineering Mathematics (4-0-8)	12	12	12
Ph 106 abc	Topics in Classical Physics	9	9	9
	Humanities Electives[1]	9	9	9
	Other Electives	9	9	9
		50	50	50

Fourth Year

APh 91 ab	Projects Laboratory in Applied Physics	6	6	.
	APh Electives	18	18	18
	Humanities Electives[1]	9	9	9
	Other Electives	18	18	18
		51	51	45

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	Ph 77 ab	APh 91 c
Ge 1	EE 91 abc	APh 100
Ge 2	EE 114 abc	Ae/APh 101 abc
Bi 1	AMa 104	APh 105 abc
Ay 1	AMa 105 ab	APh 114 abc
ME 1 ab	Ch 26 ab	AMa 101 abc
ME 3	Ay 112 abc	AMa 104
EE 13 abc	Ay 113 abc	AMa 105 ab
EE 14 abc	Ay 10	Ch 125 abc
EE 90 abc	Ay 15	Ph 125 abc
Ma 5 abc	Ge 154 abc	Ph 129 abc
	APh 100	Ph 77 ab

More Specialized Courses[2]

APh 140 abc	APh 156 abc
APh 141	APh 161 abc
APh 153 abc	APh 163
APh 154	Ch 113 abc
APh 181 abc	EE 91 abc
APh 185 abc	EE 155 abc
APh 190 abc	Ge 104 abc
APh 195 ab	Ge 166 a
AM 135 abc	Ge 166 b
ChE 103 abc	
ChE 105 abc	
ChE 126 abc	

[1]See Institute requirements for specific rules regarding humanities.
[2]These courses are taught at irregular intervals depending upon demand: consult the pre-registration course listing.

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 department, be refused permission to continue the work in this option. A fuller statement of this regulation will be found on page 156.

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	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ay 20	Basic Astronomy and the Galaxy (3-2-6)	11	.	.
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[2]	9	9	9
	Electives[3]	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[1]	9	9	9
	Electives	18-24	9-12	9-15
	Suggested total number of units	45-51	47-50	45-51

[1]Students are required to take (a) Ph 3 if not already taken, (b) Ph 5 or Ph 6, and (c) Ph 7.
[2]For rules governing humanities electives, see page 170.
[3]Sophomore electives include at least 27 units of science and engineering courses, of which at least 18 units shall be in subjects other than mathematics, physics, and astronomy. It is desirable for a student to acquire as broad as possible a background in other related fields of science and engineering.

Fourth Year

Astronomy or Physics Electives	18	18	18
Humanities Electives[1]	9	9	9
Electives	18-24	18-24	18-24
Suggested total number of units	45-51	45-51	45-51

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

Suggested Electives

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

[1]For rules governing humanities electives, see page 170.
[2]Students who plan to do graduate work in astronomy or radio astronomy should elect some of these courses during their third and fourth years, on consultation with their advisers.

Biology Option

The undergraduate option in biology is designed to give the student an understanding of the basic facts, techniques, and concepts of biological science as well as a solid foundation in physical science. Emphasis is placed on the more general and fundamental properties of living creatures, thus unifying the traditionally separate fields of the life sciences. Involvement of undergraduates in the research programs of the division is encouraged.

Flexibility to accommodate varied individual scientific interests, within the broad scope of biology, is achieved through the provision of numerous elective courses, through programs of individual research (Bi 22), and of tutorial instruction (Bi 23).

The undergraduate option serves as a basis for graduate study in any field of biology or for admission to the study of medicine.

Undergraduate Research. The division encourages undergraduate participation in its research programs; such research can frequently be of a depth and caliber so as to result in a research report or scientific publication. Research opportunities may be arranged with individual faculty members or guidance may be obtained from the Biology Undergraduate Student Adviser.

Premedical Program. The undergraduate course for premedical students is essentially the same as that for biology students and is intended as a basis for later careers in research as well as in the practice of medicine. It differs in some respects from premedical curricula of other schools; however, it has been quite generally accepted as satisfying admission requirements of medical schools. Slight modifications in the curriculum may be required for admission to certain medical schools, or in cases in which the student wishes to try to complete admission requirements in three years instead of four.

It is recommended that all students contemplating application to medical school consult with the premedical adviser, Professor Hood.

Marine Biology. In addition to the courses listed in this catalog, arrangements may be made to take courses in marine biology offered at the Santa Catalina Marine Biological Laboratory. Tutorial instruction in the biology of marine invertebrates may also be obtained in Bi 23.

Option Requirements

1. Specific courses: Bi 1, Bi 7, Bi 9, Bi/Ch 110 ab, Bi 111, Bi 122, Bi 150 or Bi 151 a, and Ch 41 abc.
2. An additional 58 units of Bi courses.
3. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

		Units per term 1st	2nd	3rd
	Second Year			
	Humanities Electives[1]	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
Ch 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			
	Humanities Electives	9	9	9
Bi 7	Organismic Biology (3-3-3)	9	.	.
Bi/Ch 110 ab	Biochemistry (4-0-8)	12	12	.
Bi 111	Biochemistry Laboratory (0-8-2)	.	10	.
Bi 122	Genetics (3-3-6)	.	.	12
	Electives[2,3]	15-21	14-20	24-30
		45-51	45-51	45-51
	Recommended Elective			
Ch 21 abc		9	9	9
	Fourth Year			
	Humanities Electives	9	9	9
Bi 150	Neurobiology (3-0-6)	9	.	.
or				
Bi 151 a	Neurophysiology (3-0-6)	9	.	.
	Electives	27-33	36-42	36-42
		45-51	45-51	45-51

[1]For rules governing humanities electives, see page 170.
[2]Electives must include sufficient units of work in Biology to complete the graduation requirement for 140 units of work in Biology.
[3]Ch 21 abc is strongly recommended for students interested in chemical biology, as many graduate programs expect entering students to have taken a course in physical chemistry.

Suggested Electives

Second Year

Second Term: Ch 46 a   Third Term: Ch 46 b

Third Year

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

Second Term: Bi 22, Bi 23, Bi 27, Bi 102, Bi 106, Bi 155, Ch 21 b, L 1 b, L 32 b, L 50 b

Third Term: Bi 3, Bi 22, Bi 23, Bi 27, Bi 119, Bi 137, Bi 156, Bi 157, Ch 21 c, 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/Ch 132 a, Bi 161, Bi 209, Bi 216, Bi 217, Bi 220 a, Bi 260, Ch 144 a, Ch 244 a

Second Term: Bi 129, Bi/Ch 132 b, Bi/Ch 133, Bi 152, Bi 209, Bi 214, Bi 220 b, Bi 260, Ch 144 b, Ch 244 b, Env 145 a

Third Term: Bi 115, Bi/Ch 132 c, Bi/Ch 133, Bi 141, Bi 153, 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 applied disciplines and involves intellectual development in the fundamental areas of mathematics, physics, and chemistry. In addition, it requires decision making in problem areas calling for judgment in economic and social matters. Study in this option leads, especially when followed by graduate work, to careers in teaching and research in colleges and universities or to careers in government and industrial concerns, including research, development, and management of broad classes of problems involving chemical systems.

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 and have passed a departmental examination 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.

Third-year students take the chemical engineering laboratory during the first term and may continue that laboratory or take the laboratory in physical chemistry. Students help plan and conduct both demonstration and open-ended experiments, analyze data taking into account uncertainty and errors, and present their results both orally and by means of a formal report. Juniors take courses in the physical description of chemical systems, and an introduction to the techniques of applied mathematics. Juniors also take a unified course in transport phenomena involving the study of transfer of momentum, energy, and materials in situations of practical interest. In addition, there are 36 units of elective courses.

Seniors take a course in applied chemical kinetics involving the basic study of chemical reactions combined with transport processes in systems of practical interest. That work is used along with other chemical engineering background in which both synthesis and analysis are applied in senior courses in the optimal design and simulation of chemical systems. 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. A full statement of this regulation will be found on page 156.

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 ab, ChE 110 ab, ChE 111, and Ec/SS 11[1]
2. 6 units of laboratory other than AMa and CS[2]
3. 18 units of chemistry electives
4. 27 units of science and engineering electives[3]
5. Passing grades must be earned in a total of 516 units, including the courses listed below.

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

		1st	2nd	3rd
ChE 126 ab	Chemical Engineering Laboratory (1-6-2)	9	9	.
AMa 95 abc	Engineering Mathematics (4-0-8)	12	12	12
Ch 21 abc	The Physical Description of Chemical Systems (3-0-6)	9	9	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
	Electives	9	9	18
		48	48	48

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

[2]Six units of laboratory beyond the freshman year requirements must be taken in addition to the laboratory associated with the 18 units of chemistry electives. None of the laboratory credits may be obtained in applied math or computer science.

[3]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.

Fourth Year

ChE 101 ab	Applied Chemical Kinetics (3-0-6)	9	9	.
ChE 110 abc	Optimal Design of Chemical Systems (3-0-6)	9	9	.
ChE 111	Simulation and Design of Chemical Systems	.	.	9
	Electives	18	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 the Advanced Placement first-year chemistry course as described on page 148. The one-term required laboratory is essentially in quantitative analysis, but is designed to train the student to plan, execute, and critically interpret experiments involving quantitative measurements of various physical quantities. The laboratory in the second and third terms is optional and is designed to introduce the student to current experimental work in chemical synthesis, structure, and dynamics.

There are no formal chemistry course requirements in the chemistry option except for 2 units of Ch 90. Each student, in consultation with his or her adviser, selects a suitable course of study under the supervision of the division. Within the total period of undergraduate study there are Institute requirements for Ma 1 abc, Ph 1 abc, Ma 2 abc, Ph 2 abc, and 108 units of humanities and/or social science as well as 9 units of physical education.

The group of courses listed below would constitute a common core for many students in the option.

Any student of the chemistry option whose grade-point average 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 90
2. Passing grades must be earned as required by the chemistry department, including the course 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	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
Ch 46 ab	Experimental Methods of Covalent Chemistry (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	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	38-42	36-40
		45-49	47-51	45-49

Fourth Year

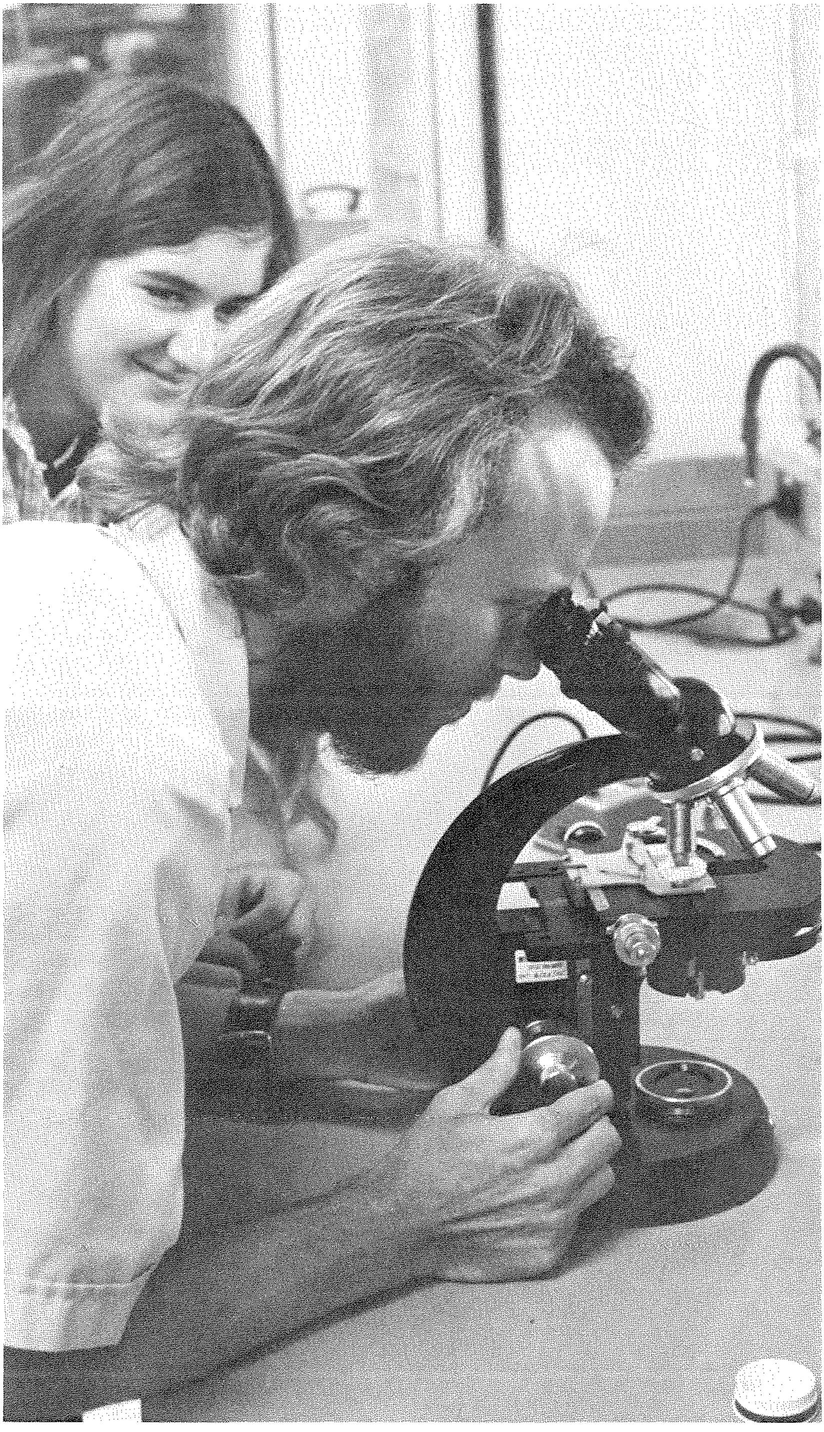
Ch 26 a	Physical Chemistry Laboratory (0-6-4)	.	10	.
	Electives	47-51	37-41	47-51
		47-51	47-51	47-51

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.

Suggested Representative Courses of Study for Those Intending To Do Graduate Work in Particular Areas of Chemistry

Inorganic Chemistry	*Chemical Physics*	*Organic Chemistry*	*Chemical Biology*
Sophomore Year	Sophomore Year	Sophomore Year	Sophomore Year
Ch 41 abc	Ch 41 abc	Ch 41 abc	Ch 41 abc
Ch 46 ab	Ch 46 a	Ch 46 ab	Ch 46 ab
Ph 2 abc	Ph 2 abc	Ph 2 abc	Ph 2 abc
Ma 2 abc	Ma 2 abc	Ma 2 abc	Ma 2 abc
Electives[1,2]	Electives[1,2]	Electives[3]	Electives[1]
Junior Year	Junior Year	Junior Year	Junior Year
Ch 21 abc	Ch 21 abc	Ch 21 abc	Ch 21 abc
Ch 14	Ch 14	Ch 14	Ch 14
Ch 15	Ch 15	Ch 15	Ch 15
Ch 90	Ch 26 ab	Ch 144 ab	Bi/Ch 110
Electives[1,2]	Ch 90	Ch 90	Ch 90
	AM 95 ab	Electives[3]	Electives[1]
	Electives[1,2]		
Senior Year	Senior Year	Senior Year	Senior Year
Ch 26 ab	Ch 125 ab	Ch 26 ab	Ch 26 ab
Ch 112 abc or Ch 113 abc	Ph 106 abc or Ch 135	L 39[1]	Ch 132 ab
Ch 125 ab or		Ch 247 ab	Ch 133
Ch 120 abc or Ch 135 or Ch 144 ab	Ch 227 ab	Electives[3]	Ch 144 ab
Electives[1,2]	Electives[1,2]		Bi 111
			Electives[1]

[1]It should be recognized that a major fraction of the existing chemical literature, especially of organic chemistry, is in German. Russian is an important language for chemistry but the leading Russian periodicals are translated and published in English. A reading knowledge of German is important for research at the doctoral level.
[2]Experience in computer programming and use is now important to all areas of chemistry.
[3]Courses in biology and biochemistry are recommended as part of these electives.



Suggested Elective Courses for the Chemistry Option

1. *Chemistry:* Experimental Chemical Science (Ch 3), Chemical Research (Ch 80), Independent Reading in Chemistry (Ch 81), Biochemistry (Bi/Ch 110), Advanced Inorganic Chemistry (Ch 112), Advanced Ligand Field Theory (Ch 113), Introduction to Electrochemistry (Ch 117), Experimental Electrochemistry (Ch 118), The Nature of the Chemical Bond (Ch 120), Methods for the Determination of the Structure of Molecules (Ch 122), The Elements of Quantum Chemistry (Ch 125), Nuclear Chemistry (Ch 127), Fundamentals of Photochemistry and Photobiology (Ch 130), Physical Chemistry of Biological Macromolecules (Bi/Ch 132), Physical Chemistry of Biological Macromolecules Laboratory (Bi/Ch 133), and Organic Chemistry (Ch 144).
2. *Chemical Engineering:* Chemical Engineering Systems (ChE 10), Chemical Engineering Thermodynamics (ChE 63), Undergraduate Research (ChE 80), Applied Chemical Kinetics (ChE 101), Transport Phenomena (ChE 103), Polymer Science (ChE 167), Polymer Science Laboratory (ChE 168), Optimal Control Theory (Ae/ChE/EE 172), Advanced Transport Phenomena (ChE 173).
3. *Biology:* Introduction to Biology (Bi 1), Cell Biology (Bi 9), Advanced Cell Biology (Bi 119), Genetics (Bi 122).
4. *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 Use of Computers (CS 10).
5. *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).
6. *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 152).
7. *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 15, Ec 121 ab, Ec 122, and Ec 126 ab
2. Ma 112 a, or CS/SS 142 a
3. 45 additional units of advanced economics and social science courses (not including Business Economics and Management). Students may take AMa 181 abc in partial fulfillment of this requirement.

4. 45 units of science, mathematics, and engineering courses. This requirement cannot be satisfied by APh 3, APh 4, APh 9, Bi 2, Ch 3, ChE 10, E 5, EE 4, EE 5, EE 10, Gr 1, CS 10, MS 4, Ph 3, Ph 4, or Ph 10. These courses are excluded because either they are freshman laboratory courses or they are 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 abc may count towards either this requirement or the economics electives requirement, but not towards 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	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
Ec/SS 11 a	Introduction to Microeconomics (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

Third Year

Ec 121 ab	Price Theory (3-0-6)	9	9	.
Ec 122	Econometrics (3-0-6)	.	9	.
Ec 126 ab	Money, Income, and Growth (3-0-6)	9	9	.
Ma 112 a or	Elementary 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.

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, information and computer science, solid mechanics, the science of materials, soil mechanics, bio-engineering science, elasticity and plasticity, plasma physics, and the theory of waves and vibrations. For those students who, in later life, hope to apply the science they learn to the useful and productive solution of the problems now confronting society, the option in engineering and applied science offers an unusually broad curriculum which permits the student to tailor a course of study to his or her individual needs. The first year of the four-year course of study leading to a Bachelor of Science degree is common for all students of the Institute, although freshman elective subjects are available as an introduction to various aspects of engineering and applied science. At the end of the first year, a student who elects the engineering and applied science option is assigned an adviser in his or her general field of interest and, together, they develop a program of study for the next three years. Beyond the Institute-wide requirements of physics, mathematics, and humanities, this program requires one year of applied mathematics and a certain number of units selected from a wide variety of engineering and applied science courses as well as interdivisional options such as applied physics and applied mathematics courses, from which the student and the adviser may choose to build a solid foundation for the kind of engineering and applied science activity which the student desires to learn.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed under the Division of Engineering and Applied Science may, at the discretion of the faculty in this division, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 156.

Option Requirements

1. E 10
2. AMa 95 abc or Ma 108 abc.
3. 99 additional units in courses in the following: AMa, APh, Ae, AM, BIS, CE, ChE, CS, E, EE, ES, Env, Gr, Hy, JP, MS, or ME

   Note that the student cannot exercise his pass/fail option on any courses offered to meet this requirement.
4. 9 units[1] of courses taken from the following list: Ae 105 abc, AM 155, APh 91 abc, APh 163, EE 90 abc, EE 91 abc, APh 154, CS 111, Env 116, Env 143, Hy 111, Hy 121, CS 140, JP 170, MS 11, MS 130, MS 131, MS 132, ME 126
5. 9 units[1] of additional laboratory[2] excluding those for which freshman credit is allowed.
6. 27 additional units of science and engineering electives.
7. 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	9	9	9
Ph 2 abc	9	9	9
Humanities Electives[3]	9	9	9
Electives[4]	18	18	18
	45	45	45

[1]These units will partially satisfy requirement 3 when in appropriate subjects.
[2]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.
[3]See statement on page 170.
[4]See items (3, 4, 5, 6), Option Requirements. The units listed are typical. Most programs will vary somewhat from these numbers of units, but the total number must be selected so as to meet the overall unit requirements indicated in item 7.

Third Year

AMa 95 abc or Ma 108 abc	12	12	12
Humanities Electives[1]	9	9	9
Electives[2]	24	24	24
	45	45	45

Fourth Year

E 10	.	2	.
Humanities Electives[1]	9	9	9
Electives[2]	33	33	33
	42	44	42

[1]See statement on page 170.
[2]See items (3, 4, 5, 6), Option Requirements. The units listed are typical. Most programs will vary somewhat from these numbers of units, but the total number must be selected so as to meet the overall unit requirements indicated in item 7.

NOTES:
I. Suggested electives suitable for particular fields of interest are given below.
II. The programs formed with these suggested electives are only samples of typical programs and are *not* meant to represent special option requirements.
III. These electives must be chosen so as to satisfy the laboratory requirements given in items 4 and 5 above.

Suggested Electives

AERONAUTICS

First Year

One course per term selected from ChE 10, E 5, CS/EE 4, CS 10

Second Year[2]

ME 17 abc or APh 17 abc; one course per term selected from: ME 1 ab, MS 15 abc, Ay 1, EE 5, APh 3, E 13

Third Year

AM 97 abc, ME 19 abc; one course per term selected from: APh 50 abc, AM 151 abc, EE 90 abc[1], ME 5 abc, MS 5 abc, 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 105 abc, AMa 101 abc, AM 155, Hy 111[1], ME 126[1], 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 11

Second Year[2]

ME 17 abc; one course per term selected from: Ge 1, Bi 1, 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[1], 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[1], AM 135 abc, AM 141 abc, Hy 101 abc, Ph 106 abc, AMa 104, AMa 105 ab

[1]Satisfies laboratory requirement, no. 4 on page 184.
[2]Students who have completed Ma 2 prior to their sophomore year are encouraged to take AMa 95 abc as sophomores. Courses suggested in the junior and senior years may then be taken correspondingly earlier.

COMMUNICATIONS & CONTROL

First Year

One or two courses per term selected from: CS/EE 4, CS 10, CS 11, EE 5, Ph 3

Second Year[2]

EE 14 abc; one course per term selected from: E 13 or EE 13 a and EE 13 bc, CS 110, Ma 112 ab

Third Year

EE 160 abc, EE 90 ab[1], CS 137, CS 138, CS 139; one course per term selected from: E 101, ChE 103 abc, EE 151 abc, Ma 5 abc

Fourth Year

AMa 104, AMa 153 abc, EE 161 abc, Ae/ChE/EE 172 abc, EE 91 ab[1], one course per term selected from: AMa 105 ab, ChE 173, Ma 144 ab

COMPUTER SCIENCE

First Year

One or two courses per term selected from: CS/EE 4, CS 10, CS 11, EE 5

Second Year[2]

CS 137, CS 138, CS 139, Ma 5 abc

Third Year

CS 110 abc, 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

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 11, Env 1, Gr 1, CS 10

Second Year

APh/ME 17 abc or ChE 63 abc; one course per term selected from: Ch 14, Env 20, EE 5, E 13 or EE 13 a, EE 13 bc, EE 14 abc, Ec/SS 11 ab, Ge 1, Ge 5, ME 1 ab, MS 15 abc

Third Year

ME 19 abc or ChE 103 abc; one course per term selected from: APh 50 abc, AM 97 abc, Ch 21 abc; EE 90, ME 5 abc, ME 126, Ec 115, Ec 116, Ec 118, 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 151 abc, AM 155, APh 105 abc, ChE/Env 157, Hy 101 abc, ME 118 abc, ME 126, MS 5 abc

NOTE: Humanities electives particularly appropriate to energy studies are Ec 115, Ec 116, Ec 118, SS 130 abc, SS 150 abc.

ELECTRON DEVICE PHYSICS

First Year

One or two courses per term selected from: APh 3, APh 9, CS/EE 4, CS 11, EE 5, Ph 3

Second Year[2]

EE 14 abc, APh 17 abc

Third Year

APh 50 abc, EE 151 abc or Ph 106 abc, EE 90 ab[1], one course per term from: EE 13 abc, MS 5, MS 120, MS 121, MS 122

Fourth Year

APh 114 abc, APh 181 abc, APh 91 ab[1]; one course per term selected from: APh 105, APh 140, MS 125, MS 126 ab, Ph 125

ELECTRONIC CIRCUITS

First Year

One or two courses per term selected from: APh 3, CS/EE 4, CS 10, CS 11, EE 5

Second Year[2]

EE 14 abc; one course per term selected from: APh 17 abc, CS 110 abc

Third Year

E 13 or EE 13 a and EE 14 bc, EE 151 abc, EE 90 ab[1]; one course per term selected from: APh 50 abc, CS 137, CS 138, CS 139, ME 19 abc

Fourth Year

EE 114 abc, Ae/ChE/EE 172 abc, EE 91 ab[1]; one course per term selected from: AMa 105 ab, APh 181 abc, EE 160, E 101

[1]Satisfies laboratory requirement, no. 4 on page 184.
[2]Students who have completed Ma 2 prior to their sophomore year are encouraged to take AMa 95 abc as sophomores. Courses suggested in the junior and senior years may then be taken correspondingly earlier.

ENVIRONMENTAL ENGINEERING SCIENCE

(Note: By suitable choice of electives, students may place special emphasis on air, water, or other aspects of the environment.)

First Year

Env 1; one course per term selected from: Bi 1, Bi 9, ChE 10, Ch 3 bc, E 5, Ge 1, CS 10, Env 20

Second Year

ME 17 abc or ChE 63 abc, Ec/SS 11; one course per term selected from: Ch 14, Ch 41 abc, CS/EE 4, CS 11, E 13, Env 144, Ge 5, MS 15 abc

Third Year

ME 19 abc or ChE 103 abc, Ec 118; one course per term selected from: AM 97 abc, Ch 15, Ch 21 or 24, Hy 111, Ma 112 ab, ChE 90 (or other electives listed above)

Fourth Year

AMa 104, AMa 105 ab, AMa 181 abc, CE 105, CE 115 ab, Env 112 abc, Env 116, Env 117, Env 142 ab, Env 145 ab, Env 146 abc, Env 170 ab, Ge 130, Hy 101 abc, Hy 113 ab, E 99, Env 103 ab, Env 120, Env 143, E 101, (or other electives listed above); also research, Env 90

NOTE: The following humanities and social science electives are of special interest for students in environmental engineering science:

An 1, An 123, Ec 115, Ec 119, Ec 128 abc, Ec 130 ab, PS/SS 122, PS 1 abc, PS 135 abc, SS 150 abc, SS 151

FLUIDS ENGINEERING AND JET PROPULSION

First Year

One course per term selected from: Gr 1, E 5, CS 10

Second Year[2]

ME 17 abc, APh 3, CS/EE 4, EE 5

Third Year

ME 19 abc, AM 97 abc; one course per term selected from: ME 5 abc, ME 126[1], ES 102 ab, E 13

Fourth Year

Hy 101 abc, AM 151 abc; one course per term selected from: AM 155, ME 118 abc, E 101, JP 121 abc, JP 170[1], Hy 111[1]

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[2]

APh/ME 17 abc; one course per term selected from: Ph 3[3], Ph 4[3], CS/EE 4, CS 11, ME 15 abc, Gr 1, E 13

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[1] or ME 126[1], 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, Gr 1, ChE 10, APh 3, APh 9, MS 4

Second Year[2]

APh/ME 17 abc; one course per term selected from: ME 1 ab, ME 3, EE 5

Third Year

AM 97 abc, MS 5 abc, APh 50 abc, ChE 107 abc

Fourth Year

MS 120, MS 121, MS 122, MS 125, MS 126 ab

MECHANICAL DESIGN

First Year

One course per term selected from: Gr 1, E 5, EE 5

Second Year[2]

ME 1 ab, 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[1], MS 11; CS 10, EE 90

[1]Satisfies laboratory requirement, no. 4 on page 184.
[2]Students who have completed Ma 2 prior to their sophomore year are encouraged to take AMa 95 abc as sophomores. Courses suggested in the junior and senior years may then be taken correspondingly earlier.
[3]Satisfies laboratory requirement, no. 5 on page 184.

Fourth Year

AM 151 abc, MS 5 ab; two courses per term selected from; Ae 241 abc, AM 155[1], E 13 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[2]

APh/ME 17 abc; one course per term selected from: Ph 3[3], Ph 4[3], CS/EE 4, CS 11, MS 15 abc, Gr 1

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[1], 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[3], MS 4

Second Year[2]

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 120, MS 121, MS 122, MS 125, MS 126 ab, Ph 125 abc, MS 130[1], MS 131[1], MS 132[1]

[1]Satisfies laboratory requirement, no. 4 on page 184.
[2]Students who have completed Ma 2 prior to their sophomore year are encouraged to take AMa 95 abc as sophomores. Courses suggested in the junior and senior years may then be taken correspondingly earlier.
[3]Satisfies laboratory requirement, no. 5 on page 184.

Geology, Geochemistry, and 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. Special emphasis is also placed on field work 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 and planetary science, and geochemistry. Sufficient flexibility in electives is provided to permit a student to follow lines of special interest in related scientific and engineering fields. Students who do well in the basic sciences and at the same time have a compelling curiosity about the earth and its natural features are likely to find their niche in the geological sciences, especially if they possess flexible minds that enable them to grapple with complex problems involving many variables. Most students majoring in the earth sciences now find further training at the graduate level necessary.

Undergraduate Research and Bachelor's Thesis. The division encourages undergraduate research, particularly of such scope and caliber as to merit the preparation of a Bachelor's Thesis. Guidance in seeking research opportunities and in drawing up a research plan leading to the Bachelor's Thesis is available from the divisional Undergraduate Research Counselor.

Attention is called to the fact that any student whose grade-point average in 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

		Year 1	2	3	S	4
Institute Requirements						
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
Division Requirements						
Ge 100	Geology Club recommended					1
Ge 102	Oral Presentation					2
Ge 104 abc	Advanced General Geology			27		
Ge 105 ab	Geologic Field Training and Problems			18		
	Language Elective[2]					30
	Total required courses[3]	126	108	72		60
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[4]	Physical Chemistry			27		
Ch 14	Chemical Equilibrium and Analysis					6
Ch 15	Chemical Equilibrium and Analysis Laboratory					10
	Total required courses	126	108	99	30	112

[1]These 27 units of sophomore electives should be used to broaden the students' background 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, Ge 5, and Ge 155, is specifically required of majors, but the election of one or more of these is highly recommended in the second year. 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 Ph 5, Ph 6, Ph 7, and Ch 15.

[2]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.

[3]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.

[4]Ch 41 abc or other chemistry courses may be substituted with prior consent of adviser and option representative.

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 Geology					36
Ch 21 abc	Physical Chemistry[1]			27		
	Geology Electives[2]			27		
	Total required courses	126	108	135	30	132

Geophysics and Planetary Science Option Requirements

Ph 106 abc	Topics in Classical Physics			27		
AMa 95 abc	Engineering Mathematics			36		
	Option Electives[3]					54
	Total required courses	126	108	135		114

[1]Ch 41 abc or other chemistry courses may be substituted with the prior consent of the 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. Ge 2 is not included, but may be included in the sophomore science electives.

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 (see below); 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. He or she will explore 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 in a topic in that area, 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 APh 3, APh 4, APh 9, Bi 2, Ch 3, ChE 10, E 5, EE 4, EE 5, EE 10, Gr 1, CS 10, MS 4, Ph 3, Ph 4, or Ph 10. These courses are excluded because either they are freshman laboratory courses or they are 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
Math 2 abc	9	9	9
Physics 2 abc	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

	1st	2nd	3rd
H 97 ab		9	9
Science or Math	9 (Ma 112a)	9 (Ma 112b)	9
History electives	9	9	9
Other electives	27	18	18
	45	45	45

Fourth Year

	1st	2nd	3rd
H 99 abc	9	9	9
Science or Math	9	9	9
History electives	9 (H98a[1])	9 (H 98b[1])	9
Other electives	18	18	18
	45	45	45

[1]If appropriate.

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 within a normal option. A student's program may consist of normal Caltech courses, research courses, courses at other schools, and independent study courses (described 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 faculty ISP Committee has over-all responsibility for the program. Each student formulates his or her individual course of study under the supervision 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 which 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 for graduation to the faculty.

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 which 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.[1] Within these 108 units, the following are required:
   a. 18 units (two terms) of Shakespeare, selected from Lit 114 a, Lit 114 b, Lit 115
   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, and 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 APh 3, APh 4, APh 9, Bi 2, Ch 3, ChE 10, E 5, EE 4, EE 5, EE 10, Gr 1, CS 10, MS 4, Ph 3, Ph 4, or Ph 10. These courses are excluded because either they are freshman laboratory courses or they are 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	Electromagnetism and Quantum Mechanics (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 expect to make mathematics their profession must normally plan to continue, either here or elsewhere, with graduate work leading to the degree of Doctor of Philosophy. Undergraduates should bear this in mind in choosing their courses of study. In particular, they are urged to include at least one year, and preferably two years, of language study in their programs. Overloads in course work are strongly discouraged; students are advised instead to deepen and supplement their course work by independent reading.

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, postponing the selected course in mathematics to the senior year. They are strongly advised to take one or preferably two full-year courses in languages.

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. A fuller statement of this regulation will be found on page 156.

Option Requirements

1. Ma 5 abc, Ma 108 abc
2. One of the following one-year courses: Ma 116 abc, Ma 118 abc, Ma 120 abc, Ma 121 abc, Ma 122 abc, Ma 125 abc, Ma 137 a followed by Ma 143 ab, Ma 137 a followed by Ma 144 ab, Ma 150 abc, Ma 151 abc, Ma 152 abc, Ma 160 abc
3. 27 additional units in Ma or AMa; 27 additional units outside of Ma and 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	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Electives in Science, Engineering or Humanities	9	9	9
	Humanities Electives,[1] minimum for first two years: 45 units	0-9	0-9	0-9
		36-45	36-45	36-45

Third Year

Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
	Selected courses in Mathematics.......minimum	9	9	9
	Humanities Electives,[1] minimum for first three years: 81 units	9-18	9-18	9-18
	Electives in Science, Engineering, or Humanities.......minimum	9	9	9
	For each term the total number of units is required to fall within range	39-48	39-48	39-48

Fourth Year

Selected course in Mathematics	9	9	9
Humanities Electives,[1] minimum for graduation: 108 units	9-18	9-18	9-18
Electives in Mathematics, Science, Engineering or Humanities.......minimum	18	18	18
For each term the total number of units is required to fall within range	36-45	36-45	36-45

Normally a junior will elect 9 units each term, and a senior 18 units each term, in mathematics. Sophomores who have not taken Ma 5 must take this course as juniors, postponing the selected course in mathematics to the senior year. They are strongly advised to take one or preferably two full-year courses in languages.

[1]For rules governing humanities electives, see page 170.

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 electricity as they apply to the dynamics of particles. More complex problems including quantum mechanics, electromagnetic fields, and atomic structure will be treated in the second year. Those who want to major in physics take intensive courses during their junior and senior years that provide an unusually thorough preparation for graduate work. The curriculum provides for the teaching of classical and modern physics from the first year through the entire undergraduate course of study. Elective courses during the junior and senior years provide flexibility which enables the 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 which are always under way and the graduate seminars which are open to undergraduates at all times.

Attention is called to the fact that any student whose grade-point average for one academic year is less than 1.9 in the subjects listed under this division will normally be refused permission to continue in the physics option. A more complete statement of this regulation will be found on page 156.

Option Requirements

1. Ph 3 or Ph 4
2. Ph 5 or Ph 6[1]
3. Ph 7
4. One of the following: Ph 92 abc, Ph 112 abc, or Ph 125 abc
5. Ph 106 abc
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 93 abc, Ph 112 abc, Ph 125 abc, Ph 127 abc, Ph 129 abc, APh 105 abc, APh 114 abc, APh 140 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.

[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.

Typical Course Schedule

Second Year

	Units per term 1st	2nd	3rd
Ph 2 abc	9	9	9
Ma 2 abc	9	9	9
Humanities Elective[2]	9	9	9
Physics Laboratory[3]	0	6	6
Electives	12	9	9
	39	42	42

Third Year

Ph 92 abc	9	9	9
Ph 106 abc	9	9	9
Humanities Elective[2]	9	9	9
Electives	18	18	18
	45	45	45

Fourth Year

Ph 77 ab	6	6	.
Physics Electives	18	18	18
Humanities Elective[2]	9	9	9
Electives	18	18	18
	51	51	45

Physics Laboratory Requirements

Students choosing a major in physics must complete the following laboratory requirements by the end of the second year:

Ph 3 or Ph 4	6 units
Ph 5 or Ph 6[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.
[2]See Institute Requirements for specific rules regarding humanities.
[3]See Option Requirements 1, 2 and 3.

Suggested Electives

Sophomore Year		
Ma 5 abc	Ay 22	EE 13 abc
Ge 1	ME 1 ab	EE 14 abc
Ge 4	ME 3	Ch 41 abc
Bi 1	APh/ME 17 abc	L 130 abc
Ay 20	EE 4	
Ay 21	EE 5	
Junior Year		
Ph 77 ab	Ge 101 abc	EE 14 abc
Ph 125 abc	Ge 166	EE 90 abc
Ph 171	Bi 9	Ch 21 abc
Ph 172	Ay 100	L 102 abc
AMa 95 abc	Ay 101	L 141 abc
Ma 108 abc	Ay 102	
	EE 13 abc	
Senior Year		
Ph 78 abc	Ph 125 abc	APh 105 abc
Ph 79 abc	Ph 127 abc	APh 114 abc
Ph 93 abc	Ph 129 abc	APh 140 abc
Ph 112 abc	APh 91 ab	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, and PS 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 APh 3, APh 4, APh 9, Bi 2, Ch 3, ChE 10, E 5, EE 4, EE 5, EE 10, Gr 1, CS 10, MS 4, Ph 3, Ph 4, or Ph 10. These courses are excluded because either they are freshman laboratory courses or they are 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 abc may count towards either this requirement or the economics electives requirement, but not towards both.
4. 45 additional units in any of the following: 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
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electromagnetism and Quantum Mechanics (4-0-5)	9	9	9
	Electives	24	24	24
		42	42	42

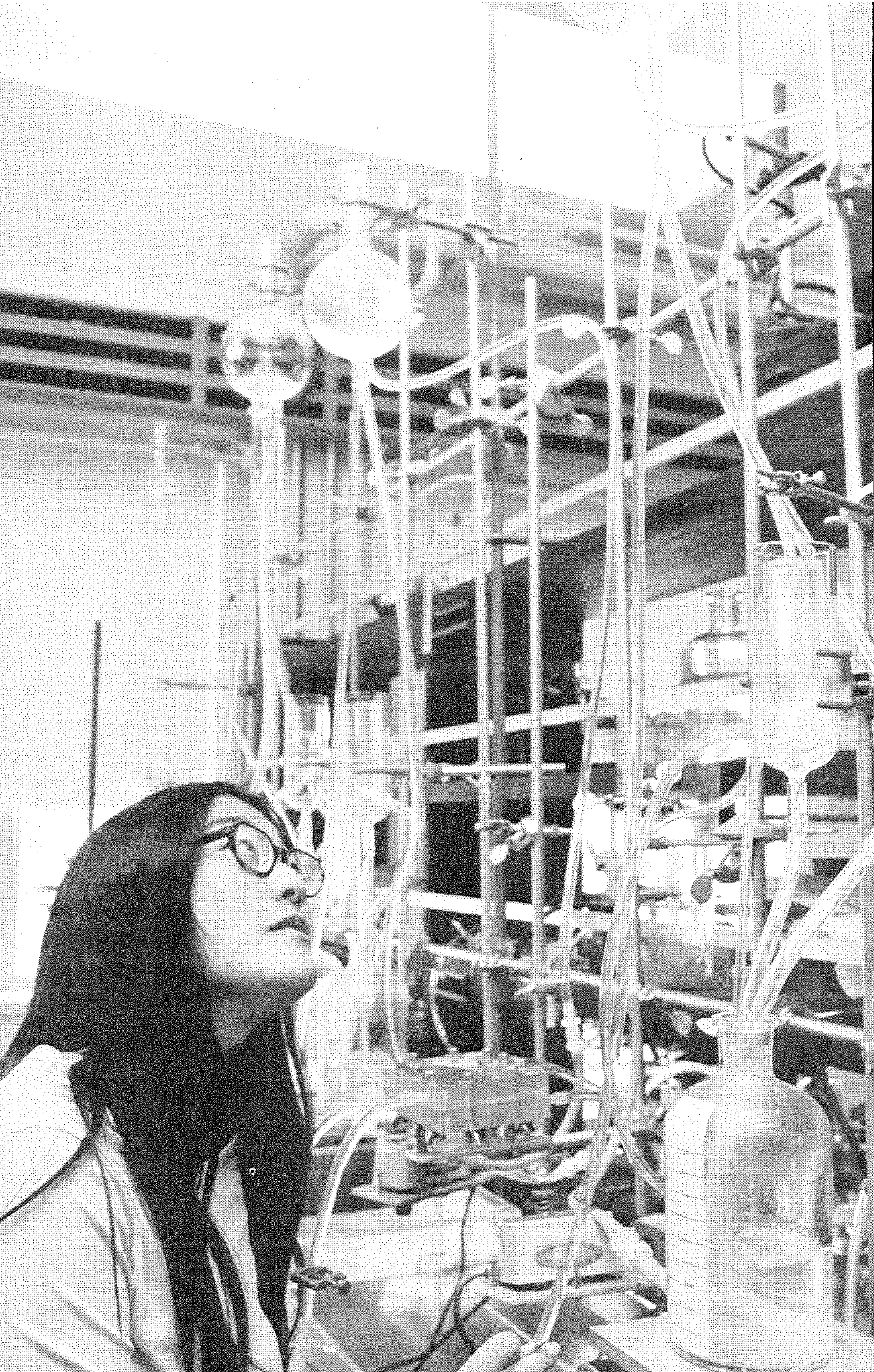
Third Year

		1st	2nd	3rd
Ma 112 a or	Elementary Statistics (3-0-6)	9	.	.
CS/SS 142 a	Computing Modeling and Data Analysis (3-0-6)	9	.	.
Ec 121 ab	Microeconomic Theory I & II (3-0-6)	9	9	.
Ec 122	Econometrics (3-0-6)	.	9	.
PS 122	Analytical Political 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

		1st	2nd	3rd
	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, Geological Engineer, Geophysical Engineer, and Mechanical Engineer.

The academic work of the Institute is organized in six divisions:

Biology
Chemistry and Chemical Engineering
Engineering and Applied Science
Geological and Planetary Sciences
The Humanities and Social Sciences
Physics, Mathematics and Astronomy

Graduate work at the Institute is further organized into graduate options. Each option is supervised by those professors whose interests and research are closely related to the area of the option, within the administrative jurisdiction of one or more of the divisions. The graduate student who is working for an advanced degree in one of the graduate options is associated with an informal group of those professors who govern the option, other faculty including research associates and fellows, and other graduate students working for similar degrees.

A faculty member from each area of graduate study is available for consultation on problems concerning academic programs, degree requirements, financial aid, etc. The representatives for 1976-77 are as follows:

Aeronautics:	Prof. C. D. Babcock, Jr.
Applied Mathematics:	Prof. H. B. Keller
Applied Mechanics:	Prof. F. S. Buffington
Applied Physics:	Prof. R. W. Vaughan
Astronomy:	Prof. J. E. Gunn
Biology:	Prof. J. F. Bonner
Chemical Engineering:	Prof. L. G. Leal
Chemistry:	Prof. D. A. Evans
Civil Engineering:	Prof. F. S. Buffington
Electrical Engineering:	Prof. R. V. Langmuir
Engineering Science:	Prof. F. S. Buffington
Environmental Engineering Science:	Prof. F. S. Buffington
Geological and Planetary Sciences:	Prof. A. L. Albee
Materials Science:	Prof. F. S. Buffington
Mathematics:	Prof. R. P. Dilworth
Mechanical Engineering:	Prof. F. S. Buffington
Physics:	Prof. S. C. Frautschi
Social Science:	Prof. L. E. Davis

GENERAL REGULATIONS

Admission to Graduate Standing

Application for admission to graduate standing should be made to the Dean of Graduate Studies, on a form obtained from his office. Admission to graduate standing will be granted *only to a limited number of students of superior ability*, and application should be made as early as possible. No application fee is required. In general, admission to graduate standing is effective for enrollment only at the beginning of the next academic year. The California Institute of Technology encourages applications from both men and women, including members of minority groups. Students 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 on campus or through 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.

In exceptional cases, students who have already decided to pursue a graduate degree may be permitted to earn credits toward that degree during their undergraduate years by being admitted also to graduate studies at the Institute prior to receipt of their undergraduate degree, thus allowing their undergraduate and graduate studies to overlap. Application for admission to graduate studies should be made in the normal way.

Special students, not working for degrees, are admitted only under exceptional circumstances.

Graduate Residence

One term of residence shall consist of one term's work of not fewer than 36 units of advanced work in which a passing grade is recorded. If fewer than 36 units are successfully carried, the residence will be regarded as shortened in the same ratio; but the completion of a large number of units in any one term will not be regarded as increasing the residence. The residency requirement for each degree will be found under the degree regulation. In general, the degree requirements are: Master of Science, after a minimum of three terms (one year) of graduate work; Aeronautical Engineer, Civil Engineer, Electrical Engineer, Geological Engineer, Geophysical Engineer, and Mechanical Engineer, after a minimum of six terms (two years) of graduate work; and Doctor of Philosophy, after a minimum of nine terms (three years) of graduate work.

Advanced work is defined as study or research in courses whose 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 which 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. At the first meeting of each class they should furnish the instructor with a class admission card for the course, obtained on registration. *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. M.S. candidates must obtain the signature of the Dean of Graduate Studies on all drop or add cards.

In registering for research, students should indicate on their program card the name of the instructor in charge, and should consult with him to determine the number of units to which the proposed work corresponds. At the end of the term the instructor in charge may decrease the number of units for which credit is given in case he feels that the progress of research does not justify the full number originally registered for.

A graduate student who undertakes activities related to the Institute (studies, research, 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 (see page 201) 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 (see page 209).

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.

The registration of a graduate student is not complete unless a photograph for the Registrar's record card is affixed thereto, or certification from the photographer is obtained to show that such photograph is in course of preparation on the date of registration. The Registrar provides the opportunity to have these photographs made, without cost to the student, on the registration days of the first and second terms of each year. Photographs taken for this purpose at other times are provided by the student at his or her own expense.

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, on the program, will be limited to the first two years of academic residence for each student. Beyond the initial period, students continuing their graduate work must do so on a full-time basis.
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 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 its 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 its 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 scholarship (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 (see page 154), the grade of "P", which denotes passed, may be used at the discretion of the instructor, for all or some of the students, in the case of seminar or other work which does not lend itself to more specific grading. In graduate research, only the grades of "P" and "F" are given.

Exchange Program with Scripps Institution of Oceanography

An exchange program has been established with the Scripps Institution of Oceanography (SIO), University of California, San Diego, permitting Caltech graduate students to enroll in and receive credit for graduate courses offered by SIO. Arrangements should be made through the student's major department and the office of the Dean of Graduate Studies. The student must obtain the advance approval of the instructors of courses to be taken at SIO. In some cases, when it is in the best interests of the student, arrangements may be made for the student to be temporarily in full-time residence at SIO.

Thesis research work done partly at SIO may be arranged directly by the student's department and the staff of appropriate research laboratories at SIO, without the necessity of enrolling for SIO courses designated for research; in this case the student will continue to be under the supervision of his or her Caltech thesis adviser and enroll for Caltech research units.

DEGREE REGULATIONS

Degree of Master of Science

The Master of Science degree is a professional degree intended to prepare a student for teaching, for further graduate studies, or for more advanced work in industry. Detailed requirements are based primarily on professional studies, and the program should be planned in consultation with the faculty in the appropriate discipline.

Under normal circumstances, the requirements for the M.S. degree can be completed in one academic year, but students from other schools who do not have completely adequate preparation may require longer.

Special regulations for the Master's Degree in each graduate option are on pages 210 through 247.

Residence and Units of Graduate Work Required

At least one academic year of residence at the Institute (as defined on page 203) and 135 units of graduate work subsequent to the baccalaureate degree are required for the master's degree. Included in these are at least 27 units of free electives or of required studies in the humanities. Courses used to fulfill requirements for the bachelor's degree may not be counted as graduate residence.

To qualify for a master's degree, a student must complete the work indicated in the section on special regulations for his 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 prior to enrollment at the Institute may be offered for credit. An examination may be required to determine the acceptability of such courses. Course credit, if granted, shall not be construed as residence credit.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree, he 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 proper authority.

All changes in registration must be reported on drop or add cards to the Registrar's Office. M.S. candidates must obtain the signature of the Dean of Graduate Studies on all drop or add cards.

Engineer's Degree

The work for an engineer's degree must consist of advanced studies and research in the field appropriate to the degree desired. It must conform to the special requirements established for the degree desired and should be planned in consultation with the members of the faculty concerned. Advanced studies are defined on page 202. Regulations governing registration will be found on page 203. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a new petition to continue graduate work toward the desired degree. Students who have received an engineer's degree will not in general be admitted for the doctor's degree.

Residence. At least six terms of graduate residence (as defined on page 203) subsequent to a baccalaureate degree equivalent to that given by the California Institute are required for an engineer's degree. Of these, at least the last three terms must be at the California Institute. It must be understood that these are minimum requirements, and students must often count on spending a somewhat longer time in graduate work.

To qualify for an engineer's degree a student must complete the work prescribed by his 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.

In the case of a student registered for work toward an engineer's degree, and holding a position as graduate assistant or other Institute employee, the actual number of hours per week required by teaching or research services shall be deducted from the total number of units for which he or she might otherwise register. This number of units shall be determined by the department.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree he 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 which appears on the approved schedule and for which the applicant is registered may be removed after the last date for dropping courses as listed in the catalog.

The student will be admitted to candidacy for the degree when 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 governing the preparation of doctoral dissertations, which may be obtained from the Graduate Office.

The use of "classified" research as thesis material for any degree will not be permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Before submitting the thesis, the candidate must obtain written approval of it 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.

Examination. At the option of the department representing the field in which the degree is desired, a final examination may be required. This examination would be conducted by a board to be appointed by the candidate's supervising committee.

Degree of Doctor of Philosophy

The degree of Doctor of Philosophy is conferred by the Institute primarily in recognition of breadth of scientific attainment and of power to investigate scientific problems independently and efficiently, rather than for the completion of definite courses of study through a stated period of residence. The work for the degree must consist of scientific research and the preparation of a thesis describing it, and of systematic studies of an advanced character primarily in science or engineering. In addition, the candidate must have acquired the power of 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. See pages 210-247.

Admission. With the approval of the Committee on Graduate Study, students are admitted to graduate standing by the department in which they choose their major work toward the doctor's degree. In some cases, applicants for the doctor's degree may be required to register for the master's or engineer's degree first. These degrees, however, are not general prerequisites for the doctor's degree. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a request to continue graduate work toward the desired degree. Students who have received an engineer's degree will not, in general, be admitted for the doctor's degree.

During the second or third term of work toward the engineer's degree, a student may apply for admission to work toward the doctor's degree. If this admission is granted, the admission for the engineer's degree will be cancelled.

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.

Residence. At least nine terms (three academic years) of residence subsequent to a baccalaureate degree equivalent to that given by the Institute are required for the doctor's degree. Of this at least one year must be in residence at the Institute. It should be understood that these are minimum requirements, and students must usually count on spending a somewhat longer time in residence. However, no student will be allowed to continue work toward the doctor's degree for more than 15 terms of graduate residence, nor more than 18 registrations for full- or part-time academic work except by special action of the Committee on Graduate Study. In either case graduate study taken elsewhere will be counted when residence credit at the Institute has been allowed. (See page 203 regarding summer registration for research.)

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.

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 pages 210-247. 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 and preferably before admission to graduate standing. Although there is no Institute-wide foreign language requirement for the degree of Doctor of Philosophy, graduate students should check for possible specific requirements set by their division or smaller academic unit.

To encourage the study of foreign languages, the Institute recognizes previous work and offers the possibility of further study as a graduate student.

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 prior to 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 pages 210-247.

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 which 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.

SPECIAL REGULATIONS OF THE GRADUATE OPTIONS

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 which are expected to form a large part of the student's program are divided into three categories as follows:

Group A. Courses in mathematics and mathematical methods. Examples of these would include: AMa 101, 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 161, AMa 181, 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 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 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

APh 110 abc	Topics in Applied Physics (2-0-0)	6 units
	Applied Physics Electives[1]	Minimum 54 units

Suggested Electives[2]: APh 105, APh 114, Ae/APh 101, APh 140, APh 141, APh 153, APh 154, APh 156, APh 161, APh 181, APh 185, 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 a, Ge 166 b

[1]Must be selected from APh 114, Ch 125 or Ph 125, APh 105, Ae APh 101 or APh 156.

[2]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
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 three of the subjects, including number 3, Mathematical Methods, must be demonstrated by grades no lower than C in an appropriate Caltech course. In unusual cases, it will be possible for a student to be deemed competent in any of the subjects by showing evidence of having done well in an equivalent course offered elsewhere, by passing a suitable written examination. The examination must cover all of the specified course, and the student will not be permitted to take it in parts (e.g., term by term) or more than twice.

b. Oral examination. The two subjects which remain will be dealt with in the oral examination. The student will be permitted to repeat a failed oral only once, with or without change of subject. Demonstration of (subject) competence must be completed before the close of the student's second year of residence.

c. Competence in research must be demonstrated as follows: The student must have a doctoral thesis adviser and must have completed 18 units of thesis research with this adviser no later than the beginning of his or her 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: APh 101, APh 156, APh 161, APh 261.

Group B: APh 105, APh 114, APh 140, APh 141, APh 181, APh 185, APh 214, APh 281.

Group C: APh 153, APh 154, APh 190, APh 195.

It is recommended that the minor 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, including those from foreign countries, for admission to graduate study in astronomy 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 Examinations in physics, (see Placement Examinations, page 244) covering material equivalent to Ph 92, Ph 106, and Ph 125. An oral examination by the staff covering material equivalent to Ay 20, Ay 21, Ay 101, and Ay 102 is given on the Friday preceding the beginning of instruction for the first term. These examinations will test whether the student's background of atomic and nuclear physics, mathematics, physics, and astronomy is sufficiently strong to permit advanced study in these subjects. If it is not, students will be required to pass the appropriate courses.

Master's Degree in Astronomy

The choice of astronomy and other science elective courses must be approved by the department. At least 36 units of the 135 units must be selected from Ay 131, Ay 132, Ay 133, Ay 134, Ay 136, Ay 138, Ay 139, Ay 201. The courses Ay 120, Ph 92, Ph 106, and Ph 125 may be required of those students whose previous training in some of these subjects proves to be insufficient. At least 27 units of advanced courses not in astronomy are required.

Degree of Doctor of Philosophy in Astronomy

Astronomy Program: The student's proposed overall program of study must be planned and approved by the department during the first year. Required courses for candidacy are Ay 131, Ay 132, Ay 133 ab, Ay 138, and Ay 139. The student should take these courses as soon as they are offered. Also required are research and reading projects, starting in the second term of the first academic year. Credit for this work will be given under courses Ay 142 and Ay 143. Written term papers dealing with the research or reading done will be required at the end of each term.

Physics Program: The student's program during the first two years of graduate study should include at least 36 units of physics courses, exclusive of Ph 92, Ph 106, and Ph 125. This requirement may be reduced on written approval of the department for students who take substantial numbers of units in Ph 92, Ph 106, and Ph 125. Students in radio astronomy should include Ph 209 in the required 36 units of physics; they may take the remaining units in an advanced course in electrical engineering or applied mechanics. Theoretical astrophysics students should include at least 54 units of physics courses in their program. Students in planetary physics may substitute appropriate advanced courses in geophysics and geochemistry. All the above courses must be passed with a grade of C or better.

The Minor: It is recommended that students take a subject minor in physics. Other fields in which subject minors are taken include geology or engineering, dependent on the student's field of specialization.

Language Requirement: To be admitted to candidacy for the Ph.D. degree in astronomy, the student must demonstrate a knowledge of Russian, German, Spanish, or French sufficient for the reading of technical material in his field. Students will be required to take a special examination administered by the staff in fulfillment of this requirement.

Admission to Candidacy: To be recommended for candidacy for the Ph.D. degree in astronomy, a student must, in addition to general Institute requirements:

a. complete satisfactorily 36 units of research Ay 142 or reading Ay 143;
b. pass with a grade of C or better, or by special examination, Ay 131, Ay 132, Ay 133 ab, Ay 138, and Ay 139;
c. pass 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 prior to 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, and mathematics, or psychology, as well as in biology and its various branches. The aims of the graduate program are to provide, for each student, individual depth of experience and competence in 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 discipline of biology, supplemented with advanced course work and independent study in this discipline; (b) an optional minor program, usually designed to provide the student with professional insight into a discipline 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 in advanced subjects, 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 advisory committee (see below). A student majoring in psychobiology or experimental psychology may arrange to do one or more terms on another campus to obtain relevant course work in psychology and medicine not offered at the Institute.

Admission

Applicants are expected to meet the following minimal requirements: mathematics through calculus, general physics, organic chemistry, physical chemistry (or the equivalent), and elementary biology. Students with deficient preparation in one or more of these categories may be admitted but required to remedy their deficiencies in the first years of graduate training, no graduate credit being granted for such remedial study. This will usually involve taking the courses in the categories in which the student has deficiencies. In certain instances, however, deficiencies may be corrected by examinations following independent or supervised study apart from formal courses. Furthermore, the program in biology is diverse, and in particular fields such as psychobiology and experimental psychology or in interdisciplinary programs such as neurophysiology-electrical engineering, other kinds of undergraduate preparation may be substituted for the general requirements listed above. Graduate Record Examinations (verbal, quantitative, and the advanced test in *any* science) are required of applicants for graduate admission intending to major in biology.

Advisory Committee

During the week preceding registration for the first term, each entering student confers with the divisional Graduate Advisory Committee. The committee consists of a chairman and three other members of the faculty representing diverse fields of biology. The committee will advise the student of deficiencies in background training; will design a remedial study program where necessary; and will recommend an individual study program of advanced course work in accordance with item (c), above. The committee will also be available for consultation and advice throughout the graduate study period until the student is admitted to candidacy (see below).

Teaching Requirements for Graduate Students

All students must acquire teaching experience.

Master's Degree in Biology

The Biology Division does not admit students for work toward the M.S. degree. In special circumstances the M.S. degree may be awarded, provided Institute requirements are met. In general the degree is not conferred until the end of the second year of residence. The degree does not designate any of the disciplines of the division, but is an M.S. in Biology.

Degree of Doctor of Philosophy in Biology

Major Subjects of Specialization. A student may pursue major work leading to the doctor's degree in any of the following disciplines:

Biochemistry
Biophysics
Cell Biology
Developmental Biology
Experimental Psychology
Genetics
Immunology
Neurobiology
Neurophysiology
Psychobiology
Virology

At graduation, a student may choose if the degree is to be awarded in biology or in the selected discipline. 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. It is the philosophy of the biology faculty, however, that a student should leave Caltech knowing more than merely the field associated with the subject of the thesis. It therefore recommends to the graduate student that one of the options below be selected:

a. The student may elect a minor in another division of the Institute. This will consist of 45 units of advanced course work or research.
b. The student may elect a minor in any of the biology disciplines listed above as major subjects of specialization, provided the subject matter of this discipline is not too closely related to that of the major field. Such a minor will consist of 45 units of advanced course work or research.

If the student elects a minor, the diploma designates the discipline of the major and minor (e.g. biophysics and chemistry; biochemistry and neurophysiology).

If the student does not elect a minor, it is strongly urged that two or more courses be taken which broaden his or her knowledge of biology.

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 and are deposited in the Institute library. A third copy is retained in 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 disciplines listed above under major subjects of specialization. Requirements for such a minor are determined by the faculty committee designated for each discipline. 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 one of the disciplines of biology may if desired arrange to have the minor designated as biology, rather than with the name of the specific minor discipline.

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 to this, 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 ChE 126 a, Chemical Engineering Laboratory, ChE 191, which is required for one, two, or three terms at the discretion of the instructor and 36 units of 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. The student who has taken ChE 126 a or its equivalent as an undergraduate may substitute an equal amount of research, ChE 280. A student originally admitted to work toward the Ph.D. degree can substitute an equal amount of research, ChE 280, for all or part of this requirement but must also submit a research report in thesis form and have it accepted by the faculty in chemical engineering. A research report is required for the master's degree. In addition, there are electives, which may include humanities as well as graduate courses from other branches of science and engineering. A minimum of 18 units of these electives must be in advanced chemical engineering subjects; the remainder are to be chosen from other approved advanced subjects but may also include up to 30 units of freely elected graduate courses, which may be in humanities as well as in engineering and science subjects. In addition to 18 units of advanced professional subjects, AM 113 abc must be taken if the equivalent has not been studied previously.

Degree of Doctor of Philosophy in Chemical Engineering

The work leading to the Ph.D. degree prepares students for careers in universities and in the research laboratories of industry and government, although Ph.D. graduates are also well qualified for the areas listed for the master's degree. Usually the first year of graduate work is principally devoted to course work in chemical engineering and related subjects. ChE 191 is required for one, two, or three terms at the discretion of the instructor. Time is also devoted during this period to the choice of 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 may be completed in three calendar years.

Admission. During the Friday preceding General Registration for the first term of graduate study, students admitted to work for the Ph.D. degree are required to consult with the professor in charge of the courses of engineering design, chemical thermodynamics, transport phenomena, and applied chemical kinetics. This informal consultation is aimed at planning course work for each student.

Course Requirements. Although there are no formal chemical engineering course requirements, except for ChE 191, 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 which is to be included in the program.

Candidacy Requirements. To be recommended for candidacy the student must demonstrate proficiency at a graduate level in chemical engineering. This will be done by way of chemical engineering courses, an oral subject examination which is to be taken 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 second term of the student's second year of graduate residence. The oral examination will cover thermodynamics, applied chemical kinetics, transport phenomena, and design, with emphasis at the discretion of the committee. Approval of the research report constitutes the final step for admission to candidacy. A student who fails to satisfy the division's candidacy requirements by the end of the second 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.

Proposition Requirements. Each student is required to submit one proposition for review and approval by the faculty. It may be submitted at any time during the period of graduate study, but in every case this requirement must be completed before the final oral examination can be scheduled. The proposition is intended to foster breadth, and to allow the student the opportunity to pursue, independently, and in some depth, a subject of interest to him or her which is outside the immediate area of the thesis research. The proposition should be stated explicitly and the argument presented in writing with adequate documentation. Originality, technical content, and clarity of presentation will constitute the primary criteria in judging the acceptability of the proposition.

Thesis and Final Examination. See page 209 for the regulations concerning theses and final examinations. A copy of the corrected thesis is to be submitted to the divisional graduate secretary for the divisional 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 which are approved by the chemical engineering faculty. In general, this program of courses should include ChE 173/174 or ChE 101/162 or ChE 164/165 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 which 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 common, and interdisciplinary programs with biology, physics, and geology are open and encouraged.

An extensive program of seminars will enable you to hear of and discuss notable work in your own and other areas. In the Divisional Research Conferences, members of the staff and distinguished visitors present accounts of research of broad interest. More specialized seminars are devoted to such subjects as 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 General Registration for the first term of graduate study, graduate students admitted to work for advanced degrees will be required to take a written placement examination in the field of inorganic, analytical, organic, and physical chemistry. This examination will cover these respective subjects to the extent that they are treated in the undergraduate chemistry option offered at the Institute. In general, it will be designed to test whether you possess an understanding of general principles and a power to apply these to specific problems, rather than a detailed informational knowledge. You will be expected to demonstrate a proficiency in the above subjects not less than that acquired by abler undergraduates.

In the event that you fail to show satisfactory performance in any area of the placement examination, you will be required to register for a prescribed course, or courses, in order to correct the deficiency promptly. If your performance in the required course or courses is not satisfactory, you will not be allowed to continue graduate studies except by special action of the Division of Chemistry and Chemical Engineering on receipt of a petition to be allowed to continue.

Course Program

For an advanced degree, no graduate courses in 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 two weeks 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 for the Ph.D. thesis and should be accompanied by a statement approving the thesis, signed by the student's Candidacy Committee 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 coursework 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 prior to 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 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 prior to 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* language: French, German, or Russian. This demonstration can be by test, good performance in a course at Caltech, or by sufficient undergraduate course work in the language.

The Minor. 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 coursework outside your principal area of research. This program consists of at least 36 units of coursework (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 prior to your final examination. One reproduced copy of the thesis, corrected after proofreading by the Graduate Office, is to be submitted to the divisional graduate secretary for the divisional library.

Subject Minor in Chemistry

Graduate students 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 coursework 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.

Engineering and Applied Science

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.

In working for a degree in aeronautics a student may do major study in, for example, one of the following areas (cf. page 110):

- Physics of Fluids
- Technical Fluid Mechanics
- Structural Mechanics
- Mechanics of Fracture
- Aeronautical Engineering and Propulsion
- Aero Acoustics

While research and course work in aeronautics at the Institute cover a very broad range of subjects, a choice of one of the above major 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 light-weight 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, which 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 6 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 Exam. 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 may 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, 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 draft, 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

(See page 210)

Applied Mechanics

Master's Degree in Applied Mechanics

Study for the degree of Master of Science in Applied Mechanics ordinarily will consist of three terms of course work totaling at least 135 units. AM 125 abc: Engineering Mathematical Principles, and E 150 abc: Engineering Seminar, are required. With faculty approval, AM 125 abc may be replaced by Ma 108 abc: Advanced Calculus, AMa 101 abc: Methods of Applied Mathematics, or other satisfactory substitute. A minimum of 54 units 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

(See page 211)

Chemical Engineering

(See page 217)

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 which 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; 27 units of courses in humanities or social sciences; 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.

Degree of Civil Engineer

Greater specialization is provided by work for the engineer's than for the master's degree. The candidate for this degree is allowed wide latitude in selecting his 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.

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.

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 of civil engineering;
b. pass at least 27 units of course work in advanced mathematics, such as AM 125, AMa 101, Ph 129, or a satisfactory substitute. For a student whose program is more closely related to the sciences of biology or chemistry than physics, AMa 104 and AMa 105 ab (or AMa 104 and AMa 181 ab) will be an acceptable substitute for the mathematics requirement;
c. pass an oral candidacy examination on the major subject, and if the student has a subject minor, examination on the minor subject may be included at the request of the discipline offering the minor.

The oral candidacy examination must be taken before registration day of the fifth term of a 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 the research report describing accomplishments to date including reading, study, and plans for future research.

At least ten days before the examination the student must present to the examining committee a brief research report.

Thesis and Final Examination. Copies of the completed thesis must be provided to the examining committee two weeks prior to the examination. The date for the final oral examination is decided at the discretion of the major professor and the division chairman to allow as necessary for such matters as publication of the examination in the Institute Calendar. The oral examination covers principally the work of the thesis, and according to Institute regulations, must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate, one of which is deposited in the Institute library and the other is deposited with University Microfilms. The examining committee will consist of such individuals as may be recommended by the chairman of the division and approved by the Dean of Graduate Studies.

Computer Science

(See page 229)

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: EE 112, EE 114, EE 151, EE 155, AMa/EE 161, EE 163, EE 194, CS/EE 281, EE 291[1], APh 105, APh 114, APh 140, APh 153, APh 154, APh 156, APh 181, APh 185, APh 190, APh 214, Ph 125, Ph 127, Ph 129, Ph 209, AM 125, CS 110, CS 137, CS 138, CS 139, BIS 240, AMa 101, AMa 104, AMa 105, AMa 153, AMa 181, Ma 108, 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 291, Advanced Work in Electrical Engineering (in the Energy Processing Laboratory); ME 102 abc, Principles of Energy Conversion and Distribution; and to many additional courses listed under other engineering options.

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.

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 related subjects listed above, 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.

[1]Not more than 21 units may be used toward the total of 99 units.

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 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 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.

Energy Engineering

Aims and Scope of Graduate Study in Energy Engineering

Energy Engineering activities are so lively and so vital a part of several options in the Division of Engineering and Applied Science (as well as in other divisions—see page 122), that each student wishing to pursue graduate study in energy will do so within that option closest to his or her own interest.

In Mechanical Engineering programs in fluids engineering, heat transfer, jet propulsion and nuclear engineering are described on pages 234-236. The central area of fundamental combustion research is focused here. In Aeronautics (p. 221) research and study are directed toward support of the large national effort for energy efficient aircraft. More generically, any thermal power plant—fossil, atomic, or solar—is critically dependent on the efficiency of its heat transfer systems—typically convective transfer involving turbulent flow of often anomalous fluids. Consequently, the understanding of turbulent transfer, two-phase fluid flow problems, etc., is crucial for all thermal power generation. World centers of research in this field are found in both Aeronautics and Mechanical Engineering.

Radiation damage in crystalline materials is of particular importance in thermonuclear reactor systems. Defect production and void growth in metallic crystals are being investigated in the W. M. Keck Laboratory of Engineering Materials. The defects introduced by ion beams are studied by use of transmission electron microscopy.

In direct energy conversion from chemical, nuclear or solar sources into electricity, the material and solid-state physics aspects of the problem become predominant and relate to research in Materials Science (p. 233), Electrical Engineering (p. 226), and Applied Physics (p. 211), where both advanced solar cell principles and the fundamentals of fusion are subjects of intense research effort.

The management of electrical power through great networks is an area of research in Electrical Engineering (p. 226). Investigations in conversion, control, and regulation of electric energy are conducted in the Energy Processing Laboratory.

In Environmental Engineering Science (p. 231) the crucial energy-environment relationship is the subject of many projects including studies of pollutant formation in combustion systems, emission control technology, environmental modeling of urban basins, environmental economics, waste heat dispersion and effects of temperature increases on chemical reactions in natural waters, and mariculture as a source of energy.

Finally, the safety of any power station is critically dependent on its structural integrity. Work in earthquake engineering, wind-loads, failure and fatigue in the Materials Science and Civil Engineering options is often fairly directly focused on power plant integrity.

Engineering Science

Aims and Scope of Graduate Study in Engineering Science

The Engineering Science option at Caltech is designed for students of subjects which 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, computer science, 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, Methods in Applied Mathematics I; AM 125, Engineering Mathematical Principles; or Ph 129, Methods of Mathematical Physics.

A minimum of 54 units must be selected from the Elective Course List below; however, substitutions for electives in this list may be made with the approval of the student's adviser and the faculty in engineering science.

Degree of Doctor of Philosophy in Engineering Science

Course Requirements. To be recommended for candidacy for the Ph.D. degree in engineering science, the student must, in addition to the general Institute requirements:

a. complete 12 units of research;
b. complete at least 50 units of advanced courses arranged by the student in conference with his 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, Ph 129, or AMa 101, acceptable to the faculty in engineering science. In place of AM 125, Ph 129, or AMa 101, students in information science are required to take Ma 108 abc and at least 27 units of advanced mathematics such as Ma 116 abc, AMa/EE 161 abc, or AMa 153 abc.

   The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward the minor requirements.

Language Requirements. Students are encouraged to discuss with their advisers the desirability of taking foreign languages, which may be included in a general minor with the proper approvals. Foreign languages are not required.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidates' knowledge in their specialized fields of research.

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 computer science provided the program consists of 45 units sufficiently far removed from their major program of study and is approved by the Computer Science Committee.

Master's Degree in Engineering Science with Emphasis on Computer Science

See description on page 123. Both M.S. and Ph.D. degrees are given in this area under the option of Engineering Science. The same general requirements of Engineering Science apply.

A minimum of 54 units must be selected from the Elective Course List below; however, substitutions for electives in this list may be made with the approval of the student's adviser and the faculty in Computer Science.

Degree of Doctor of Philosophy in Engineering Science, with Emphasis on Computer Science

Course Requirements. See Engineering Science requirements. Course of study must be approved by the student's adviser and the Computer Science faculty.

Master's Degree in Engineering Science with Emphasis on Bioinformation Systems

See description on page 123. Both M.S. and Ph.D. degrees are given in this area under the option of Engineering Science. The same general requirements of Engineering Science apply with the following exceptions:

a. One of the following courses is required in place of those listed on page 229:

AMa 104	Matrix Theory
AMa 105 ab	Introduction to Numerical Analysis
E 102 abc	Introduction to Systems Analysis and Control
CS 137	Systematic Computer Programming
CS 138	Data Structures and Algorithms
CS 139	Multiprogramming and Resource Sharing

b. A minimum of 54 units must be selected from the Elective Course List below; however, substitutions for electives in this list may be made with the approval of the student's adviser and the faculty in bioinformation systems.

Degree of Doctor of Philosophy in Engineering Science with Emphasis on Bioinformation Systems

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. 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 bioinformation systems. Students in bioinformation systems are required to take at least an additional 27 units of advanced mathematics such as Ma 116 abc, AMa/EE 161 abc, or AMa 153 abc.

Foreign Languages. The student is encouraged to discuss with his or her adviser the desirability of taking foreign languages, which may be included in a general minor with the proper approvals. Foreign languages are not required.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge of his or her specialized field of research.

A subject minor is not required for the Ph.D. degree in Engineering Science with emphasis on bioinformation systems; however, students majoring in other fields may take a subject minor in Engineering Science with an emphasis on bioinformation systems provided the program consists of 45 units sufficiently far removed from their major program of study and is approved by the bioinformation systems committee.

Elective Course List

AMa 104, AMa 105, AM 135, APh 105, APh 114, APh 153, APh 156, APh 161, APh 185, APh 190, APh 261, ChE 103, Env 142, Env 160, ES 131, Hy 101, Hy 204, CS 110, CS 130, CS 137, CS 138, CS 139, Ma 108, Ma 125, Ph 106, Ph 112, Ph 125, Ph 127, Ph 209.

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 disciplines in achieving solutions. Interactions among engineers, scientists, and social scientists are important in this program.

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 design, 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 the 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 abc, Env 150 abc, Env 155, Env 156, ChE/Env 157 ab, Env 160, Env 170 ab.

Group B. Env 100, Env 200, Env 206, Env 214 abc, Env 250, Env 300, AMa 101 abc, AMa 104, AMa 105 ab, 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 164, ChE 165 ab, Ae/ChE 172 abc, ChE 173 ab, ChE 203 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 the major research interest has become clearly defined.

The program of courses for the Ph.D. should be designed to meet the student's needs 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, bioengineering, hydraulic engineering, coastal engineering, environmental economics, and systems analysis.

Course Requirements. A student is expected to present at least 135 units of major courses in addition to research units and the units required to satisfy the minor program and the advanced mathematics requirement. At least 45 of these units should represent work in scientific or engineering electives beyond that encountered in introductory courses in the student's immediate area of concentration.

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 will 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 by 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. The examination will consist of a comprehensive review of the candidate's complete academic record by an examining committee. If the examination indicates that the academic record is marginal, or deficient, the committee 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 prior to 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 prior to 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 the other is deposited with University Microfilms. The examining committee will consist of such individuals as may be recommended by the Chairman of the Division of Engineering and Applied Science and approved by the Dean of Graduate Studies.

Subject Minor in Environmental Engineering Science

A doctoral student in another major field who wishes to take a subject minor in environmental engineering science should submit 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 will be expected to pass a separate oral examination.

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	.
MS 122	Phase Transformations in Solids (3-0-6)	.	.	9
MS 125	Crystal Structure and Properties of Metals and Alloys (3-0-6)	.	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 69 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 which 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 140 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 abc.

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 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 thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his specialized field of research.

Subject Minor in Materials Science

A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in materials science and the faculty in his 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.

Mechanical Engineering

Master's Degree in Mechanical Engineering

Study for the degree of Master of Science in Mechanical Engineering ordinarily will consist of three terms of course work totaling at least 135 units. Each student is assigned to a member of the faculty, who will serve as the student's adviser and who will assist the student in planning 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 on the next page.

Mechanical Engineering

		Units per term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
	Electives as below[1]	Minimum	75 per year	
	Free electives[2]	Minimum	27 per year	
	Total	Minimum	135 per year	

Program Suggested for Propulsion

		1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
JP 121 abc	Jet Propulsion Systems and Trajectories (3-0-6)	9	9	9
	Electives as below[3]	Minimum	98 for year	
	Free electives[2]	Minimum	27 for year	
	Total	Minimum	135 for year	

Approved electives: Ae/AM 102, Ae 105, AM 151, Hy 101, JP 134, JP 170, ME 102, ME 118, ME 126

Program Suggested for Energy

		1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
ME 102 abc	Principles of Energy Conversion and Distribution (3-0-9)	9	9	9
	Electives as below[3]	Minimum	98 for year	
	Free electives[2]	Minimum for	27 year	
	Total	Minimum	135 for year	

Approved electives: Ae 103, APh 140, APh 141, 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 nonfree electives. Otherwise, courses from AM, AMa, ME, JP, MS, Ae and Hy with numbers of 101 and above will generally meet the conditions for electives in this group.
[2]Students are urged to consider including a humanities course in the free electives.
[3]Elective units may be divided among the three terms in any desired manner. Students who have not had the equivalent of AMa 95 abc are required to take AM 113 abc which *must* be included in the free electives and *cannot* be included in the nonfree electives. Substitution for approved electives may be made with the approval of the student's adviser and the faculty in mechanical engineering.

Degree of Mechanical Engineer

Work toward the degree of Mechanical Engineer requires a minimum of two years following completion of the bachelor's degree or the equivalent. Upon admission to work toward the M.E. degree, a committee of three members of the faculty is appointed to advise the student on his 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. The student shall meet with the committee before registration for the purpose of planning the student's work.

Not less than a total of 55 units of work shall be for research and thesis; the exact number shall be determined by the supervising committee, appointed by the Dean of Graduate Studies, which succeeds the counseling committee. The courses shall be closely related to mechanical engineering, and the specific courses to be taken and passed with a grade of C or better by the candidate shall be planned with the 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, 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. One member of the committee who is most closely related to the student's field of interest serves as the adviser and the chairman.

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

a. complete 12 units of research;
b. complete at least 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, 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.

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 as 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 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, chemistry, and biology. 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 not less than that attained by undergraduate students at the California Institute. 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 provide background, fulfill requirements, and to constitute a sensible, integrated program. 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 undergraduate curriculum (pages 188-190). 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. 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 requirements of 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 which 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. 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 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 by May 15 must submit to the Core Committee a preliminary status report of their choice of proposition topics. The statement should be as specific as possible, and should preferably give the specific title 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 4th term of residence, and the examination will be taken within the ensuing two-week period at a time and before a committee arranged by the division.

Graduate students are encouraged to register for as many as 15 units per term of advanced study (Ge 297) under appropriate staff members to gain experience and background for preparation of their propositions.

Minimum Course Requirements for Ph.D.

Basic Division Requirement: The solution of many problems in each of the subdisciplines or major subjects included within the division requires some basic understanding of the other subdisciplines. Therefore all graduate students are required to take at least 45 units within the division in subjects other than their own major subject. The courses are chosen in consultation with the student's adviser, and are subject to the approval of the staff at admission to candidacy. Ge 101 abc is specifically required and 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.

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. Throughout their graduate work students are expected to participate in departmental seminars and in seminar courses led by distinguished visitors.

Geochemistry: In addition to the general Institute and basic division requirements, the Ph.D. candidate in geochemistry must demonstrate a knowledge of both geology and chemistry equivalent to the average attained in the Caltech undergraduate curriculum in geochemistry. 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 81 units of 100-200 level courses chosen from the three categories listed below. At least 18 units must be completed in each group.

Group A. Courses in mathematics and applied mathematics: Ph 129, AMa 101, AMa 110, AMa 151, AMa 201, AMa 204, Ma 142, Ma 143, Ma 205, AM 113, AM 141, EE 161, EE 255. A minimum proficiency in basic mathematical methods at the level of Ph 129 or AMa 101 and AMa 201 is required.

Group B. Courses in physics, applied physics, and chemical physics: Ph 106, Ph 125, APh 114, APh 120, APh 214, Ph 127, Ph 205, Ph 236, MS 205, EE 133, Ch 21, Ch 125, Ch 226. Geophysics courses cannot be substituted for courses in this group.

Group C. Courses in geophysics: Ge 160, Ge 166, Ge 176, Ge 177, Ge 260, Ge 261, Ge 264, Ge 265.

The recommended courses in these three categories are only representative of the required level, and substitutions can be made upon consultation with the student's adviser. Students with an exceptionally strong background in one or more of the areas represented by these groups may, upon petition to the option representative, be excused from up to 18 units of the overall 81 unit requirement. Research and reading courses cannot be used to satisfy these requirements but are highly recommended as preparation for the oral qualifying examination.

Planetary Science: In addition to general Institute and basic division requirements the candidate for a Ph.D. degree in planetary science shall acquire at least a minimum graduate background in each of three categories of course work: (1) The Earth Sciences, (2) Physics, Mathematics, Chemistry, and Astronomy, and (3) Planetary Science.

These requirements may be met by successful completion of at least 45 units of suitable course work at the 100 or higher level in each category. The requirements in the first category are coincident with the basic division requirement. Reading and research courses may not be used, although students are expected to take such courses and to devote each summer to research in planetary science. Planetary Science Seminar (Ge 225 abc) is required each year for all planetary science students.

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 which 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 2nd academic year: 1) satisfactory completion of divisional oral examination; 2) tentative approval of courses in the major and secondary fields; 3) tentative thesis topic in planetary science.

End of 3rd academic year: 1) satisfactory completion of major requirements; 2) satisfactory completion of secondary requirements; 3) satisfactory progress on thesis; 4) admission to candidacy.

End of 4th academic year: completion of Ph.D. thesis.

Fifth academic year or beyond: satisfactory thesis progress required each quarter.

Minor Requirement. A minor is required in the planetary science option, but not in geology and geobiology, geophysics, or geochemistry options. The purpose of a minor is to give diversification of training and a broadening of outlook. It should involve basic approaches, techniques, and knowledge distinct from those of the major field. 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. The oral examination requirement may be met through the choice of propositions or a special examination may be held.

A proposed minor program should be discussed with the adviser and the option representative and submitted to the staff for preliminary evaluation before the end of the 6th term of residence. Final approval will be given only after completion of all courses.

Language Requirement. Due to the diversity of fields within geological and planetary sciences, the division does not have a uniform language requirement. All entering graduate students are expected to have some knowledge of French, German, or Russian. (Other languages may be acceptable in particular cases.) A student who has not had either one year of college study in one of these languages or the equivalent thereof will be expected to make up this deficiency in 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 theses 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 sumitted 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. The student should consult the division graduate representative on the choice of courses and on the scheduling of the required oral examination.

History

The program for a subject minor in history must be approved by the department prior to 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.

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 130. 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 which are offered are listed in Section V. They are divided in three categories. The courses numbered between 100 and 199 are basic graduate courses open to all graduate students. The course Ma 108 is the fundamental course in analysis. It is a prerequisite to most courses, and its equivalent is expected to be part of the undergraduate curriculum of the entering graduate student. The basic course in algebra, Ma 120, presupposes an undergraduate introductory course in modern algebra similar to Ma 5 abc. Particular mention is made of Ma 190. It is a seminar required of all first-year graduate students and restricted to them. It is intended to stimulate independent work, to train students in the presentation of mathematical ideas, and to develop an independent critical attitude. 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.

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 acquire an understanding of the main fields of modern mathematics and to demonstrate 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 shall be given soon after completion of the minor program.

Physics

Aims and Scope of Graduate Study in Physics

The physics department offers a program leading to the degree of Doctor of Philosophy in Physics. This program seeks to prepare students for careers in scientific research, or research combined with teaching, and independent research is an essential part of the graduate program. Courses are offered which will help a beginning graduate student prepare for research and 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 which 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, 1977. Special inquiries will be welcomed by Professor C. W. Peck, Chairman, Physics Graduate Admissions Committee. It is strongly recommended that applicants 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, atomic and nuclear physics, quantum mechanics, and mathematical physics, approximately as covered in Ph 106, Ph 112, Ph 125, and Ph 129. In general, they will be designed to test whether the student possesses an understanding of general principles and the ability to apply these to concrete problems, rather than detailed informational knowledge. In cases in which there is a clear basis for ascertaining the status of the entering graduate student, the placement examinations may be waived.

Physics Course List

The following courses are referred to several times in the regulations below. These courses are described fully on pages 329-333.

Ph 127, Ph 129, Ph 203, Ph 205, Ph 209, Ph 213, Ph 221, Ph 224, 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 218

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 127 abc, Ph 129 abc, Ph 203 ab, Ph 205 abc, Ph 209 abc, Ph 213 ab, Ph 221, Ph 224 abc, Ph 230 abc, Ph 231 abc, Ph 236 abc, Ph 237 abc.

Non-physics electives .... 27 units
These must be graduate courses from any option, including humanities, except physics.

With the approval of the 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 which 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 129, Ph 205, and Ph 209.

Course Requirements. In order to be recommended for the Ph.D. degree, each candidate must, in addition to the requirements for candidacy and the general Institute requirements for a Ph.D. degree, pass satisfactorily a total of 54 units from the courses enumerated in the above Physics Course List. Ph 129 and Ph 209 are excluded from the list. These two courses will presumably be of use to the student in preparing for the written candidacy examination, but are not required, nor may they be counted toward course requirements. The purpose of course requirements is to broaden the student's knowledge of physics and 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 any requirements for these courses. In addition to these 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 parts and requiring a total of about twelve hours, is given each year in the third term. Each student must pass this examination before being permitted to register for the third year of graduate study. The examination covers that body of knowledge felt to be essential no matter what the candidate's ultimate field of specialization may be.

An oral candidacy examination is also required. This examination may be taken no sooner than one month after the written examination is passed, and is primarily a test of the candidate's suitability for research in his 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 second term 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 on page 207.

Research Requirements. There is no specific requirement but in general a substantial effort is required to master the research techniques in a given field and carry out a significant piece of original research. Each student is strongly advised to start research as soon as possible and carry it on in parallel with course work.

The Minor. 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

A subject minor in physics will be approved by the minor division if it includes at least 18 units of physics courses, chosen from the courses in the Physics Course List, but excluding Ph 129, all Ay and APh courses, and any specific courses in physics required for the student's major program. Physics courses with numbers over 100 will be allowed for the subject minor, but, where reduced credit is given to physics graduate students, will count at the same reduced rate toward the required total of 45 units. The required oral examination in the subject minor will normally be a separate examination but may be part of one of the oral examinations in the major subject if sufficient time is made available. It is the responsibility of the candidate to make arrangements for this examination with the chairman of the Physics Graduate Committee.

Social Science

Aims and Scope of Graduate Study in Social Science

The Division of the Humanities and Social Sciences offers a program leading to the degree of Doctor of Philosophy in Social Science. The focus of the program is on social change, and it is highly analytical. The program is designed to prepare students to assume senior staff positions in policy-making organizations where they will be able to conceive and execute complicated research projects and to utilize the products of their research to provide the basis for actual policy decisions. It is also anticipated that over the next few years there will be an increasing demand in colleges and universities for people who are trained more broadly than in a single social science. Depending on their individual orientation, students graduating from the program will also be qualified to take positions in departments of economics or political science.

Admission

The only specific requirements for admission to the graduate program in social science are in the field of mathematics. Mathematical requirements consist of (1) courses in calculus at the levels of Ma 1 abc and Ma 2 abc; (2) a course in linear algebra and/or matrix algebra at the level of AMa 104; (3) courses in elementary mathematical statistics at the level of AMa 112 ab. The completion of courses in advanced calculus or applied mathematics is also recommended. Under certain circumstances, students may be permitted to complete some of the mathematical requirements after entering the program. Students will find that courses in abstract algebra, functional analysis, topology, and probability theory will be of significant help in their graduate work, and they will be expected to take whatever courses in mathematics are directly relevant to their research after entering the program.

Placement Examinations

Entering students will take placement examinations in social science and mathematics to determine their level of attainment. Required remedial work, if any, will be determined by the option committee in consultation with the student and will be based primarily on the results of the placement examinations and review of the student's undergraduate program. In cases where there is a clear basis for ascertaining the status of entering students, the placement examinations may be waived.

Course Program

No graduate courses in social science are specifically required for an advanced degree in social science. However, students will, in consultation with the option committee and their research adviser, develop a program which 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, analytical political science, and social psychology.

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 which all graduate students will be expected to attend.

Master's Degree in Social Science

Entering graduate students are admitted for the Ph.D. program. The M.S. degree is awarded in exceptional cases. Of the 135 units of graduate work required by Institute regulations, at least 81 units of advanced work should be in social science.

Degree of Doctor of Philosophy in Social Science

Requirements for the Ph.D. include passing a written and oral candidacy examination covering basic material in social science (to be taken before the close of the sixth quarter of residency), the writing of a thesis which describes the results of independent research, and the passing of a final oral examination based on the thesis and research. Students will be expected to have completed all requirements for the Ph.D. degree no later than the end of their fourth year of residency.

A minor is also required, the requirements for which are discussed on page 208.

Subject Minor in Social Science

Graduate students taking social science as a subject minor shall complete a program of no less than 45 units in social science approved by the option committee.

GRADUATE EXPENSES

The tuition charge for all students registering for graduate work is currently $3,648 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 $34 a unit for fewer than 36 units with a minimum of $340 a term. Adjustments of tuition charges may be arranged for changes in units if reported during the first three weeks of a term. Additional tuition will be charged to students registering for special courses made available to them which are not part of the normal educational facilities of the Institute.

The payment of tuition by graduate students is required (a) without reference to the character of the work 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 in attendance at regular classes; (b) without reference to the number of terms in which the student has already been in residence; and (c) without reference to the status of the student as an appointee of the Institute, except that members of the academic staff of rank of Instructor or higher are not required to pay tuition.

A summer health fee of $38 must be paid by students who register for summer work, and who have not paid full tuition at the Institute during the preceding academic year.

Each graduate student is required to make a general deposit of $25 to cover loss of, or damage to, Institute property used in connection with 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 delinquent may be refused registration for the term following that in which the delinquency occurs. No degrees are awarded until all bills due the Institute have been paid. Transcripts cannot be released until all bills due the Institute have been paid or satisfactory arrangements have been made with the business office for repayment.

Information regarding fellowships, scholarships, and assistantships is discussed on the following pages. Students of high scholastic attainment may be awarded graduate scholarships covering all or a part of the tuition fee. Loans also may be arranged by making an application to the Faculty Committee on Scholarships and Financial Aid.

Expense Summary 1976-77

General:

General Deposit	$ 25.00[1]
Tuition	3,648.00
Graduate Student Council Dues	2.00
	$3,675.00

Other:

Books and Supplies (approx.)	$325.00

Graduate House Living Expenses
Room—$670.00 to $740.00 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 1976-77, together with the dates on which they are due. Charges are subject to change at the discretion of the Institute.

	First Term	
September 27, 1976	General Deposit	$ 25.00
	Tuition	1,216.00
	Graduate Student Council Dues	2.00
	Second Term	
January 3, 1977	Tuition	1,216.00
	Third Term	
March 28, 1977	Tuition	1,216.00

Tuition fees for fewer than normal number of units:

Over 35 units	Full Tuition
Per unit per term	34.00
Minimum per term	340.00

Audit Fee, $40.00 per term per lecture hour.

[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.

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

Associated Student Body Dues. Graduate students are eligible for membership in the Associated Students of Caltech, pursuant to by-laws thereof. Dues are $22 annually.

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.)

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 $2 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 Student Accounts office. 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.

Living Accommodations for Graduate Students

Housing Facilities. The Institute has four residence houses providing single rooms for 167 graduate students. These handsome and comfortable residences, located on campus, were donated by William M. Keck Jr., Samuel B. Mosher and Earle M. Jorgensen, David X. Marks Foundations, and the family of Carl F Braun. The rates per academic year vary depending upon the accommodations and services provided. During the summer only, rooms may be rented on a month-to-month basis. Complete information may be obtained and reservations made by writing to the Office of Residence and Dining Halls, California Institute of Technology.

The Institute owns three apartment buildings and a limited number of houses for exclusive rental to married students and families.

The Off-Campus Housing Office also maintains a current file of available rooms, apartments and houses in the Pasadena area. The Institute cannot make negotiations for individual housing off campus but will be glad to furnish detailed information. Address: California Institute of Technology, Off-Campus Housing Office, 1-56.

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 Hale Observatories, 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 is maintained to help foreign students and visiting scholars with non-academic problems. They will find the services of the desk very helpful, particularly when they first arrive on campus. The International Desk operates with the advice of the Faculty Committee on Foreign Students and Scholars.

FINANCIAL ASSISTANCE

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

A request for financial assistance is included on the application for admission to graduate standing. These applications should reach the Institute by February 15. Appointments to fellowships, scholarships, and assistantships are for one year only; and a new application must be filed with option representatives each year by all who desire appointments for the following year, whether or not they are already holders of such appointments.

In addition, loans are available to graduate students who need such aid to continue their education. They are made upon application, subject to the approval of the Scholarships and Financial Aid Committee, and to the extent of the available funds. Loan forms are available in the Graduate Office. In addition to loans, the Deferred Payment Plan is also available to graduate students.

Graduate Assistantships

Graduate assistants devote, during the school year, not more than 20 hours a week to teaching, laboratory assistance, or research of a character that affords them useful experience. This time includes that required in preparation and in marking notebooks and papers, as well as that spent in classroom and laboratory. The usual assistantship assignment calls for 20 hours per week at most and ordinarily permits the holder to carry a full graduate residence schedule as well.

Graduate Scholarships, Fellowships, and Research Funds

The Institute offers a number of named fellowships and scholarships for tuition and/or stipend to graduate students of exceptional ability who wish to pursue advanced study and research.

Earle C. Anthony Fellowships
ARCS Foundation of Los Angeles Scholarships
Meridan Hunt Bennett Scholarships
Blacker Scholarships
Bridge Fellowship in physics
Edith Newell Brown Scholarships
Theodore S. Brown Scholarships
Lucy Mason Clark Fellowship in plant physiology
Ray G. Coates Scholarship in physics
Samuel H. and Dorothy Breed Clinedinst Foundation Scholarship
Cole Fellowships
Caroline W. Dobbins Scholarships
Donald Wills Douglas Prize Fellowship at the Graduate Aeronautical Laboratories
Drake Scholarsips

Camille and Henry Dreyfus Visiting Fellowship Awards
Richard P. Feynman Fellowships in physics
Gilbert W. Fitzhugh Visiting Fellowship Awards provided by the Metropolitan Life Insurance Company
GALCIT Wind Tunnel Fellowships in aeronautics
Daniel and Florence Guggenheim Foundation Fellowships
Beno Gutenberg Fellowships in geophysics
Robert H. Halpenny Memorial Scholarship in electrical engineering
Clarence J. Hicks Memorial Fellowship in Industrial Relations
Albert Hall Hughey Scholarship
Saul Kaplun Scholarships in applied mathematics
William N. Lacey Fellowship in chemical engineering provided by the Union Oil Company Foundation
Henry Laws Scholarships
Robert L. Leonard Scholarships in organic chemistry
Joseph F. Manildi Scholarships
Clark B. Millikan Scholarships
Greta B. Millikan Fellowship Fund for fellowships in physics
Li Ming Memorial Scholarship
Blanche A. Mowrer for the benefit of students in chemistry
David Lindley Murray Scholarships
May McManus Oberholtz Scholarship Endowment Fund
Elbert G. Richardson Scholarship and Fellowship Fund
Frederick Roeser Scholarship
William E. Ross Memorial Scholarships
Eben G. Rutherford Scholarship Fund
Bruce H. Sage Fellowship in chemical engineering provided by the Union Oil Company Foundation
Evelyn Sharp Scholarship in behavioral biology
Royal W. Sorensen Fellowship in electrical engineering
Keith Spalding Memorial Scholarship Fund
Van Maanen Fellowships in astronomy
Weyerhaeuser Company Foundation Fellowship in chemical engineering
Laszlo Zechmeister Scholarships in chemistry

Special Fellowships and Research Funds

In addition to the National Science Foundation, the Department of Health, Education, and Welfare, the Environmental Protection Agency, and the California State Graduate Fellowship program, the following corporations, foundations, and individuals contribute funds for the support of graduate fellowships:

African American Institute
R. C. Baker Foundation
Louis D. Beaumont Foundation
C F Braun & Co
California Foundation for Biochemical Research
California Institute Research Foundation
Elmer West Clark Fellowship
Continental Oil Company
Corning Glass Works Foundation
Danforth Foundation
E. I. du Pont de Nemours & Company, Inc.
Exxon Education Foundation
Fluor Corporation
Ford Foundation
Foremost-McKesson Foundation, Inc.
Lawrence A. Hanson Foundation
Fannie and John Hertz Foundation
Hughes Aircraft Company
International Business Machines Corporation
Josephine de Karman Trust
Latin American Scholarship Program
The Link Foundation
William F. Marlar Memorial Foundation
Arthur McCallum Fund
Northrop Corporation
Research Corporation
Rockwell International
Gordon Ross Medical Foundation
Schlumberger Foundation
Jack Schoustra
The Spencer Foundation
Standard Oil Company of California
Stauffer Chemical Company
John and Beverly Stauffer Foundation
TRW Foundation
United States Steel Foundation
Waltmar Foundation

A number of governmental units, industrial organizations, educational foundations, and private individuals have contributed funds for the support of fundamental research related to their interests and activities. These funds offer financial assistance to selected graduate students in the form of graduate research assistantships.

Work-Study Programs

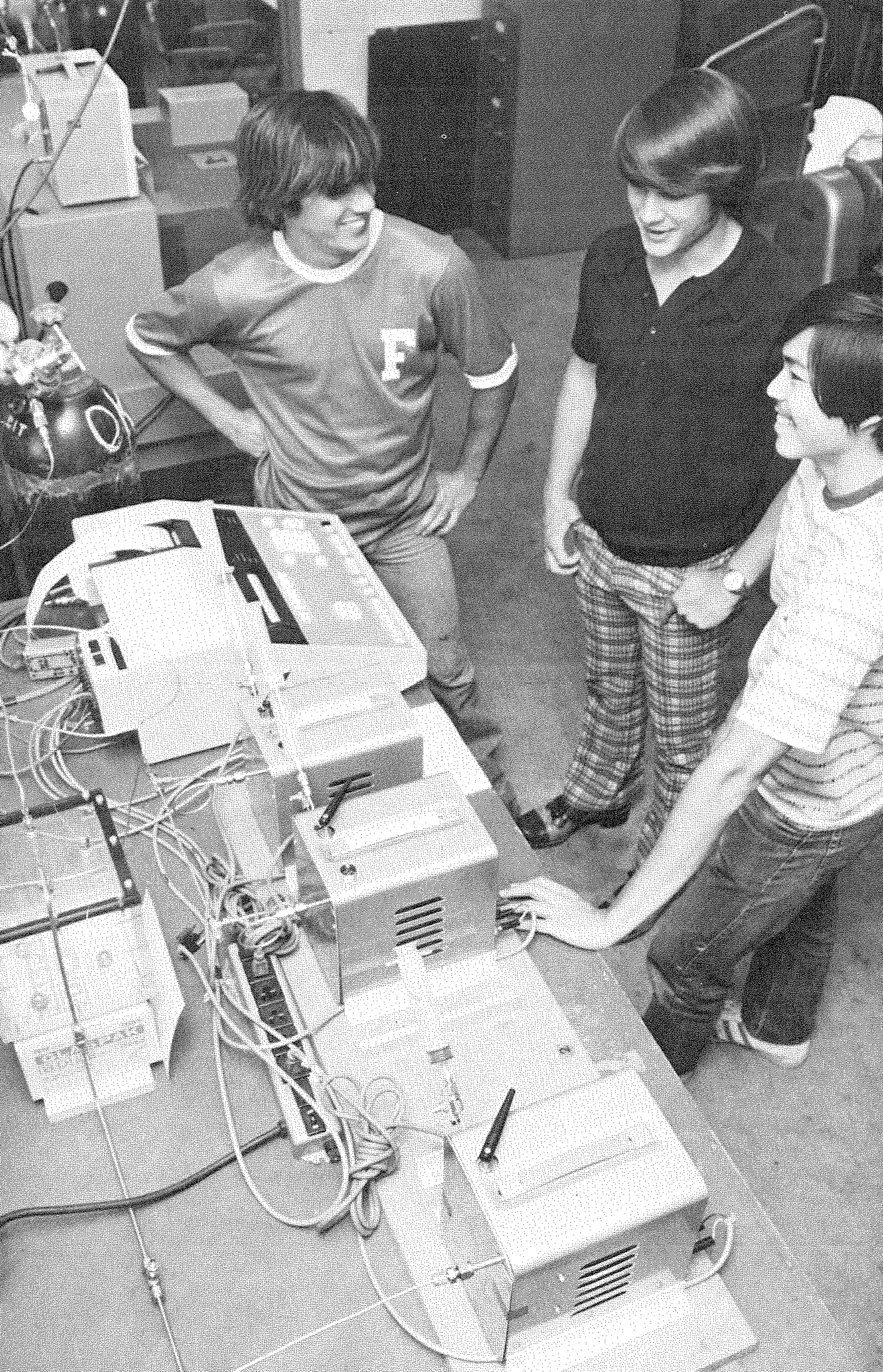
Limited opportunities are available for work-study programs in certain areas of interest. At the present time the sponsors of such programs are the Hughes Aircraft Company, Scientific Education Office, World Way, P.O. Box 90515, Los Angeles, California 90009, and the Jet Propulsion Laboratory of the California Institute of Technology. Potential students wishing to consider participation in the Hughes program may make inquiry to the address above or through the appropriate option at this Institute. Those wishing to be considered for the JPL program should inquire through their option. In general such programs require some part-time employment during the academic year, as well as full-time work during the summer.

Loans and Deferred Payments

There are three 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, and loans from special funds of the California Institute of Technology. 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 165. Loans from Institute funds normally may not exceed $2,500 per year. These loan funds are listed on page 165. Repayment terms, including interest rates, may be obtained from the Office of the Dean of Graduate Studies or the Office of Student Accounts.

A Deferred Payment Plan is also available to graduate students. The terms and conditions of this plan are outlined on page 165.

Loans and the Deferred Payment Plan may be used in combination.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Section V

SUBJECTS OF INSTRUCTION

The school year is divided into three terms. The number of units assigned in any term to any subject represents the number of hours spent in class, laboratory, and preparation per week. In the following schedules, figures in parentheses denote hours in class (first figure), hours in laboratory (second figure), and hours of outside preparation (third figure). 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

(See Engineering and Applied Science)

ANTHROPOLOGY

An 11. The Evolution and Current Status of Small-Scale Human Societies. *9 units; (3-0-6); first term.* 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.

An 101 abc. Selected Topics in Anthropology. *9 units (3-0-6).*

An 123 ab. The Anthropology of Development. *9 units (3-0-6); second, third terms.* Social change in contemporary tribal and peasant societies. Emphasis will be placed on the impact of modernization, especially through urbanization, industrialization and the intensification of agriculture, and of revitalization on the social organization of selected societies in Latin America, Europe, Africa and elsewhere over the past half century. Instructor: Scudder.

APPLIED MATHEMATICS

Undergraduate Courses

AMa 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. Instructor: 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 examples of how digital computers can be used for numerical and non-numerical applications. Both high level and low level languages are discussed. Instructor: Fornberg.

b. **Ordinary Differential Equations.** *Prerequisite: Ma 2.* Qualitative theory of linear and nonlinear differential equations, phase-plane, Poincaré-Bendixson theory, stability. Applications. Instructor: Cohen.

c. **Introduction to Perturbation Methods.** *Prerequisites: Ma 2, Ph 2.* Asymptotic and approximate methods for obtaining useful information about solutions of differential equations. Applications to orbit problems, chemical and biochemical kinetics, oscillations in mechanical and electrical systems. Instructor: Cohen.

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. Instructor: 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: Franklin.

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: Franklin.

AMa 106 ab. Numerical Linear Algebra. *9 units (3-0-6); second, third terms. Prerequisite: Some familarity 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. Instructor: Fornberg.

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. Instructor: Cohen.

AMa 151 abc. Perturbation Methods. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 101 or equivalent; may be taken concurrently.* 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 1976-77.

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: White.

AMa/EE 161 abc. Mathematical Theory of Information, Communication, and Coding. *9 units (3-0-6); three terms. Prerequisites: some knowledge of probability and linear algebra.* Shannon's coding theorem and its converse for a variety of channel models: binary symmetric, finite memoryless, discrete-time Gaussian, wideband Gaussian. Minimum redundancy source coding. Error-control systems, e.g., BCH codes (with underlying theory of finite fields) and Viterbi decoding of convolutional codes. Practical applications. Not offered in 1976-77. Instructors: Staff.

AMa 181 abc. Mathematical Programming and Game Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: some knowledge of linear algebra.* Theory of linear and nonlinear programming. Simplex algorithm. Integer programming and network flows. Zero-sum, two-person games. Linear models of exchange and production. Kakutani fixed-point theorem. Theory of n-person games. Applications to engineering and economics. Not offered in 1976-77.

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 1976-77.

AMa 204 abc. Numerical Solution of Differential and Integral Equations. *9 units (3-0-6). Prerequisites: 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 1976-77.

AMa 220 abc. Bifurcation Theory and Nonlinear Boundary Value Problems. *9 units (3-0-6). Prerequisites: 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. Catastrophy theory. Nonlinear boundary value and eigenvalue problems. Monotonicity methods. Stability theory. Degree theory. Instructor: Keller.

AMa 251 abc. Applications of Group Theory. *9 units (3-0-6). Prerequisite: some knowledge of linear algebra.* Applications of group theory to differential equations and to physics 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 1976-77.

AMa 253 ab. Topics in Applied Probability Theory. *9 units (3-0-6); first, second terms. Prerequisite: AMa 153 or equivalent.* Stochastic differential and integral calculus, Wiener-Hermite analysis with applications, prediction and filtering, Markov fields, Boltzmann equation. Not offered in 1976-77.

AMa 260 abc. Special Topics in Continuum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Some knowledge of elasticity or fluid mechanics and instructor's permission.* A course designed to reflect recent and current research interests of the staff and students working on mathematical problems in the areas of elasticity, fluid mechanics and related fields. Instructor: Saffman.

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, Ph 209, and Ph 227.

APPLIED MECHANICS

(See Engineering and Applied Science)

APPLIED PHYSICS

Undergraduate Courses

APh 3. Introduction to Solid-State Electronics. *6 units (3-0-3); first term.* An introduction to the significant concept of most modern electronic devices such as diodes, junction and field effect transistors, etc. Topics will include: electronic conduction in metals and semiconductor materials, energy barriers, junctions, carrier recombination and light emission, operating principles of transistors and transistor-like devices. Graded pass/fail. Instructor: Humphrey.

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 non-structured project laboratory designed to provide an opportunity for projects related to the course APh 3. All of the facilities used for demonstrations in APh 3 are available as well as general semiconductor device fabrications facilities. The student is expected to design and carry out his own project either as an extension of one of the APh 3 demonstrations or fabricating and characterizing a device. Typical devices possible with facilities available: junction transistor, junction FET, MOSFET, light-emitting diode, solar cell, tunnel diode. Graded pass/fail. Instructor: 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 methods in physics and engineering. The material will include such topics as the classical laws of thermodynamics, Maxwell's relations, basic chemical thermodynamics and chemical equilibrium, approach to molecular thermodynamics through similarity considerations, kinetic theory and statistical mechanics, analysis of heat engine cycles and power conversion systems. Instructor: Liepmann.

APh 23. Demonstration Lectures in Optics. *6 units (2-0-4); first term. Prerequisites: Ma 1 abc and Ph 1 abc.* Ten demonstration lectures covering the fundamentals of optics. Emphasis is placed on showing the breadth of modern optics with comprehensive explanations of many relatively new applications. These demonstrations include lasers, lenses and imaging systems; gratings and multilayers; optical resonators and mode locking; linewidths, coherence and interference; holograms; matched filtering, Fourier transforms and diffraction pattern sampling; modulators and integrated optics; dielectrics, dispersion and harmonic generation; synthetic aperture radar and optical processors; detection of signals in noise, line scan and lidar.

APh 24. Introductory Modern Optics Laboratory. *6 units; second term. Prerequisite: APh 23.* Laboratory experiments to acquaint students with the contemporary, yet basic, aspects of modern optical research and technology. Experiments encompass many of the topics and concepts covered in APh 23. Text: Notes and selected references.

APh 50 abc. Applied Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc, Ma 2 abc, or equivalents.* Application of quantum mechanics to problems of the three states of matter: solids, gases, and liquids. Starting point will be the free and bound particle, the one-electron atom, and quantum statistics. Additional topics will be selected from electron transport in solids, plasma physics, kinetic theory, and other topics in physics depending on the instructor and interests of the students. Instructor: Culick.

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. Instructor: Humphrey.

Advanced Courses

APh 100. Advanced Work in Applied Physics. Special problems relating to applied physics will be arranged to meet the needs of students wishing to do advanced work. Primarily for undergraduates. Students should consult with their advisers before registering for this course. Graded pass/fail.

Ae/APh 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms.* Definition and classification of fluids. Kinematics of fluid flow, vorticity. Stress tensor and heat flux vector. Equations of motion. Dynamics of ideal and real fluids, the limiting cases of small and large Reynolds number flows, boundary layer theory. Laminar stability turbulence. Gravity waves, acoustic waves, shock waves. Additional topics will be selected from subjects such as: heat flow and diffusion in gases; dynamics of rarefied gases; plasma flow and magnetohydrodynamics, super fluid flow; rotating fluids. Text: *Fluid Mechanics*. Instructor: Sturtevant.

APh 105 abc. States of Matter. *9 units (3-0-6); first, second, third terms.* A survey of current ideas about the states of matter emphasizing unifying concepts, such as order parameters, scaling laws, quasi-particle excitations and correlation functions. Topics will include long-range ordered states such as crystals, superfluids and ferromagnets, phase transitions of first and higher orders, critical phenomena, band theory of solids, liquids, and ideal classical and degenerate gases. Instructor: Corngold.

APh 110. Topics in Applied Physics. *2 units (2-0-0); first, second, third terms.* A course designed to acquaint first-year graduate students with the various research areas represented in the option. Lecture each week given by a different faculty member of the option. Graded pass/fail. Instructors: Staff.

APh 114 abc. Solid-State Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 50 or Ph 102 abc or equivalent.* A lecture and problem course dealing on an introductory level with experimental and theoretical problems in solid-state physics. The topics to be discussed include: crystal structure, lattice vibrations, Fermi electron gas, semiconductors, superconductivity, magnetic resonance, ferroelectricity, linear and nonlinear optical phenomena in insulators. Instructor: McGill.

APh 140 abc. Cryogenics. *9 units (3-0-6); first, second, third terms.* An introductory course on the behavior of condensed matter at low temperatures. Topics include superfluidity, superconductivity, quantum phase coherence, liquid He^3, ultralow temperature experiment, cryogenic techniques, and macroscopic quantum devices. Offered in alternate years; not offered in 1976-77. Instructor: Mercereau.

APh 141. Superconductivity and Its Applications. *9 units (3-0-6); third term. Prerequisite: APh 114 abc.* A course on the basic principles and the engineering applications of superconductivity. After a review of basic properties of superconductors, phenomenological treatment and microscopic theory of superconductivity, the topics covered include: magnetic properties of type II superconductors, proximity effect, superconducting compounds, alloys and composites, high field superconducting magnets, magnetic suspensions for high-speed transportation, superconductive power transmission and rotating machines. Not offered in 1976-77.

APh 153 abc. Modern Optics. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc.* The analysis of optical systems based on electromagnetic theory. Mode theory and functions for optical resonators and transmission structures, image formation and spatial filtering with coherent light, partial coherence and partial polarization, theory of dielectrics, theory and applications of holography and selected topics of research importance. Text: Class notes and selected references. Instructor: George.

APh 154. Modern Optics Laboratory. *9 units (1-4-4); second term. Prerequisite: APh 153 or APh 190 (may be taken concurrently).* Primarily for graduate students. Laboratory experiments to acquaint students with the contemporary, yet basic, aspects of modern optical research and technology. Experiments encompass holography and interferometry, single-mode and mode-locked lasers, nonlinear optics, acousto-optic interactions, coherence, diffraction, optical data processing, photosensitive materials, liquid crystals, and ferroelectric ceramics.

APh 156 abc. Plasma Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* An introduction to the principles of plasma physics. Topics presented will include: orbits of charged particles in electric, magnetic, and gravitational fields; elementary processes in the production and decay of ionized gases; continuum magnetohydrodynamics and elementary stability theory; transport processes such as conductivity and diffusion; waves, oscillations, and radiation in plasmas. Examples from physics, engineering, and astrophysics will be discussed. Instructor: Gould.

APh 161 ab. Nuclear Energy. *9 units (3-0-6); first, second 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 1976-77.

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 185 abc. Ferromagnetism. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 50.* Review of current theories of ferromagnetism. Phenomenological treatment of magnetization using the Landau-Lifshitz equation to treat flux reversal, spin wave resonance and micromagnetics. Relaxation mechanisms. Applications of magnetic materials in modern technology. Not offered in 1976-77.

APh 190 abc. Quantum Electronics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125, or equivalent.* This course is concerned with generation, manipulations, propagation, and applications of coherent radiation. Starting with the basic theory of the interaction of electromagnetic radiation with resonant atomic transitions, the course takes up the subjects of laser oscillation, important laser media, Gaussian beam modes, the electro-optic effect, nonlinear-optics theory, second harmonic generation, parametric oscillation, stimulated Brillouin and Raman scattering. Other topics include: Light modulation, diffraction of light by sound and quantum noise theory. Text: *Quantum Electronics* by Yariv, class references and research literature. Offered in alternate years; offered in 1976-77. Instructor: Yariv.

APh 195 ab. 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. Offered in alternate years; not offered in 1976-77. Instructor: Culick.

APh 200. Applied Physics Research. *Units in accordance to work accomplished.* Offered to Ph.D. candidates in applied physics for research leading directly towards a Ph.D. degree. Students should consult their adviser before registering for the course.

APh 214 abc. Advanced Solid-State Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 114 abc and Ch 125 abc or Ph 125 abc.* A course in experimental and theoretical solid-state physics. Topics include: phonons; electronic excitation in solids; electron-phonon interactions; optical transport, and magnetic properties; superconductivity; ferroelectricity. The emphasis will be mainly theoretical with frequent comparison between theoretical predictions and experimental results. Offered in alternate years; offered in 1976-77. Instructor: Darryl Smith.

APh 250. Advanced Topics in Applied Physics (Seminar). *Units, offering date, and duration by arrangement.* Consideration of selected topics in applied physics. Instructors: Members of the staff and guest lecturers.

APh 261 abc. Theory of Particle Transport. *9 units (3-0-6). Prerequisite: instructor's permission.* The formulation and solution of the transport equation for neutrons, photons and simple gases, transport in dense fluids. Not offered in 1976-77.

APh 281 Advanced Theory of Semiconducting Solid State. *9 units (3-0-6); first, second, third terms.* Selected areas in the theory of the solid state relevant to semiconductors will be developed in detail. Emphasis will be placed on areas of current research interest in the field. Topics include: electronic and vibrational spectra, optical properties, electron phonon interactions, transport phenomena, disordered semiconductors, impurities, defects, and interfaces. Offered in alternate years; not offered in 1976-77.

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); first term.* 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. 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 which produced them. 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: Cohen.

Ay 20. Basic Astronomy and the Galaxy. *11 units (3-2-6); first term. Prerequisites: Ma 1 abc, Ph 1 abc.* Astronomical terminology. Stellar masses, distances and motions. Star clusters and their galactic distribution. Stellar spectra, magnitudes and colors. Structure and dynamics of the galaxy. Laboratory exercises including double star orbits and the use of an astrograph. Instructor: Werner.

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. Instructors: Sargent, Blandford.

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; 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: Zirin 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); first 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, Moffet.

Ay 101. The Physics of Stars. *11 units (3-2-6); first term. Prerequisite: Ay 20.* The physics of stellar atmospheres and interiors. Instructors: Goldreich, Wannier.

Ay 102. Plasma Astrophysics and the Interstellar Medium. *9 units (3-0-6); third term. Prerequisite: Ay 20.* An introduction to fluid mechanics; sound waves and shock waves. 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: Knapp.

Ay 110. Senior Seminar in Astrophysics. *6 units (2-0-4); second term.* Designed for Ay seniors. Seminar on astrophysical topics of current interest. The lectures will be given by the students. The emphasis will be on topics which require a synthesis of previous formal course work. Instructor: Greenstein.

Ay 120. Basic Astronomy and Astrophysics from an Advanced Viewpoint. *9 units (1-0-8); first term.* A lecture-reading course open to graduate students with deficient undergraduate background in astronomy and astrophysics. Content tailored to needs of students. Instructor: Greenstein.

Ay 131. Stellar Atmospheres. *9 units (3-0-6); first term. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) and Ph 92 abc or equivalents.* General survey of the methods for studying the structure and composition of stellar atmospheres. Instructor: Castor.

Ay 132. Stellar Interiors. *9 units (3-0-6); first term. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) and Ph 92 abc or equivalents.* Polytropes, opacity and energy generation. Stellar models and evolution. White dwarfs. Pulsating stars. Problems of stellar rotation, convection, and stability. Instructor: Gunn.

Ay 133 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. Instructors: Cohen, Moffet, Blandford, Wannier.

Ay 134. The Sun. *9 units (3-1-5); second term.* The physical state of the sun as derived from observations from the ground and from space. The 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. Not offered in 1976-77.

Ay 138. Interstellar Matter. *9 units (3-0-6); third term. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) or equivalents.* The interstellar gas and dust. Reddening, absorption and polarization of light. Interstellar absorption lines. Ionized and neutral regions. Excitation of emission lines. The dynamics of gas clouds. Interstellar molecules. Star formation. Given in alternate years. Offered in 1976-77. Instructor: Wannier.

Ay 139. Stellar Dynamics and Galactic Structure. *9 units (3-0-6); third term. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) or equivalents.* Dynamical and kinematical description of stellar motions. Galactic rotation and the density distribution. Dynamics of clusters; relaxation times. Structure and mass of the galaxy and external systems. Given in alternate years. Not offered in 1976-77.

Ay 141 abc. Research Conference in Astronomy. *2 units (1-0-1); first, second, third terms.* These conferences consist of reports on investigations in progress at the Hale Observatories and the Owens Valley Radio Observatory, and on other researches which are of current interest. Graded pass/fail.

Ay 142. Research in Astronomy, Radio Astronomy, and Astrophysics. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of research outlined with him. Approval of the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy. Graded pass/fail.

Ay 143. Reading and Independent Study. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of reading and independent study outlined with him. Approval of the 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); third 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. Offered in 1976-77. Instructor: Oke.

Ay 207 ab. Galaxies and the Universe. *9 units (3-0-6); first, second terms. Prerequisites: Ay 20 (undergraduates), Ay 120 (graduates) 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 1976-77. Instructors: Sargent, Schmidt, Gunn.

Ay 208. Modern Observational Astronomy. *6 units (1-0-5); second term. Prerequisite: instructor's permission.* An observational course for graduate students in astronomy in which modern astronomical techniques are used in conjunction with the various telescopes on Mount Wilson and Palomar Mountain. Students will be permitted to register for only one term. Given in alternate years. Not offered in 1976-77.

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. Offered in 1976-77. Instructors: Goldreich, Gunn.

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, synchrotron, bremsstrahlung, inverse Compton, and coherent). Relativistic gravity. Given in alternate years. Not offered in 1976-77.

Ay 234. Seminar in Radio Astronomy. *6 units (2-0-4); second term. Prerequisite: Ay 133 abc.* Recent developments in radio astronomy for the advanced student. Current publications and research in progress will be discussed by students and staff. Given in alternate years. Offered in 1976-77. Instructors: Staff.

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.

BIOLOGY

Undergraduate Courses

Bi 1. Introduction to Biology. *9 units (3-3-3); second term.* The course emphasizes the importance of cells in biology and their role as building blocks of organs and organisms. Elements of developmental biology and genetics are also presented. The course can be taken by itself although its contents are integrated with the offerings in Cell Biology (Bi 9). Instructors: Revel and staff.

Bi 2. Current Research in Biology. *6 units (2-0-4); first term. An elective course, open only to freshmen.* Current research in biology will be discussed, on the basis of reading assigned to students in advance of the discussions, with members of the divisional faculty. Graded pass/fail. Instructors: Owen and staff.

Bi 3. Biology and Social Problems. *6 units (2-0-4); third term.* The relation of biological knowledge to major social problems. Topics may include over-population, environmental pollution, distribution of limited medical resources, "genetic engineering," biological warfare, the ethics of human medical research, etc. Not offered in 1976-77. Instructor: Sinsheimer.

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, and staff.

Bi 9. Cell Biology. *9 units (3-3-3); third term.* Studies of life at the cellular level; nature, functions, and integration of ultrastructural components; physical and chemical parameters; influences of external agents and internal regulation. Instructors: Bonner and staff.

Bi 22. Special Problems. *Units to be arranged; first, second, 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: Wood and staff.

Bi 27. Biology Scholars Program. *Units to be arranged.* A program providing, by arrangement, a flexible combination of course work and independent study in biology for selected students in the junior and senior years. Pass/fail grading may be permitted. Instructors: Wood and staff.

Advanced Courses

(A) Subjects intended for graduate students but open to qualified undergraduates.

Bi 102. Vertebrate Biology. *12 units (2-5-5); second term. Recommended prerequisites: Bi 7 and Bi 9.* A survey of structure, function, and development in vertebrates, with emphasis on physiology. Offered alternate years. Not offered in 1976-77. Instructors: Brokaw and staff.

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 ab. Biochemistry. *12 units (4-0-8); first, second terms. Prerequisite: Ch 41 or instructor's permission.* Lectures and discussions on the molecular basis of biological structure and function. The first term emphasizes macromolecular structure and the metabolic processes involved in energy storage and utilization. The second term considers the storage, transmission and expression of genetic information in prokaryotes and eukaryotes, and other topics in the biochemistry of higher organisms, such as molecular regulatory mechanisms and the biochemistry of cell membranes. Instructors: Raftery, Richards, Wood, and staff.

Bi 111. Biochemistry Laboratory. *10 units (0-8-2); second term. Open to students enrolled in Bi 110; others require consent of instructor.* An introduction to current methods in biochemical research, through laboratory projects suggested by the lecture and seminar material of Bi/Ch 110. Instructors: Mitchell and staff.

Bi 114. Immunology. *9 units (4-0-5); first term. Prerequisite: Bi 122 or equivalent.* A course on the principles and methods of immunology and their application to various biological problems. Instructor: Hood.

Bi 115. Virology. *10 units (3-4-3); third term. Prerequisite: Bi 110 or instructor's permission.* An introduction to the chemistry and biology of bacterial, plant, and animal viruses. The subject matter will include viral structure, the biochemistry and regulation of virus replication, viral genetics, and virus-induced changes in the host cell. Instructor: Strauss.

Bi 116. Immunology Laboratory. *5 units (0-5-0); first term. Open to students enrolled in Bi 114; others require instructor's permission.* Laboratory research projects serve primarily as a means of acquiring experience with some of the methods and problems of immunology. Instructor: Owen.

Bi 119. Advanced Cell Biology. *9 units (3-0-6); third term. Prerequisites: Bi 9, Bi 110 or instructor's permission.* Principles of general microbiology and of the growth and differentiation of the cells of higher organisms. Regulatory circuits in nucleic acid and protein synthesis; mechanisms of control of enzyme activity; regulation of cell multiplication; surface properties of cells. Instructor: Attardi.

Bi/BIS 121 abc. Biosystems Analysis. *6 units (2-0-4); first, second, third terms. Prerequisite: Bi 151 or instructor's consent.* A systematic consideration and application of the methods of systems analysis, information theory and computer logic to problems in neurobiology. The subjects to be considered include the mechanical properties of striated muscle, the analysis of neuronal integrative mechanisms and reflex behavior in terms of logical net theory. The course will seek to describe some aspects of human cortical activity in terms of information theory and conceptual modeling. The course will be conducted as a research seminar and the detailed subject matter will change from year to year. Instructor: Fender.

Bi 122. Genetics. *12 units (3-3-6); third term. Prerequisite: Bi 1 or Bi 9, or instructor's permission.* A lecture, discussion, and laboratory course covering the basic principles of genetics. Instructors: Lewis and staff.

Bi 129. Biophysics. *6 units (2-0-4); second term.* An examination of the notions of truth and reality in mathematics, classical and quantum physics, biology and psychology, and the standing of these notions on the evolution and in the development of the cognitive functions of man. Instructor: Delbrück.

Bi/Ch 132 abc. Biophysical Chemistry of Macromolecules. *9 units (3-0-6); first, 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. Instructors: Chan, Davidson, Stroud.

Bi/Ch 133. Biophysical Chemistry of Macromolecules Laboratory. *14 units (0-10-4); second, third terms.* A laboratory course designed to provide an intensive training in the techniques for the characterization of biological macromolecules. Open to selected students. Offered alternate years; not offered in 1976-77. Instructors: Staff.

Bi 134. Advanced Research Techniques in Molecular Biology. *14 units (0-10-4); first term.* A laboratory course designed to provide research experience in utilizing important, new methods in molecular biology as they become available. Open to selected students. In charge: Dreyer and staff. Offered alternate years; offered in 1976-77.

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 1976-77. 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 1976-77. Instructor: Revel.

Bi 137. Multicellular Assemblies. *8 units (2-2-4); third term. Prerequisite: Bi 1.* The course will deal with the structural organization of tissues viewed as basic cellular assemblies common to all of the organs. Emphasis will be placed on correlation between morphology and function. Not offered in 1976-77. 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. *9 units (3-0-6); first term. Prerequisites: Bi 1 and Bi 9 or instructor's permission.* General principles of the organization and function of nervous systems, providing both an overview of the subject and a foundation for advanced courses. Topics will include gross neuroanatomy and neurocytology; developmental neurobiology, the biophysical basis for action potentials, synaptic transmission and sensory transduction; and the integration of these processes in complex sensory and motor pathways. Not offered 1976-77. Instructors: Hudspeth, Van Essen.

Bi 151 ab. Neurophysiology. *9 units (3-0-6); first, second terms.* This course presents the fundamentals required for advanced study in neurobiology. The first term treats cellular neurophysiology: the structure of neurons, receptor cells, and effector cells; the biophysics of excitable membranes; synaptic transmission; sensory transduction; neuropharmacology; muscular contraction, and simple reflexes. Instructor: Lester.
In the second term, knowledge of membrane and synaptic biophysics is used to show how complex nervous systems perform sensory information processing and patterning of motor behavior. A recurring theme will be the visuo-motor system of vertebrates, but

parallels will be drawn with other modalities such as touch and hearing, and with other phyla, such as the Annelida and the Mollusca. Instructors: Pettigrew and staff.

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 153. Brain Studies of Motivated Behavior. *12 units (2-4-6); third term. Prerequisite: instructor's permission.* A lecture and laboratory course concerned with the anatomical and physiological bases of drives, arousal, rewards, and learning. Emphasis is placed on the mammalian brain, particularly the midbrain, hypothalamus, and paleocortex with reference to the effects of lesions and electric stimulation upon physiological and behavioral activity. Instructor: Olds.

Bi 155. Psychobiology. *6 units (2-0-4); second term.* An introduction to the study of neural mechanisms of behavior with emphasis on development, circuitry and the problem of correlating brain processes with psychological functions. Instructor: Sperry.

Bi 156. Neurochemistry. *9 units (3-0-6); third term. Prerequisite: Bi 151 or instructor's permission.* A lecture and discussion course covering chemical aspects of synaptic transmission, impulse conduction, axonal transport, neuroendocrine control mechanisms, and control of nerve cell differentiation, growth, and systemic organization. Not offered in 1976-77.

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. Instructor: Allman.

Bi 161 ab. Neurobiology Laboratory. *6 units (0-4-2); first term. Prerequisite: Bi 150 or 151 a, or concurrent enrollment in Bi 151 a.* A laboratory course in techniques of cellular neurophysiology, as exemplified by the frog nerve-muscle preparation and the leech central nervous system. Students conduct all aspects of the experiments, including dissections, fabrication of microelectrodes, and intracellular stimulation and recording. Instructor: Lester.

(B) Subjects primarily for graduate students.

Bi 201. General Biology Seminar. *1 unit; all terms.* Meets weekly for reports on current research of general biological interest by members of the Institute staff and visiting scientists. In charge: Hood, Russell.

Bi 202. Biochemistry Seminar. *1 unit; all terms.* A seminar on selected topics and on recent advances in the field. In charge: Mitchell.

Bi 204. Genetics Seminar. *2 units; all terms.* Reports and discussion on special topics. In charge: Russell and staff.

Bi 207. Biophysics Seminar. *1 unit; all terms.* A seminar on the application of physical concepts to biological problems. Reports and discussions. In charge: Delbrück.

Bi 209. Psychobiology Seminar. *Units to be arranged; all terms. Prerequisite: instructor's permission.* Advanced seminar in brain mechanisms and behavior. In charge: Sperry.

Bi 214. Topics in Sensory Transduction. *6 units (2-0-4); second term. Prerequisite: Bi 150 or 151 a and instructor's permission.* Anatomy, biophysics, physiology, and psychophysics of sensory transduction systems in both invertebrates and vertebrates. Visual and auditory-vestibular senses will be emphasized, but touch, taste, olfaction, thermoception, electroception, and magnetoception will be included. Lectures and extensive discussions of the original research literature. Offered in alternate years; offered in 1976-77. Instructor: Hudspeth.

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 1976-77. 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 1976-77. 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 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: animal physiology (280), biochemistry (281), bio-organic chemistry (282), developmental biology (283), genetics (284), immunology (285), marine zoology (286), plant physiology (287), biophysics (288), psychobiology (289), cell biology (290), physiological psychology (291).

BUSINESS ECONOMICS AND MANAGEMENT

Advanced Courses

BEM 100 abc. 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 106 abc. Business Economics (Seminar). *Units by arrangement; first, second, third terms. Prerequisite: instructor's permission.* This seminar uses various methods to assist students who want specialized study of some aspects of business economics or industrial relations. Graded pass/fail. Instructor: Gray.

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. Instructor: Gray.

BEM 132. The Management of an Enterprise. *9 units (3-0-6); third term.* Covers solutions to management problems related to equipment, materials, and production such as selection of products and plant location; work and plant layout; cost, production, and inventory controls; and systems. Instructor: Gray.

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. Instructors: Pings (ab), Gavalas (c).

ChE 80. Undergraduate Research. *Units by arrangement.* Research in chemical engineering and industrial chemistry offered as an elective in any term. If ChE 80 units are to be used to fulfill elective requirements in the chemical engineering option, a thesis approved by the research director must be submitted in duplicate before May 10 of the year of graduation. The thesis must contain a statement of the problem, appropriate background material, a description of the research work, a discussion of the results, conclusions, and an abstract. The thesis need describe only the significant portion of the research. Graded pass/fail.

ChE 81. Special Topics in Chemical Engineering. *Units by arrangement.* Occasional advanced work involving reading assignments and a report 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 ab. Applied Chemical Kinetics. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 abc or the equivalent.* Chemical kinetics, including an introduction to heterogeneous catalysis. Study of kinetics in combination with transport processes in gas-solid, gas-liquid, and liquid-liquid reacting systems. Chemical reactors, including fixed and fluidized beds. Transition state theory. Chain reactions and combustion. Statistical treatment of kinetic data. Instructor: Gavalas.

ChE 103 abc. Transport Phenomena. *9 units (3-0-6); first, second, third terms. Prerequisites: AMa95 or AM 113ab, 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: Shair (a), Seinfeld (bc).

ChE 110 ab. Optimal Design of Chemical Systems. *9 units (3-0-6); first, second terms. Prerequisites: ChE 63 ab, ChE 103 abc or equivalent, or enrolled in ChE 103 concurrently.* 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 abc. Chemical Engineering Laboratory. *9 units (1-4-4); first, second, third terms.* Projects illustrative of problems in transport phenomena, unit operations, chemical kinetics, and reactor control are performed. Instructor: Vaughan.

Graduate and Advanced Undergraduate Courses

ChE/Env 157ab. Fundamentals of Air Pollution Engineering. *9 units (3-0-6); first, second terms. Open to graduate students and seniors with instructor's permission.* Basic concepts necessary to understand the sources, control, and atmospheric behavior of air pollutants. Air quality and emission standards; sources, quantities, and nature of emissions; combustion, chemistry of pollutant formation and control; control technology: absorbers, filters, electrical precipitators; aerosol physics, atmospheric chemistry; urban basin modeling and control; air monitoring systems. Instructors: Friedlander, Seinfeld, Flagan.

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/Ch 164. Introduction to Statistical Thermodynamics. *9 units (3-0-6); first term. Prerequisite: Ch 21 abc or the equivalent.* Ensembles and a statisical mechanical formulation of the second and third laws of thermodynamics. Classical statistical mechanics and an introduction to quantum statistics. The ideal monatomic, diatomic and polyatomic gas-translational, rotational, vibrational and electronic partition functions. Chemical equilibria. Real gases. The ideal crystal lattices. Instructor: Weinberg.

ChE 165 ab. Applied Chemical Thermodynamics. *9 units (3-0-6); second, third terms. Prerequisite: ChE 63 abc or equivalent.* Thermodynamics applied to both open and closed systems including those involved with chemical change. Ideal and real systems. Third term not offered in 1976-77. Instructor: Shair.

ChE 166 a. Polymer Engineering. *9 units (3-0-6); first term.* Basic engineering properties of polymeric materials for the chemical, mechanical, electrical, and civil engineer. (Everything you always wanted to know about polymers but were afraid to ask.) Not offered in 1976-77. Instructor: Tschoegl.

ChE 167 ab. Polymer Science. *9 units (3-0-6); second, third terms. Prerequisite: ChE 166 or equivalent.* A course in the science of synthetic macromolecules: their synthesis, characterization, and properties. The emphasis is on an understanding of polymer properties in terms of molecular structure. Not offered in 1976-77. Instructor: Tschoegl.

ChE 168. Polymer Science Laboratory. *9 units (0-7-2); third term. Prerequisite: ChE 167 ab or equivalent.* An introduction to some of the basic techniques employed in the polymerization and characterization of synthetic polymers. Not offered in 1976-77. Instructor: Tschoegl.

Ae/ChE/EE 172 abc. Optimal Control Theory. *9 units (3-0-6); first, second, third terms.* Classical and modern control theory. Optimization problems for dynamical systems with terminal and path constraints. Optimal control in the pressure of noise, recursive filtering, smoothing and interpolation for linear system with additive Gaussian noise. Instructors: Staff.

ChE 173 ab. Advanced Transport Phenomena. *9 units (3-0-6); first, second terms. Prerequisites: 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. 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 191 abc. Chemical Engineering Conference. *2 units (1-0-1); first, second, third terms.* Oral presentations on problems of current interest in chemical engineering and industrial chemistry with emphasis on the techniques of effective oral communication with groups. Graded pass/fail for undergraduates. Instructors: Staff.

ChE 203 ab. Interfacial Phenomena. *9 units (3-0-6); second, third terms. Prerequisite: ChE 103 abc, or instructor's permission.* Review of the theory of the Brownian motion and irreversible thermodynamics, structure of the interface, absorption and monomolecular layers, membrane transport, facilitated transport, active transport, convective diffusion, concentration boundary layers, current flow through electrolytic solutions, interfacial turbulence. Instructor: Friedlander.

ChE 207 abc. Mechanical Behavior of Polymers. *9 units (3-0-6); first, second, third terms. Prerequisite: ChE 166, ChE 167, or equivalent.* The theoretical and experimental foundations of the mechanical behavior and ultimate (failure) properties of polymeric materials. Special attention is given to the controlling molecular parameters. Not offered in 1976-77. Instructor: Tschoegl.

ChE 280. Chemical Engineering Research. *Offered to Ph.D. candidates in Chemical Engineering.* The main lines of research now in progress are covered in detail on page 117.

CHEMISTRY

Undergraduate Courses

Ch 1 abc. General and Quantitative Chemistry. *6 units (3-0-3); first, second, third terms.* Lectures and recitation dealing with general principles of chemistry. Fundamental laws and theories of chemistry are discussed and illustrated by factual material. Text: *Chemical Principles,* Dickerson, Gray, and Haight. Graded pass/fail. Instructors: Dickerson, Gagné.

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 modern methods for the determination of molecular structure and the elucidation of molecular pathways for chemical transformation. Graded pass/fail. Instructors: Chan, Gray.

Ch 3 abc. Experimental Chemical Science. *First term, 6 units (0-6-0); second, third terms. 3 units (0-3-0); or 6 units (0-6-0).* First term is an introduction to experimental chemistry. Experiments involve quantitative analysis, chemical dynamics, and the use of chemical instrumentation; initial stages of Project Acac optional. Second and third terms follow one or more of three project outlines in coordination chemistry, organotransition metal chemistry, and biochemistry. Graded pass/fail. Instructors: Bercaw, Zewail.

Ch 14. Chemical Equilibrium and Analysis. *6 units (2-0-4); first term.* Association equilibria, including ions and neutral ligands in solution; examples relevant to biochemistry will be emphasized, including acid-base equilibria, solubililty, complex ions and chelation, binding of ligands by macromolecules, cooperative binding equilibria, oxidation-reduction reactions and some aspects of reaction mechanisms. Instructor: Richards.

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 some of the modern instrumental techniques that are currently employed in industrial and academic research. Emphasis will center on determinations of chemical composition, measurement of equilibrium constants, and trace-metal analysis. Instructors: Anson, 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.* A lecture and recitation course. The main emphasis is on atomic and molecular theory, quantum mechanics, statistical mechanics, thermodynamics, and chemical kinetics. Instructors: Dickerson, McKoy.

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 which provide illustrations of the principles of physical chemistry, an introduction to problems of current interest, and techniques of contemporary research. Instructors: Stroud and staff.

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. Instructor: Bergman.

Ch 46 ab. Experimental Methods of Covalent Chemistry. *9 units (1-6-2); second, third terms. Prerequisite: Ch 1 abc.* Laboratory accompaniment to Ch 41 abc. Experiments stressing modern techniques for investigating the structures and dynamic behavior as well as synthesis, purification, and characterization of covalent compounds both organic and inorganic. Instructor: Evans.

Ch 80. Chemical Research. *Offered to B.S. candidates in chemistry. Prerequisite: consent of research supervisor.* Experimental and theoretical research experience requiring a report containing an appropriate description of the research work. No more than 60 units of Ch 80 credit for undergraduate research may be accumulated as chemistry electives without special permission. Graded pass/fail.

Ch 81. 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); first term.* Training in the techniques of oral presentation of chemical topics. Practice in the effective organization and delivery of reports before groups. Instructors: Dickerson, Gagné, Ireland.

Advanced Courses

Bi/Ch 110 ab. Biochemistry. *12 units (4-0-8); first, second terms. Prerequisite: Ch 41 or instructor's permission.* A lecture and discussion course on the molecular basis of biological structure and function. The first term emphasizes macromolecular structure and the metabolic processes involved in energy storage and utilization. The second term considers the storage, transmission and expression of genetic information in prokaryotes and eukaryotes. Instructors: Raftery, Richards, Wood.

Ch 112 abc. Advanced Inorganic Chemistry. *9 units (2-0-7); first, second, third terms. Prerequisite: Ch 21 abc or concurrent registration.* Thorough treatment of the electronic structures and reaction mechanisms of inorganic molecules, with emphasis on transition metal complexes. Instructors: Gray, Lever.

Ch 113 abc. Advanced Ligand Field Theory. *12 units (1-0-11); first, second, third terms. Prerequisite: Ch 21 abc or concurrent registration.* A tutorial course which involves problem solving in the more advanced aspects of ligand field theory. This course is recommended only for students interested in detailed theoretical work in the inorganic field. Instructor: Gray.

Ch 117. Introduction to Electrochemistry. *6 units (2-0-4); second term.* An examination of the theory and experimental results in the study of the kinetics of simple and complex electrode reactions. Emphasis will be placed on the effects of interfacial structure and composition on reaction rates and mechanisms. Specific topics include equilibrium properties of the electrode-solution interface, the quantum mechanical analysis of electron transfer, electrostatic and covalent interactions of reactants and products with their environment, and the effects of electrode material. Instructor: Fawcett.

Ch 118 ab. Experimental Electrochemistry. *Units by arrangement; second, third terms.* Laboratory practice in the use of selected electrochemical instruments and techniques. The student may pursue a set of expository experiments or elect to carry out a research project in electrochemistry. Instructor: Anson.

Ch 120 ab. The Nature of the Chemical Bond. *9 units (3-0-6); second, third terms. Prerequisite: Ch 21 a or an equivalent brief introduction to quantum mechanics.* Modern ideas of chemical bonding will be discussed with the emphasis on the qualitative concepts and how they are used to 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 the first 28 elements and will include some discussion of impurity states in solids, and the bonding and reactions at surfaces of solids. The b term will be in tutorial form. Offered in 1976-77. 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: Marsh, Roberts, and staff.

Ch 125 ab. The Elements of Quantum Chemistry. *9 units (3-0-6); first, second 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 interaction of matter with electromagnetic radiation, rotational and vibrational states of molecules, basic elements of scattering theory, and the fundamental ideas about chemical bonding. Instructors: Baldeschwieler, Goddard, Zewail.

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 1976-77. Instructor: Burnett.

Ch 130. Spectroscopic Probes of Biological Light Energy Transduction. *6 units (3-0-3); second term.* Conversion of light energy into chemical energy in photobiological systems. The role of new spectroscopic techniques in our understanding of the primary events which are essential in this initial conversion of light energy will be discussed. These primary processes will be discussed and the biological role of the stored light energy will be explored. Instructor: Lewis

Bi/Ch 132 abc. Biophysical Chemistry of Macromolecules. *9 units (3-0-6); first, 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. Instructors: Chan, Davidson, Stroud.

Bi/Ch 133. Biophysical Chemistry of Macromolecules Laboratory. *14 units (0-10-4); second, third terms.* A laboratory course designed to provide an intensive training in the techniques for the characterization of biological macromolecules. Open to selected students. Given in alternate years; offered in 1976-77. Instructors: Staff.

Ch 135 ab. Chemical Dynamics. *9 units (3-0-6); second, third terms. Prerequisites: Ch 21 abc and Ch 41 abc or equivalent.* The interrelation of rates, energetics and mechanisms of chemical reactions both in solution and the gas phase. Topics covered include general kinetic methods, theories of elementary reactions, treatment of complex processes, organic and inorganic reaction mechanisms, and enzyme kinetics. Given in alternate years; not offered in 1976-77. Instructor: Beauchamp.

Ch 140 abc. Special Topics in Chemistry. *Units by arrangement; first, second, third terms. Prerequisite: Ch 41 abc or equivalent.* Lectures on a series of subjects of current interest at the forefront of chemistry. Not offered in 1976-77.

Ch 144 ab. Advanced Organic Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 41 abc or equivalent.* Lectures and discussions of a number of basic unifying themes in organic chemistry. Problems in synthetic, theoretical, organometallic, and bio-organic chemistry with emphasis on stereochemistry. Instructors: Ireland, Roberts.

Ch 154. Organometallic Chemistry. *6 units (2-0-4); third term. Prerequisite: Ch 41 abc or equivalent.* A general discussion of the preparation, structure and bonding, reaction mechanisms, and synthetic and catalytic uses of transition metal organometallic compounds. Not offered in 1976-77. Instructors: Bercaw, Bergman.

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. The ideal crystal lattices. Instructor: Weinberg.

Ch 180. Chemical Research. *Offered to M.S. candidates in chemistry.* Graded pass/fail.

Ch 223 abc. Statistical Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 127 ab or an introductory course in statistical mechanics; or the consent of the instructor.* The present course assumes knowledge of the Ph 127 material and will direct itself to applications of chemical interest such as statistical thermodynamics, transport phenomena, gases at high pressure, and liquids, polymers, and crystals. Not offered in 1976-77.

Ch 224 abc. Magnetic Resonance. *9 units (3-0-6); first, second, third terms. Prerequisite: background in elementary statistical and quantum mechanics, and some familiarity with elementary magnetic resonance.* The principles of nuclear magnetic resonance and electron paramagnetic resonance will be discussed. The theoretical background behind the various types of magnetic resonance experiments will be developed. Methods for the analysis of spectra will be treated as well as the theory of interaction between nuclear spins, electron spins, nuclear-electronic coupling and the dynamic coupling of spins to lattice degrees of freedom. Not offered in 1976-77. Instructors: Chan, Vaughan.

Ch 227 ab. Advanced Topics in Chemical Physics. *9 units (3-0-6); second, third terms. Prerequisite: Ch 125 or equivalent.* Experimental and theoretical aspects of molecular collisions will be discussed. These will include chemical reactions in crossed molecular beams, ion-molecule reactions, electron impact excitation, and photoionization. Applications to current research in elementary processes will be emphasized. Not offered in 1976-77. Instructor: Kuppermann.

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. Offered in 1976-77. Instructors: Marsh, Samson.

Ch 242 ab. Chemical Synthesis. *4 units (2-0-2); second, third 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 1976-77. Instructors: Evans, Ireland.

Ch 244 a. Topics in Chemical Biology. *6 units (3-0-3); third 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. Instructors: Raferty, Richards.

Ch 247 ab. Organic Reaction Mechanisms. *6 units (2-0-4); second, third terms.* Various tools for the study of organic reaction mechanisms will be discussed with major emphasis on kinetic methods. Given in alternate years; offered in 1976-77. Instructor: Dervan.

Ch 254. 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 1976-77. Instructor: Schroeder.

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

(See Engineering and Applied Science)

COMPUTER SCIENCE

(See listing under Engineering and Applied Science)

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: Staff.

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.* This course concentrates on non-market decisions. It focuses on committee and legislative decision-making as well as providing an introduction to recent work in the theory of voting and the political process. Instructors: Staff.

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.* 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. Instructors: Staff.

Ec 13. Reading in Economics. Units to be determined for the individual by the department. Not available for credit toward humanities-social science requirement. Graded pass/fail.

Ec 15. Introduction to Macroeconomics: Principles and Problems. *9 units (3-0-6); second term. Prerequisite: Ec/SS 11 a.* Problems of inflation and depression and the tools of monetary and fiscal policy. Instructors: Staff.

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 316 for description.

Advanced Courses

Ec 101. Selected Topics in Economics. *9 units (3-0-6).* Instructors: Staff, visiting lecturers.

Ec 112. History of Economic Analysis. *9 units (3-0-6); first term. Prerequisite: Ec/SS 11 a.* An examination of the traditions, schools of thought, and controversies which have helped shape modern economic analysis. Instructor: Montgomery.

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: Sweezy.

Ec 116. Contemporary Socioeconomic Problems. *9 units (3-0-6); first term. Prerequisites: Ec/SS 11 a and Ec/SS 11 b.* 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. Instructors: Staff.

Ec 118. Environmental Economics. *9 units (3-0-6); third term. Prerequisite: Ec/SS 11 a.* 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.* 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: Staff.

Ec 122 ab. Econometrics. *9 units (3-0-6); second, third terms. Prerequisite: Ma 112 a.* The application of statistical techniques to the analysis of economic data. Instructors: 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 which 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 instructor's permission.* This course includes an intensive study of Keynes' *General Theory of Employment* and post-Keynesian developments in the theory of income, consumption, investment, and growth. Instructor: Sweezy.

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 abc. The Elements of Dynamic Economics. *9 units (3-0-6); first, second, third terms. First term prerequisite: Ec/SS 11a.* 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 ab. Economic History of the United States. *9 units (3-0-6); second, third terms. Prerequisite: Ec/SS 11 a.* 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 classic problems of welfare economics and economic policy. Instructor: Plott.

Ec 135. Marxist Economics. *9 units (3-0-6); second term. Prerequisite: Ec/SS 11 a.* A critical survey of the economic theory of capitalism as developed in the writings of Marx, Engels, and Lenin. Instructors: Montgomery, 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: Sweezy, H. Brown, Bonner, Scudder, Munger.

ELECTRICAL ENGINEERING

(See Engineering and Applied Science)

ENGINEERING AND APPLIED SCIENCE

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, gasdynamics, combustion, materials science, environmental health, solid-state electronics, biomedical engineering, information science, chemical engineering, etc. The student is given some choice in selecting experiments of particular interest to him. Instructors: Sturtevant and staff.

E 10. Technical Presentations. *2 units (1-0-1); second term.* A course concerned with oral presentations of technical material. Instructors: Staff.

E 13. System Dynamics. *9 units (3-0-6); 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 bc.* 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. Instructor: Cannon.

E 99. Laboratory on Automotive Emissions. *6 units (1-3-2); third term.* The problems of automotive exhaust emissions will be examined from both a theoretical and practical viewpoint. Students will measure emissions, fuel consumption, and power of an experimental vehicle to prepare a performance map for the vehicle. Using this map, the students will develop a tuning specification for the vehicle to meet an emission standard while trying to minimize fuel consumption. Instructors: Staff.

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. Instructor: Cannon.

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. Instructor: Caughey.

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 analyse and synthesize a number of engineering systems using interactive computer facilities. Instructor: Caughey.

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.

AERONAUTICS

Advanced Courses

Ae/APh 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms.* Definition, classification, and properties of fluids. Thermodynamics of fluid flow; compressibility, real gas effects. Acoustic waves, shock waves, gravity waves. Euler equations. Vorticity. Subsonic and supersonic flow fields. Nonstationary flows. Stress-strain relations. Viscosity and heat conduction effects at low and high Reynolds numbers. Boundary layers. Turbulent shear flows. Additional topics will be selected from subjects such as: heat flow and diffusion in gases; dynamics of rarefied gases; plasma flow and magnetohydrodynamics; super fluid flow; rotating fluids. Instructor: Sturtevant.

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. Aerodynamics. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95.* Vector, tensor, and matrix analysis and the behavior of systems described by linear ordinary and partial differential equations. Review of analytical dynamics and fluid mechanics. Idealized and real flows around wings and bodies and through internal flow systems. The performance, stability, and control of aircraft, airships, submarines, surface ships, and sailing craft. The course work will be supplemented by guest lectures given by practicing engineers, and by demonstrations in the GALCIT wind tunnels and water tunnels. Instructor: Clauser.

Ae 105 abc. Experimental Methods. *9 units (3-0-6 first term; 1-3-5 second and third terms). Prerequisite: Me 19 abc, AM 97 abc or equivalent, Ae/APh 101 abc (may be taken concurrently).* First term: Experiment design and implementation. Measurement methods, transducers, signal processing, and instrumentation. Analog and digital electronic fundamentals. Data acquisition and processing systems. Second and third terms: Laboratory in solid and fluid mechanics. Emphasis on current research problems and methods. Topics include low-speed and high-speed aerodynamics, turbulence, acoustics, gas dynamics, vibrations, flutter, waves in solids, fracture, Text: class notes. Instructor: Dimotakis.

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. Instructors: Sechler, Stewart.

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: Babcock.

Ae/ChE/EE 172 abc. Optimal Control Theory. *9 units (3-0-6); first, second, third terms.* Classical and modern control theory. Optimization problems for dynamical systems with terminal and path constraints. Optimal control in the pressure of noise, recursive filtering, smoothing and interpolation for linear system with additive Gaussian noise. 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. Offered in odd-numbered years.

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 1976-77.

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. Instructor: Stewart.

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 non-steady 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). 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 non-linear theories of stressing and buckling of shells. Not offered in 1976-77.

Ae 213. The Mechanics of Fracture. *9 units (3-0-6). Prerequisite: Ae 202 or equivalent and instructor's permission.* An advanced course stressing the analysis of fracture in metallic and non-metallic 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 1976-77.

Ae 217. Aero- and Hydroelasticity. *9 units (3-0-6); second term. 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. Instructor: Babcock.

Ae 221. Theory of Viscoelasticity. *9 units (3-0-6). 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 1976-77.

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 non-linear problems.

Ae 231. Wing Theory. *9 units (3-0-6); first 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. Instructor: Kubota.

Ae 232 ab. Numerical Methods in Fluid Mechanics. *9 units (3-0-6). Prerequisites: Ae 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 1976-77.

Ae 233. Gasdynamic Lasers and Molecular Energy Transfer. *9 units (3-0-6); third term. Prerequisites: Ae 101, AM 125, APh 50 or equivalent, and instructor's permission.* Fluid mechanics of high-temperature flow through supersonic nozzles, under conditions producing population inversion in vibrational/rotational states. Transfer of molecular energy and kinetics of reacting flows in nozzles. Not offered in 1976-77.

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 1976-77.

Ae 235. Acoustical Problems in Fluid Mechanics. *9 units (3-0-6); third 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: Culick.

Ae 237. Non-Steady Gasdynamics. *9 units (3-0-6). Prerequisites: Ae/APh 101, AMa 95 or AM 113, and instructor's permission.* Review of shock waves in moving coordinate systems, in real and perfect gases. Simple expansion waves. Basic shock-tube equation. Reflected shock waves. Wave interactions and geometrical effects. Shock tube applications; non-ideal behavior in shock tubes, diaphragm opening effects, boundary layer effects. Shock-tube techniques and measurements. Driver types and characteristics. Illustrations of shock-tube applications; shock-wave structure, shock-wave interactions, experiments on chemical and physical properties of gases, reaction rates, aerodynamic experiments, light gas guns, etc. Not offered in 1976-77.

Ae 239. Turbulent Shear Flows. *9 units (3-0-6).* 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 1976-77.

Ae 240 abc. 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.

Ae 250. Special Topics in Flight Mechanics. *9 units (3-0-6); first, second, third terms.* Subject matter may change from term to term and from year to year depending upon staff.

APPLIED MATHEMATICS

(See page 255)

APPLIED MECHANICS

Undergraduate Course

AM 97 abc. Analytical Mechanics of Deformable Bodies. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 1 abc and Ma 2 abc.* 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.

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: Jennings, staff.

AM 125 abc. Engineering Mathematical Principles. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or AM 113 abc, or Ma 108, or equivalent.* Topics include: matrix theory, ordinary linear and nonlinear differential equations, stability theory, two-point boundary value problems and partial-differential equations. Applications to various engineering disciplines are stressed. Instructor: Knowles.

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: Sternberg.

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 the nonlinear theory. Specific content varies according to interest of students and instructor. Not offered in 1976-77.

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.* Classical particle and rigid body dynamics with emphasis on technical applications. Response of systems to periodic and transient excitations. General normal mode theory. Introduction to random vibrations and to nonlinear vibration problems. 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 every year.

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 every year.

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

(See page 258)

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 151 or instructor's permission.* This course presents a systematic consideration and application of the methods of systems analysis, information theory and computer logic to problems in neurobiology. The subjects to be considered include the mechanical properties of striated muscle, the analysis of neuronal integrative mechanisms and reflex behavior in terms of logical net theory. The course will seek to describe some aspects of human cortical activity in terms of information theory and conceptual modeling. The course will be conducted as a research seminar and the detailed subject matter will change from year to year. Instructor: Fender.

BIS 203 ab. Identification and Estimation Procedures for Dynamic Systems. *9 units (3-3-3); second, third terms. Prerequisite: prior approval of instructor.* Through new techniques employing the interactive computer concept, effective methods of modeling by estimation and identification theory have now become practical for a variety of systems that cannot be analyzed by traditional methods. Both time-domain and frequency-domain approaches are covered. Examples will be taken from diverse fields, such as engineering, biological systems and economic models. This course will be presented in a newly developed computer interactive classroom and laboratory environment. Instructors: Marmarelis and McCann.

BiS 220. Theories of Visual Nervous Systems. *9 units (3-0-6); third term. Prerequisites: Bi/BiS 121 abc and BiS 203 ab.* Strategies for the correlation of experimental techniques for studying nervous systems with computer-instrumented methods of examining experimental results by data analysis and modeling. Comparisons will be made between models based upon formal mathematics and new computer-instrumented strategies that provide more complete and detailed correlations with experimental results. Instructor: McCann.

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. Instructor: Shantz.

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 instructor. A written report will usually be required. Instructors: Fender and McCann.

CHEMICAL ENGINEERING

(See page 271)

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, inter-particle reactions, and soil structure. Linear constitutive relations for soils, including steady state and transient water flow. In the second term, attention is given to non-linear 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 121. Analysis and Design of Structural Systems. *9 units (0-9-0); third term. Prerequisite: Ae/AM 102 abc.* The analysis and design of complete structural systems. In general, students will work on a single problem for the entire term. The problem may be primarily one of analysis or one of design. Instructors: Staff.

CE 124. Special Problems in Structures. *9 units (3-0-6); any term.* Selected topics in structural mechanics and advanced strength of materials to meet the needs of first-year graduate students. Instructors: Housner, Jennings.

CE 130 abc. Civil Engineering Seminar. *1 unit (1-0-0); each term.* 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 transducer and recorder types 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. Instructors: Staff.

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: Hudson.

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; observed effects of earthquakes on structures; earthquake behavior of special structures such as long-span suspension bridges, and fluids in tanks and reservoirs; earthquake design criteria. Instructor: Housner.

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: Wilts.

CS 10. Introduction to the Use of Computers. *6 units (1-2-3); one-term course offered second and third terms. Freshmen only or instructor's permission.* The purpose of this course is to introduce to the students the use of computers for solving mathematical problems arising in engineering and science. By solving a variety of sample problems, the student will learn basic techniques of computational mathematics. Algebraic computer languages will be employed in batch processing and in conversational time-sharing. Graded pass/fail. Instructor: McCann.

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 own digital system. Graded pass/fail. Instructor: Mead.

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 is intended to provide 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: Computer science staff; Course Supervisor: Sutherland.

Advanced Courses

CS 110 abc. Principles of Digital Information Processing. *9 units (3-3-3); first, second, third terms.* This course presents the principles and concepts of information processing systems with emphasis on the design of stored program, synchronous computers. This includes Boolean Algebra, switching theory, arithmetic algorithms and their application to logical design. The organization of digital processors at the hardware level is covered together with a comprehensive review of modern digital technology. The laboratory includes exposure to modern computers at the hardware level, the development of a complete system design, and the opportunity to design and build digital devices. Instructor: Ray.

CS/EE 111. Digital Electronics Laboratory. *6 units (0-6-0); third term. Prerequisite: CS/EE 11 or EE 90 and CS 110 c concurrent.* A non-structured project laboratory for the hardware implementation of digital projects designed in CS 110. Instructors: Ray, Humphrey.

CS 130 abc. Language Systems. *9 units (3-0-6). Prerequisite: CS 137 or equivalent.* Issues involved in designing and using programming languages are considered in detail. Current languages (FORTRAN, ALGOL, LISP, PL/I, SIMUIA, etc.) together with languages now being developed (ALGOL/6 8, PPL, EII, PLANNER, etc.) are used to illustrate such issues. Selected topics in the theory of programming languages, such as formal models of syntax and semantics, program verification and automatic program synthesis will be examined. May not be offered in 1976-77.

[1]For linguistics see page 318.

CS 137. Systematic Computer Programming. *12 units (3-3-6); first term.* An informal introduction to computer programming in a well-structured, efficient programming language. The main goal is to enable the student to write small programs with a clearly 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. May not be offered in 1976-77. Instructors: Staff.

CS 138. Data Structures and Algorithms. *12 units (3-3-6); second term. Prerequisite: IS 137 or equivalent.* An introduction to the abstract properties and implementation techniques of computer programming languages. The main topic is the axioms and representation of data structures and algorithms. Exercises in language implementation are solved by small student teams. May not be offered in 1976-77. 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. May not be offered in 1976-77. Instructors: Staff.

CS 140 ab. Programming Laboratory. *12 units (3-9-0); 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: Sutherland.

CS 141. Formal Models of Computation. *9 units (3-0-6); first term.* The aim of this course is to make students familiar with the main theoretical results of computer science, to point out to which extent these results are relevant to computer applications, and to facilitate further study of the literature. Models of effective computations: Turing machines, combinatorial systems, lambda calculi, recursive functions, decidable and undecidable problems. Formal languages: their specification by phrase structure grammars, their generation and recognition by automata. Instructor: Thompson.

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. Taught in alternate years; not offered in 1976-77. Instructor: Thompson.

CS 150. Selected Topics in Artificial Intelligence. *9 units (3-0-6); first term.* An introductory course focusing on major research areas of artificial intelligence showing its typical problems, concepts, methods, and programming languages. Topics will be chosen from the areas of problem solving, scene analysis, natural-language processing, and robotics. The aim is to show the interplay between the experimental programming approach to the study of intelligent processes, and its theoretical implications and practical applications. May not be offered in 1976-77.

CS 250 ab. Mathematical Linguistics. *9 units (3-0-6); second and third terms. Prerequisite: Ma 116 abc or CS 141.* This course presents a systematic development of the syntactic and semantic properties of languages. This includes the natural languages as well as the formal languages of symbolic logic and information processing. The philosophical aspects of languages will be stressed together with the formalization of language structures suitable for computer simulation. Taught in alternate years. Offered in 1976-1977. Instructor: Thompson.

CS 280. Research in Computer Science. *Units in accordance with work accomplished. Approval of student's research adviser and his department adviser must be obtained before registering.*

CS/EE 281 abc. Integrated Circuit Design. *9 units (3-0-6); first, second, third terms. Prerequisite: Proficiency in semiconductor device physics, circuit design, and logic design.* An advanced graduate course in the physics, design, production, and use of large-scale integrated circuits. Emphasis on system realization in LSI. Instructor: Mead.

CS 282. 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 literature of a potential research area of computer science. Only qualified students will be admitted after consultation with the instructor. A written report will usually be required. Instructor: Sutherland.

CS 284 abc. Computer Graphics. *9 units (3-3-3). Prerequisites: CS 110 and CS/EE 111 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. Instructor: Sproull.

CS 286. Computer Architecture. *9 units (3-0-6); 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. Instructor: Sutherland.

CS 288 ab. 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. Offered in 1976-77. Since the content of this course may change from year to year, it may be repeated for credit. Instructor: Kay.

The following courses cover related basic mathematics and applied mathematics:

AMa 104. Matrix Theory. See Applied Mathematics Section.

AMa 105 ab. Introduction to Numerical Analysis. See Applied Mathematics Section.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. See Mathematics Section.

Ma 121 abc. Combinatorial Analysis. See Mathematics Section.

Ma 125 abc. Analysis of Algorithms. See Mathematics Section.

Ma 205 abc. Advanced Numerical Mathematics. See Mathematics Section.

Ma 216 abc. Advanced Mathematical Logic. See Mathematics Section.

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: Wilts.

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. Instructor: Wilts.

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 own digital system. Graded pass/fail. Instructor: Mead.

EE 13 abc. Circuit Theory. *9 units (3-0-6); three terms. Prerequisites: Ma 1 abc and Ph 1 abc.* Introduction to the 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, noise, and distributed linear systems. Introductory synthesis and filter theory. The last term treats AM, FM, sampling theory, and information theory. Computer solution of problems. Instructor: Langmuir.

EE 14 abc. Electronic Circuits. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Active devices and their circuit applications. Transistor and vacuum tube amplifiers, biasing, gain, frequency response, class A, B and C power output circuits and their limitations. Nonlinear electronics, diodes, rectifiers, mixers, switching circuits, saturation, power converters, etc. Text: *Electronics: BJT's, FET's, and Microcircuits,* Angelo. Instructor: Martel.

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. Instructors: Staff.

EE 91 abc. Experimental Projects in Electronic Circuits. *Units by arrangement; 6 units minimum each term. Prerequisites: EE 14 abc and EE 90 or equivalent. Recommended: EE 114 abc or IS 110 (may be taken concurrently). Open to seniors; others only with consent of instructor.* 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. Instructors: Staff.

Advanced Courses

CS/EE 111. Digital Electronics Laboratory. *6 units (0-6-0); third term. Prerequisite: CS/EE 11 or EE 90, and CS 110 c concurrent.* A non-structured project laboratory for the hardware implementation of digital projects designed in CS 110. Instructors: Ray, Humphrey.

EE 112 abc. Network Synthesis. *9 units (2-0-7); first, second, third terms. Prerequisite: AM 95 abc.* Passive network analysis and synthesis, feedback amplifiers, closed loop transfer functions, active filters. Sample data systems, digital/linear delay functions, digital filters, and digital signal processing. Instructors: Staff.

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 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: Langmuir.

EE 155 abc. Electromagnetic Fields. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 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. Text: Course notes. Instructor: Papas.

EE 160 abc. Topics in Communications. *6 units (2-0-4); first, second, third terms. Prerequisite: Ma 2 abc.* Topics relevant to all forms of terrestrial, satellite and space communication, including data, voice, and video. Instructor: Pierce.

AMa/EE 161 abc. Mathematical Theory of Information, Communication, and Coding. *9 units (3-0-6); three terms. Prerequisites: some knowledge of probability and linear algebra.* Shannon's coding theorem and its converse for a variety of channel models: binary symmetric, finite memoryless, discrete-time Gaussian, wideband Gaussian. Minimum redundancy source coding. Error-control systems, e.g., BCH codes (with underlying theory of finite fields) and Viterbi decoding of convolutional codes. Practical applications. Not offered in 1976-77. Instructors: Staff.

EE 163 abc. Introduction to Communication Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc.* The optimum operation of the components of a communication system. Probability theory. Random and noise waveforms, correlation functions, power spectra. Optimum receiver principles. Channel capacity. Instructors: Staff.

Ae/ChE/EE 172 abc. Optimal Control Theory. *9 units (3-0-6); first, second, third terms.* Classical and modern control theory. Optimization problems for dynamical systems with terminal and path constraints. Optimal control in the pressure of noise, recursive filtering, smoothing and interpolation for linear system with additive Gaussian noise. Instructors: Staff.

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); third term. Prerequisite: EE 151 abc or Ph 106 abc, may be taken concurrently.* Selected laboratory experiments and related theory on microwave generation and amplification; measurements of impedance, frequency and power; properties of microwave cavities, waveguides, junctions, and irises. Open to undergraduates. Instructor: Gould.

EE 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 opto-electronics. 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. Instructor: Papas.

CS/EE 281 abc. Integrated Circuit Design. *9 units (3-0-6); first, second, third terms. Prerequisite: Proficiency in semiconductor device physics, circuit design, and logic design.* An advanced graduate course in the physics, design, production, and use of large-scale integrated circuits. Emphasis on system realization in LSI. Instructor: Mead.

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 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 131 abc. Thermodynamics and Statistical Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or equivalent.* Thermodynamics; kinetic theory; classical statistical mechanics; quantum statistical mechanics; diffusion theory and transport theory. Not offered in 1976-77. Instructors: Plesset, Wu.

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, Wayland, Wu.

ES 250 abc. Research in Engineering Science. By arrangement with members of the staff, properly qualified graduate students are directed in research in Engineering Science. Hours and units by arrangement.

ENVIRONMENTAL ENGINEERING SCIENCE

Undergraduate Courses

Env 1. Engineering Problems of Man's Environment. *9 units (3-0-6); third term. Prerequisites: Ph 1 ab, Ch 1 ab, and Ma 1 ab.* This course explores ways in which man is adversely changing his environment, ways in which these alterations are affecting him and other forms of life, and methods of engineering control. Typical problem areas are: air pollution, water pollution, solid and industrial wastes, harmful substances, impact of energy utilization, and land erosion. Instructors: Morgan, et al.

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 non-renewable 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. Instructors: Lees, 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 ab. Introduction to Processes of the Oceans and Atmosphere. *9 units (3-0-6); first and second terms. Prerequisites: Ma 2 and Ph 2.* Emphasis will be on developing an order of magnitude understanding of the oceans and atmosphere through analysis of observations and physical reasoning. The first term will include such topics as: chemical composition of the oceans, tides, waves and currents, precipitation. The second term will include the global balance of energy, momentum and mass, vertical atmospheric structure, radiative and convective heat exchange, circulation systems, weather prediction, climatic change. Instructor: Ingersoll.

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, ground-water recharge, and seawater intrusion in aquifers. Instructor: Brooks.

Env 116. Experimental Methods in Air Pollution. *9 units (1-4-4); third term. Open to graduate students and seniors with instructor's permission.* 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: Friedlander, 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; computer simulation of natural water systems. Instructor: Morgan.

Env 143. Water Chemistry Laboratory. *9 units (1-4-4); third term. Prerequisite: Env 142 ab or equivalent.* Laboratory experiments and measurements dealing with the major and minor constituents of natural waters. Topics include heterogeneous equilibrium systems, rates of precipitation, and redox processes, adsorption, ion exchange, and particle coagulation. Measurement techniques include electrometric methods, visible and UV spectrophotometry, chromatography, light scattering, and atomic absorption spectrophotometry. Instructor: Morgan.

Env 144. Ecology. *6 units (2-1-3); second term.* Basic principles of ecology and ways in which human activities can influence natural populations. (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 abc. Analysis and Design of Water and Wastewater Systems. *9 units (3-0-6); each term. Prerequisites: ME 17 abc, ME 19 abc, or equivalents.* 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; water rights; and economic aspects of projects. Instructor: McKee.

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.

Env 155. Special Problems in Waste Management. *9 units (2-3-4); first term. Prerequisite: instructor's permission.* Environmental pollution related to nuclear energy; solid wastes from municipalities, industries, and agriculture; transportation and storage of hazardous materials, and detailed case studies of specific problems. Field trips to illustrative examples in southern California. Instructor: McKee.

Env 156. Industrial Wastes. *9 units (3-0-6); third term. Prerequisite: Env 146 ab.* The production and characteristics of liquid industrial wastes; their effects upon municipal sewage treatment plants, receiving streams, and ground waters; the theory and methods of treating, eliminating, or reducing the wastes. Offered only in even-numbered years. Instructor: McKee.

ChE/Env 157 ab. Fundamentals of Air Pollution Engineering. *9 units (3-0-6); first, second terms. Open to graduate students and seniors with instructor's permission.* Basic concepts necessary to understand the sources, control, and atmospheric behavior of air pollutants. Air quality and emission standards; sources, quantities, and nature of emissions; combustion, chemistry of pollutant formation and control; control technology: absorbers, filters, electrical precipitators; aerosol physics, atmospheric chemistry; urban basin modeling and control; air monitoring systems. Instructors: Friedlander, Seinfeld, Flagan.

Env 160. Biological Fluid Flows: Hemorheology. *6 units (2-0-4). Prerequisites: AMa 95 abc, Hy 101 abc or equivalent.* The problems of measurement of bulk rheological properties of blood; the influence of the composition of the suspending medium on blood flow properties; the influence of the particulate nature of blood on its flow in narrow tubes and small blood vessels; the influence of cell deformation on flow through capillaries. See Env 206. Instructor: Wayland.

Env 170 ab. Principles of Particulate Pollution. *9 units (3-0-6); second, third terms. Prerequisites: ME 19 ab or Ch 21 abc, or equivalent.* Fundamentals of small particle behavior with applications to gas cleaning, air pollution and cloud physics. The first term is concerned with the characterization of particulate systems and their transport and optical properties. The second term deals with the dynamics of the particle size distribution function and gas-to-particle conversion processes. Instructor: Friedlander.

Env 200. Advanced Topics in Environmental Engineering Science. *Units by arrangement, any term.* Courses to explore new approaches to environmental problems. The topics covered vary from year to year, depending on the interests of the students and staff. Visiting professors may present portions of the course from time to time.

Env 206. 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: Friedlander, Leal, Wayland, 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 1976-77 and alternate years. Instructor: List.

Env 250. Advanced Environmental Seminar. *4 units (2-0-2); every term. Prerequisite: instructor's permission.* A seminar course for advanced graduate students and staff to discuss current research and technical literature on environmental problems. As the subject matter changes from term to term, it may be taken any number of times. Instructors: Staff.

Env 300. Thesis Research.

Other closely related courses (listed elsewhere) are: ChE 103, Ae/ChE/EE 172, ChE 173, ChE 203, 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 (see page 205). Graduate students majoring in environmental engineering science should consult Professor Morgan, executive officer, for more information.

HYDRAULICS

Advanced Courses

Hy 100. Hydraulics Problems. *Units to be based upon work done, any term.* Special problems or courses arranged to meet the needs of first-year graduate students or qualified undergraduate students. Graded pass/fail.

Hy 101 abc. Fluid Mechanics. *9 units; first, second, third terms. Prerequisites: ME 19 abc and Hy 111 or equivalent.* General equations of fluid motion: two- and three-dimensional steady and non-steady potential motion; cavity and wake flow; surface waves, linear and nonlinear shallow-water waves, 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 103 ab. Advanced Hydraulics and Hydraulic Structures. *9 units (3-0-6); first, second terms. Prerequisites: ME 19 abc and Hy 111 or equivalent.* Steady and unsteady flow in open channels; high-velocity flow in open channels; theory and design of some hydraulic structures such as chutes, energy dissipators, manifolds and canals; unsteady flow in closed systems, e.g., surge and waterhammer. Not offered every year. Instructor: Raichlen.

Hy 105. Analysis and Design of Hydraulic Projects. *6 or more units as arranged; any term.* The detailed analysis or design of a complex hydraulic structure or water resources project emphasizing interrelationships of various components, with applications of fluid mechanics and/or hydrology. Students generally work on a single problem for the entire term, with frequent consultations with the instructor. Instructors: Staff.

Hy 111. Fluid Mechanics Laboratory. *6-9 units as arranged with instructor; second or third term. Prerequisite: ME 19 ab.* A laboratory course illustrating the basic mechanics of incompressible fluid flow, and complementing the lecture course ME 19 abc. Students will usually select approximately three regular experiments, but with the permission of the instructor they may propose special investigations of brief research projects of their own in place of some of the regular experiments. Objectives also include giving students experience in making engineering reports. Although the course is primarily for seniors, it is also open to first-year graduate students who have not had an equivalent course. Instructor: Raichlen.

Hy 113 ab. Coastal Engineering. *9 units (3-0-6); first, second terms. Prerequisites: ME 19 abc and Hy 111 or equivalent; AMa 95 abc.* Engineering applications of the theory of small and finite amplitude water waves; diffraction, reflection, refraction; wind-generated waves and wave prediction procedures; tides and their interaction with the coastline; effect of waves on coastal structures such as breakwaters and pile-supported structures; coastal processes. 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 which are not already available in courses offered by the Division of Engineering and Applied Science. The subject matter will be variable depending upon the needs and interests of the students. It may be taken any number of times with permission of the instructor. Instructor: 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.

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: 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. 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, 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. Nozzle for rockets and air-breathing engines; nozzle flow with chemical reactions, characteristic theory, integral methods, two-phase flow. Instructor: Marble.

JP 250 abc. Turbomachines. *6 units (2-0-4); first, second, third terms.* A study of aerodynamic turbomachines including fans, compressors, turbines, propellers, windmills. Radial and axial cascade theory, axisymmetric flow and linearized perturbations of strong vorticity fields, transonic and supersonic blading; effect of distorted inlet flow and propagating stall; secondary flows and blade tip clearance flows. Not offered every year. Instructors: Rannie, Acosta.

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.

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). Instructors: Buffington (MS 5 b), Wood (MS 5 a, c).

MS 10. Engineering Physical Metallurgy. *9 units (3-0-6); first term.* The principles of physical metallurgy basic to the selection, treatment, and use of engineering metals and alloys. Text: *Physical Metallurgy for Engineers,* Clark and Varney. (Replaced by MS 15 abc; will not be offered after 1976-77.) Instructor: Buffington.

MS 15 abc. Principles of Materials. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 abc.* 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); first 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 110. Special Topics in Physical Metallurgy. *9 units (3-0-6); third term. Prerequisites: MS 10, MS 120, MS 121, MS 122.* The emphasis is on recent developments, so topics will vary from year to year. Both metals and nonmetals are considered. Areas of interest include: the influence of special environments, such as nuclear reactors and high temperatures; the development of specific physical properties, such as magnetic and electrical properties; the study of special systems and procedures, such as transformations in titanium-base alloys, ultra-high-strength steels, and fiber reinforcement of metals. (Replaced by MS 15 abc; will not be offered after 1976-77.) Instructor: Buffington.

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.

MS 122. Phase Transformations in Solids. *9 units (3-0-6); third term. Prerequisite: MS 121.* Discussion of nucleation and growth and phase transformation in one- and two-component systems; taught at the level of Christian, *The Theory of Transformations in Metals and Alloys.* Instructors: Buffington, Lau.

MS 125. Crystal Structure and Properties of Metals and Alloys. *9 units (3-0-6); first term.* Structure of crystals, symmetry operations, symmetry classes and space groups; reciprocal lattice and its use in interpreting the X-ray diffraction patterns obtained by the Laue, the rotating crystal, and the powder methods of crystal structure analysis; structure of the elements in relation to their electronic configuration; various types of alloys and phase diagrams; factors governing the formation of solid solutions and intermediate phases (Hume-Rothery rules); nature of amorphous alloys and their unusual properties. Text: Barrett and Massalski, *Structure of Metals.* Instructor: Duwez.

MS 130. Metallography and Pyrometry. *9 units (0-6-3); first term. Prerequisite: MS 10 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 which 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 125.* Experiments on X-ray emission spectra and absorption edges. Determination of crystal structures by the Von Laue and Debye-Scherrer methods. Use of the X-ray spectrometer. Study of preferred orientation in cold worked metals. Application of X-ray diffraction methods to the study of phase diagrams. Instructor: Duwez.

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. Prerequisites: MS 120, MS 125.* The theory of crystal dislocations in isotropic and anisotropic crystals. Applications of dislocation theory to physical and mechanical properties of crystals taught at the level of Hirth and Lothe, *Theory of Dislocations.* Instructors: Vreeland, Wood.

MS 250 abc. Advanced Topics in Materials Science. *6 units (2-0-4); first, second, third terms.* The content of this course will vary from year to year. Topics of current interest will be chosen according to the interests of students and staff. Visiting professors may present portions of this course from time to time. Instructors: Staff.

MS 300. Thesis Research.

MECHANICAL ENGINEERING

Undergraduate Courses

ME 1 ab. Introduction to Design. *9 units (1-6-2); second, third terms. Prerequisites: Gr 1, ME 3, 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 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. Emphasis will be placed on broadening the student's individual background experience 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 methods in physics and engineering. The material will include such topics as the classical laws of thermodynamics, Maxwell's relations, basic chemical thermodynamics and chemical equilibrium, approach to molecular thermodynamics through similarity considerations, kinetic theory and statistical mechanics, analysis of heat engine cycles and power conversion systems. Instructor: Liepmann.

ME 19 ab. Fluid Mechanics and Gasdynamics. *9 units (3-0-6); first, second terms. Prerequisites: Ma 2 abc, Ph 1 abc.* Basic equations of fluid mechanics, theorems of energy, linear and angular momentum, potential flow, elements of airfoil theory. Flow of real fluids, similarity parameters, flow in closed ducts. Boundary layer theory in laminar and turbulent flow. Introduction to compressible flow. Flow and wave phenomena in open channels. Instructors: Acosta, Sabersky.

ME 19 c. Heat and Energy Transfer. *9 units (3-0-6); third term. Prerequisites: ME 19 ab desirable or with instructor's permission.* An introductory course treating selected topics in energy production, fluid machinery, heat transfer and energy technology. Subjects to be discussed may include energy conservation laws; introduction to flow machines; basic differential equations of energy and mass transfer; conduction of heat in solids, convection in moving fluids with application to heat exchange in thermal systems; discussion of mechanical, chemical, nuclear and solar sources of energy as time permits. Instructors: Sabersky, Acosta.

Advanced Courses

ME 100. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses or problems to meet the needs of students working toward the M.S. degree or of qualified undergraduate students. Graded pass/fail for research and reading.

ME 101 abc. Advanced Design. *9 units (1-6-2); first, second, 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, electrohydraulic 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: 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 118 abc. Advanced Thermodynamics and Energy Transfer. *9 units (3-0-6); first, second, third terms. Prerequisites: 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: 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, including some from ChE 126. Specific areas from which experiments may be selected include free and forced convection, boiling heat transfer, combustion, solid-state energy conversion, free surface flows, 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 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.

See Engineering and Applied Science for:

ENGINEERING (GENERAL)

ENGINEERING GRAPHICS

ENGINEERING SCIENCE

ENVIRONMENTAL ENGINEERING SCIENCE

FRENCH

(See Languages)

GEOLOGICAL AND PLANETARY SCIENCES

GEOLOGY, GEOBIOLOGY, GEOCHEMISTRY, GEOPHYSICS, PLANETARY SCIENCE

Undergraduate Courses

Ge 1. Introductory Geology. *9 units (3-3-3); first, third terms.* This course aims to present a broad and up-to-date view of the earth by focusing upon major geological items currently of high interest, such as paleomagnetism, mid-oceanic rises, sea-floor spreading, plate tectonics, continental drift, evolution of continental plates, the earth's interior, and environmental geology. 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: Shoemaker in charge, and staff.

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: Helmberger.

Ge 4. Introduction to the Solar System. *6 units (3-0-3); third term.* An introductory survey course emphasizing our current knowledge of the constituent bodies in our solar system. The Sun and the meteorites are briefly discussed as sources of the average solar system chemical composition. 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 and our improved understanding of the Moon. 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.* 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: Albee.

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. Instructors: Melosh and staff.

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: Shoemaker.

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: Ahrens.

Ge 102. Oral Presentation. *2 units (1-0-1); first term.* Training in the technique of oral presentation. Practice in the effective organization and delivery of reports before groups. Successful completion of this course is required of all candidates for degrees in the division. Instructors: To be announced.

Env/Ge 103 ab. Introduction to Processes of the Oceans and Atmosphere. *9 units (3-0-6); first and second terms. Prerequisites: Ma 2 and Ph 2.* Emphasis will be on developing an order of magnitude understanding of the oceans and atmosphere through analysis of observations and physical reasoning. The first term will include such topics as: chemical composition of the oceans, tides, waves and currents, precipitation. The second term will include the global balance of energy, momentum and mass, vertical atmospheric structure, radiative and convective heat exchange, circulation systems, weather prediction, climatic change. Instructor: Ingersoll.

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: Albee.

104 c. Tectonics and Earth History. *Third term.* Major structural features and tectonic processes of the earth's crust. Principles of paleontology and animal stratigraphy. Elements of the Phanerozoic history of the earth with emphasis on both faunal and physical history. Problems of the Precambrian history of the earth. Instructors: Silver, Lowenstam.

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. Instructors: Allen, Taylor.

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 21a.* The mineralogical and chemical composition, origin, occurrence, and classification of igneous rocks considered mainly in the light of chemical equilibrium and of experimental studies. Detailed consideration of the structures, phase relations, and identification of the major igneous minerals. Instructor: Albee.

115 b. Sedimentary Petrology and Petrography. *12 units (3-6-3); third term. Prerequisite: Ge 115 a.* The mineralogic and chemical composition, occurrence, and classification of sedimentary rocks; consideration of the chemical, physical, and biological processes involved in the origin, transport, and deposition of sediments and their subsequent diagenesis. Not offered in 1976-77.

115 c. Metamorphic Petrology and Petrography. *12 units (3-6-3); third term. Prerequisite: Ge 115 a.* The mineralogic and chemical composition, occurrence, and classification of metamorphic rocks; interpretation of mineral assemblages in light of chemical equilibrium and experimental studies. Detailed consideration of structure, phase relations, composition, and determination of the major metamorphic minerals. Instructor: Taylor.

Ge 121 abc. Advanced Field Geology. *12 units (0-9-3). Prerequisites: Ge 104 abc, Ge 105 ab, Ge 107.* Interpretation of geologic features in the field, with emphasis on problems of the type encountered in professional geologic work. The student investigates limited but complex field problems in igneous, sedimentary, and metamorphic terranes and prepares reports interpreting the results of his investigations. Instructors: Sharp, Albee, Shoemaker.

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. Instructors: Westphal in charge, and staff.

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 geologic report. The course is designed to complement the field training in southern California afforded by Ge 105 and Ge 121. It is required at the end of the junior year for the bachelor's degree in the geology and geochemistry options. The course begins immediately after commencement and runs for six weeks. Instructors: Allen in charge, and staff.

Ge 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 (1976-77). 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 125. Engineering Geology. *6 units (2-4-0); first term.* An introduction to the application of geology to engineering problems. Case history illustrations. Field trips to construction sites and examples of geologic hazards. Offered in alternate years (1977-78).

Ge 126. Geomorphology. *9 units (3-0-6); second term.* Primarily a consideration of dynamic processes acting on the surface of the earth, and the genesis of landforms. Instructor: Sharp. Not offered in 1976-77.

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 planetary bodies in the solar system and the processes and time scales required for evolution into their present states. Topics include: survey of mechanisms of nucleosynthesis; solar system elemental abundances; formation times of planetary bodies; the chemical composition and evolution of the earth and moon; speculations on the compositions of other planets; composition and origin of planetary atmospheres. Instructor: Burnett. Offered in alternate years (1976-77).

Ge 135. Regional Geology of Southern California (Seminar). *6 units (3-0-3); second term. Prerequisites: Ge 104 abc, Ge 105 abc or equivalent.* Reading and discussion of selected topics in the geology of southern California and adjacent areas, with emphasis on outlining the important regional research problems. Instructor: Silver.

Ge 136. Regional Field Geology of Southwestern United States. *9 units (1-0-8); second or third term. Prerequisites: Ge 104 and 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. Instructor: Sharp.

Ge 137 ab. Laboratory Techniques in the Geological Sciences. *9 units (1-4-4); second and third terms. Prerequisite: instructor's permission.* A series of laboratory experiments covering X-ray, mass spectrometric, and counting techniques. The emphasis is placed on understanding the physical and chemical principles on which the measurements are based. Instructors: Patterson, Burnett, Epstein. Offered in alternate years (1976-77).

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: The 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 which can be tested by all possible observational techniques including radio interferometry, planetary occultation, and radar astronomy. Offered alternate years (1977-78). 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 (1976-77). Instructors: Goldreich and Ingersoll.

Ge 160. Introduction to Modern Geophysics. *4 units (2-0-2); first term.* Seminar on current topics in geophysics with emphasis on active research programs within the department. The course is designed to acquaint new graduate students with outstanding problems in geophysics and with current methods of investigation. Instructors: Anderson and staff.

Ge 166. Physics of the Earth's Interior. *9 units (3-0-6); second term. Prerequisite: AMa 95 abc or AM 113 abc, or instructor's permission.* Interpretation of the fundamental data of seismology, gravity and heat flow using available high-pressure laboratory data and equations of state with the aim of understanding the structure, composition and phase of the earth's deep interior. Thermal history of the earth. Internal constitution of the terrestrial planets. 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. Instructor: Goldreich. Offered in alternate years (1977-78).

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. 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. Instructor: Allen. Offered in alternate years (1977-78).

Ge 212 ab. Thermodynamics of Geological Systems. *9 units each term (3-0-6); first, second terms.*

212 a. *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 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 (1976-77). Instructor: Taylor.

212 b. *Prerequisite: 212 a.* Lectures and problems on the chemical and physical properties of aqueous solutions, with emphasis on those electrolyte solutions important in nature. Topics to be covered include the effects of solution composition on mineral equilibria, Eh-pH diagrams, extension of thermodynamic data to high temperatures and pressures, non-ideality in mixed-gas systems, and reaction kinetics in systems involving water. Text: *Solutions, Minerals, and Equilibria,* Garrels and Christ. Offered in alternate years (1976-77). Instructor: Epstein.

Ge 213. Seminar on special topics and problems of current interest in the fields listed below. *5 units. Prerequisites dependent upon topics.* Offered by announcement only.

Ge 213 a—Mineralogy Seminar.
Ge 213 b—Petrology Seminar.
Ge 213 c—Geochemistry Seminar.
Ge 213 d—Geochronology Seminar.
Ge 213 e—Planetary Science Seminar.

Ge 214. Advanced Mineralogy. *9 units (3-3-3); third term. Prerequisite: Ge 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 (1976-77). 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.*

215 a. Chemical Petrology. *First term.* Lectures, seminars, and laboratory studies of the chemical reactions that occur in rocks. Emphasis will be placed on rock-water interactions, mineral deposition, hydrothermal alteration, and the formation of ore deposits. Offered in alternate years (1977-78). 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 (1977-78). 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 (1977-78). 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 (1976-77). Instructor: Wasserburg.

Ge 221 ab. The Terrestrial Planets. *9 units (4-0-5); second, third terms.* A comparative study of the present state and past history of Earth, Moon, Mars, Venus, and Mercury. Offered alternate years (1976-77). Instructor: To be named.

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: Muhleman.

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: Westphal.

Ge 226. Observational Planetary Astronomy. *9 units (3-0-6); first 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 (1976-77). Instructor: Westphal.

Ge 229. Glaciology. *9 units (3-0-6); second term.* Origin and behavior of the North American ice sheet, physical conditions and structures of existing glaciers, glacier flow, erosional and depositional processes and products. Offered by announcement only. 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: Sharp.

Ge 244 ab. Paleoecology (Seminar). *5 units; second, third terms.* Critical review of classic investigations and current research in paleoecology and biogeochemistry. Instructor: Lowenstam.

Ge 247. Tectonics. *9 units (3-0-6); third term. Prerequisites: Ge 104 abc, Ge 105 abc.* Structure and geophysical features of continents, ocean basins, geosynclines, mountain ranges, and island arcs. Structural histories of selected mountain systems in relation to theories of orogenesis. Offered in alternate years (1976-77). Instructor: Allen.

Ge 248. Tectonophysics. *9 units (3-0-6); third term. Prerequisites: Ge 104 abc, AMa 95 abc or equivalent.* Analysis of stress, deformation, and failure in tectonic processes with emphasis on the varied properties and behavior of geologic materials. Offered in alternate years (1977-78). Instructor: Kamb.

Ge 260. Solid-State Geophysics. *9 units (3-2-4); third term. Prerequisite: familiarity with basic concepts of thermodynamics and mineralogy. See instructor.* This course deals with the application of high-pressure physics to geologic problems. Topics to be covered include: concepts of elastic and shock propagation in single and polycrystalline solids and in fluids, and their relation to various thermodynamic processes; phase changes, dynamic yielding, shock metamorphism, and high-pressure electrical properties of minerals and application of shock and ultrasonic equation-of-state data to earth and planetary interiors. Offered in alternate years (1977-78). Instructor: Ahrens.

Ge 261 abc. Advanced Seismology. *9 units (3-0-6). 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. Offered in alternate years (1976-77). Instructors: Harkrider, Helmberger.

Ge 264 abc. Theoretical Geophysics. *9 units (3-0-6). Prerequisite: 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. Instructor: Minster.

Ge 265 ab. Advanced General Geophysics. *9 units (3-0-6); first, second terms. Prerequisite: Ph 129 abc.* A discussion of problems of current geophysical importance selected from among the general categories of: planetary magnetic and gravity fields, thermal history and evolution, mass transport processes in the earth and tectonics, high temperature-pressure geophysics, anelastic processes, wave propagation theory and solid state geophysics. Offered in alternate years (1976-77). Instructors: Anderson in charge, and staff.

Ge 282 abc. Geological Sciences Seminar. *1 unit; first, second, third terms.* Presentation of papers by invited investigators. In charge: Burnett.

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

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).* 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 6 abc. American Life and Thought. *9 units (3-0-6).* Topics in the development of American culture, explored through an examination of selected social, political, and artistic materials, including essays, novels, and films. Instructors: Staff.

H 8 ab. Introduction to Asia. *9 units (3-0-6); second, third terms.* Topics in the history of Asia from Exodus and Confucius to Indira Gandhi and the Yom Kippur War. Some emphasis on Asian religions. Instructor: Fay.

H 23. Cultural History of Early Medieval Europe. *9 units (3-0-6); first term.* From the end of the Roman Empire to the First Crusade. Shows how classical, Christian, and barbarian cultures combined to form a new civilization. Not offered in 1976-77. Instructor: Benton.

H 24. Cultural History of the High Middle Ages and Renaissance. *9 units (3-0-6); second term. H 23 precedes but is not a prerequisite for H 24.* Europe from the twelfth through the fifteenth centuries. Shows relationship of art, literature, music, and social relations to political, economic, and religious institutions. Not offered in 1976-77. Instructor: Benton.

H 25. Europe in the Seventeenth and Eighteenth Centuries. *9 units (3-0-6). Not intended for students who took European history as freshmen.* A survey of Europe in this period, with special attention to the English revolutions, Louis XIV, the Enlightenment, and the French Revolution. Not offered in 1976-77. Instructors: Staff.

H 26. Europe in the Nineteenth and Twentieth Centuries. *9 units (3-0-6). 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, fascism, and the Cold War. Instructors: Staff.

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. Instructor: Benton.

H/Psy 107. Psychohistory. *See Psychology.*

H 108. Europe and Asia. *9 units (2-0-7).* 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. 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 Becket and Henry II, the medieval ghetto, Luther, the Wars of Religion, Darwin and Huxley, and the "final solution." Not offered in 1976-77. Instructor: Fay.

H 112. Contemporary Europe. *9 units (3-0-6); first term.* This course will deal with some of the public issues, social trends, and cultural developments which are of special interest in Europe today. While the setting will be historical, particular emphasis will be placed on what has been going on in the last twenty-five years. Instructor: Elliot.

H 116. Germany. *9 units (3-0-6).* Principal historical developments in Germany from the Reformation to the present day. Emphasis on the evolution of social and political institutions and attitudes. Not offered in 1976-77. Instructor: Ellersieck.

H 117. Russia. *9 units (3-0-6).* An attempt to discover and interpret the major recurring characteristics of Russian history and society, with attention particularly to developments in the Soviet period. Instructor: Ellersieck.

H 118. Britain. *9 units (3-0-6).* Main elements in the political life of modern Britain. Attention will be concentrated primarily on events since 1832, and emphasis will be placed on economic and social trends, on political and constitutional development, and on the lives of important statesmen. Not offered in 1976-77. Instructor: Elliot.

H 120. The British Empire and Commonwealth. *9 units (3-0-6).* The growth of the imperial idea and the institutional development of the Empire and the Commonwealth with particular reference to Africa and Asia. Instructor: Huttenback.

H 121. India and Pakistan. *9 units (3-0-6).* The growth of Indian nationalism in the years before independence, and developments in India and Pakistan since partition. Special emphasis will be placed on the philosophical conflict between British and indigenous Indian attitudes and the consequent effect on contemporary India and Pakistan. Not offered in 1976-77. Instructor: Huttenback.

H 130. History of War. *9 units (3-0-6).* An examination of instructive episodes in the evolution of warfare. Emphasis upon the role of political, economic and social factors in influencing the choice of organization, armament, tactics and the timing of conflict. Instructor: Ellersieck.

H 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. 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. 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 151. The Shaping of Modern America, 1890-1917. *9 units (3-0-6).* An examination of the consolidation and expansion of economic, political, and social control by regional and national power elites. Instructor: Kousser.

H 152. 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 1976-77. 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. Instructors: Kevles, Rosenstone.

H 154. American Foreign Policy in the Twentieth Century. *9 units (3-0-6).* How American foreign policy has been formed and administered in recent times: the respective roles of the State Department, Congress, and the President, of public opinion and pressure groups, of national needs and local politics. Not offered in 1976-77. Instructor: Paul.

H 156. The History of Modern Science. *9 units (3-0-6); first term.* 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. 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. American Intellectual History. *9 units (3-0-6); first term.* A study of selected topics in the history of American thought and attitudes. Not offered in 1976-77. 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 1976-77. 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 1976-77. 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

(See Engineering and Applied Science)

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 192 for complete details.

INFORMATION AND COMPUTER SCIENCE

(See Engineering and Applied Science)

JET PROPULSION

(See Engineering and Applied Science)

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 316 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 insructor before registering. Instructor: A. Smith.

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. Not offered in 1976-77. 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: Wayne.

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 an instructor before registering. Instructors: Carmely, Wayne.

L 139. Independent Reading in French, German, or Russian Literature. For graduate students who have completed at least one year of literature in the foreign language. 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 1976-77. Instructor: Wayne.

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. Not offered in 1976-77. 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); first 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 abc. 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 sociohistorical context from the Classical period to contemporary Soviet texts. Authors will range from Pushkin to Solzhenitsyn. All readings in English. Instructors: Staff.

L 166 abc. Russian Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 153 or equivalent.* 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. Not offered in 1976-77. Instructors: Staff.

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 1976-77. Instructor: B. Thompson.

Lin/SS 105. Computational Linguistics. *9 units (2-1-6); first term. Prerequisite: Lin 101a or Lin 101b 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; first offered in 1976-77. Instructors: B. Thompson, F. Thompson.

LITERATURE

Courses above Lit 10 are open only to students who have fulfilled the freshman humanities requirements. See page 170 for further information.

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 3.*

Lit 2. Comedy. *9 units (3-0-6); first term.* Readings in the theory and practice of comedy (and satire), in an effort to understand the nature of the genre, the sources from which it springs, and the different forms it may take. Instructors: Staff.

Lit 3. Tragedy. *9 units (3-0-6); second term.* Readings in the theory and practice of tragedy, as above (in Lit 2). Instructors: Staff.

Lit 4. The "I" in Literature. *9 units (3-0-6); third term.* Beginning with a study of lyric poetry, both traditional and contemporary, the course will focus upon the ways in which first-person literature has become a dominant form in the modern era. Instructors: S. Ende and staff.

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); second term.* 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 the ways in which they have influenced the literature of Western civilization—particularly the literature of Britain and America. Instructor: Ende.

Lit 8. The Literature of Quest. *9 units (3-0-6).* A study of works that center on the quest motif, together with a consideration of the artistic and historical importance of the idea of quests. Instructors: Staff.

Lit 9. The American Traditions in Prose Fiction. *9 units (3-0-6); third term.* This survey of the paths followed by American novelists will emphasize the continuity and the polarities of American culture. It will include such authors as Poe, Hawthorne, Melville, Twain, James, Hemingway, and Faulkner. Instructor: Penn.

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. Instructors: J. Penn, 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. *Not available for credit toward humanities-social science requirement.*

Lit 98. Tutorial for Literature Majors. *9 units (2-0-7). Prerequitite: 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 316 for description.

Courses Primarily for Upperclassmen

Lit 100 (formerly Lit 8). The Bible as Literature. *9 units (3-0-6); first term.* A study of ancient Hebrew history, legend, epic, short fiction, poetry, and wisdom literature in the Old Testament. A study of selections from the gospels, Acts, and epistles in the New Testament. Major emphasis will be placed upon Old Testament materials. Instructors: Langston, Penn.

Lit 102 ab (formerly Lit 9, Lit 119, and Lit 120). 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. Instructors: Langston, Jackson.

Lit 106 ab (formerly Lit 121). English and Continental Medieval Literature. *9 units (3-0-6); first, second terms.* A study of major medieval literary works and their relationship to the great philosophical and social currents of the time. The first term will concentrate upon English texts, with Chaucer as the central figure; the second term will deal with Continental texts, in translation, with Dante as the central figure. The first term is not a prerequisite to the second. Instructors: Staff.

Lit 112 ab (formerly Lit 125). English Renaissance Literature. *9 units (3-0-6); first, second terms.* A study of the English Renaissance as a movement stretching from the Reformation of the early sixteenth century to Milton's death in 1674. First quarter: More, Castiglione, Machiavelli, Sidney, Spenser, Shakespeare (sonnets), Marlowe. Second quarter: Shakespeare (drama), Jonson, Webster, Donne, Marvell, Bacon, Hobbes, Milton. Instructor: Jackson.

Lit 114 ab (formerly Lit 123). Shakespeare. *9 units (3-0-6); first, second terms.* A chronological study of Shakespeare's plays with emphasis on the development of his technique and vision. First quarter: the major histories, festive comedies, and the early tragedies. Second quarter: several of the great tragedies, the problem comedies, and the late romances. The first term is not a prerequisite for the second. Instructor: Jackson.

Lit 115. Advanced Shakespeare Seminar. *9 units (3-0-6); third term. Prerequisite: Lit 114a or b.* A close reading of several plays in the light of Shakespeare's education, his creativity with source material, Elizabethan dramatic practices, and the major issues of the Renaissance. Instructor: Jackson.

Lit 116 (formerly Lit 10). Milton. *9 units (3-0-6); third term.* 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. Instructor: Jackson.

Lit 120 (formerly Lit 126). Satire and Common Sense in Restoration and Eighteenth-Century Literature. *9 units (3-0-6); third term.* 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 (formerly Lit 127). The English Novel. *9 units (3-0-6); first, second, third terms.* 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. Instructors: Clark and Staff.

Lit 125 ab (formerly Lit 129). Romanticism. *9 units (3-0-6); first, second terms. 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. Instructor: Ende.

Lit 126. Victorian Poetry and Prose. *9 units (3-0-6); third term.* 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. Instructor: Rubin.

Lit 130 abc (formerly Lit 100). The Nineteenth- and Twentieth-Century Novel. *9 units (3-0-6); first, second, third terms.* 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. Instructors: Penn, D. Smith, Splitter.

Lit 132 (formerly Lit 105 and Lit 106). American Naissance-Renaissance. *9 units (3-0-6); first term.* 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. Instructors: Langston, Penn, D. Smith.

Lit 134. Hawthorne and Melville. *9 units (3-0-6); first term.* An in-depth critical reading of America's first two great novelists. Instructor: D. Smith.

Lit 136. Nineteenth-Century American Poetry. *9 units (3-0-6); third term.* 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. Instructor: Langston.

Lit 138 (formerly Lit 107). The Gilded Age. *9 units (3-0-6); second term.* 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. Instructors: Langston, Penn, D. Smith.

Lit 140. Twain and James. *9 units (3-0-6); second term.* An in-depth critical reading of the two writers who dominated post-Civil War American literature. Instructor: D. Smith.

Lit 142 abc (formerly Lit 108). 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. Instructors: Langston, Penn, D. Smith.

Lit 146 ab (formerly Lit 118). Twentieth-Century American and British Poetry. *9 units (3-0-6); first, second terms.* 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. Instructors: Clark, Rubin.

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. Not offered in 1976-77. Instructor: A. Smith.

L/Lit 154. French Literature in Translation: The French Novel. *9 units (3-0-6); first 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. Instructors: Staff.

Lit 170 abc (formerly Lit 110). From Mysteries to Absurdism: A Survey of Drama. *9 units (3-0-6); first, second, third terms.* 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. Instructor: Mandel.

Lit 180 (formerly Lit 101). Special Topics in Literature. *9 units (3-0-6).* See Registrar's announcement for details. Instructors: Staff.

Lit 184 (formerly Lit 151). 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. *Not available for credit toward humanities-social science requirement.*

MATERIALS SCIENCE

(See Engineering and Applied Science)

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. Instructor: Dilworth.

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: Foote, Holladay.

Ma 31. Introduction to the Constructive Theory of Functions. *9 units (3-0-6). Prerequisite: Ma 1 abc.* Polynomial approximation. The Weierstrass theorem and the Bernstein polynomials. Extremal properties of the Chebyshev polynomials. Markov's theorems. Classical orthogonal polynomials. Applications to interpolation and approximation integration. Not offered in 1976-77.

Ma 91 a. Numerical Analysis of Algebra and Number Theory. *9 units (3-0-6); first term. Prerequisite: Ma 5 abc or equivalent.* Instructor: Hall.

Ma 91 b. Functional Equations. *9 units (3-0-6); second term.* Instructor: J. Todd.

Ma 91 c. Numerical Analysis. *9 units; third term.* Instructors: Staff.

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 ab. Differential Geometry. *9 units (3-0-6).* Not offered in 1976-77.

Ma 103. Algebraic Geometry. *9 units (3-0-6); third term. Prerequisite: Ma 5 abc.* Not offered in 1976-77.

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 1976-77.

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. Instructor: Dashiell.

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. Applications to ordinary and partial differential equations. Instructor: Luxemburg.

Ma 112 abc. Statistics. *9 units (3-0-6); first, second, third terms.* First term: a complete short course in probability and typical statistical methods. Rest of year: nonparametrics, estimation, sequential analysis, decision theory, and Bayes procedures. Instructor: 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: Schlipf.

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: De Prima.

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: Dean.

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: Seitz, Saxl.

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 1976-77.

Ma 128 a. Lie Algebras. *9 units (3-0-6); first term.* Topics will include solvable and nilpotent Lie Algebras and the classification theorem for simple Lie Algebras in terms of the Dynkin Diagram. Instructor: Wales.

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: Zibman.

Ma 141 abc. Ordinary Differential Equations. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 or equivalent.* Not offered in 1976-77.

Ma 142 abc. Introduction to Partial Differential Equations. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 143 or equivalent.* Topics from classical second order differential equations: Maximum principles, Green's functions, Schauder estimates. Sobolev spaces. Higher order linear problems: weak solutions, regularity, spectral theory. Some non-linear problems, variational techniques. Not offered in 1976-77.

Ma 143 ab. Introduction to Functional Analysis. *9 units (3-0-6); second, third terms. Prerequisite: Ma 137a.* 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: Zibman.

Ma 144 ab. Probability. *9 units (3-0-6); second, third 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. Instructor: Fuller.

Ma 151 abc. Fixed Point Theory and Its Applications to Analysis. *9 units (2-0-7); first, second, third terms.* The Schauder fixed point theorem. The contraction principle. Leray-Schauder fixed point theory for compact maps. Existence theorems for differential and integral equations. Current research on monotone and non-expansive maps and minimization problems for non-linear functions. Not offered in 1976-77.

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 1976-77.

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. Instructor: Kisilevsky.

Ma 165. Diophantine Analysis. *9 units (3-0-6); third term. Prerequisite: Ma 5.* The study of rational or integral solutions of equations. Theory of rational approximations to irrational numbers, and theory of continued fractions. The theorems of Thue-Siegel and Roth will be included. Not offered in 1976-77.

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. Instructor: J. Todd.

Ma 191 a. Sums of Squares. *First term.* Instructor: O. Todd.

Ma 191 b. Coding Theory. *Second term. Prerequisite: Ma 120 or equivalent.* Instructor: van Tilborg.

Ma 191 c. Matroids. *Third term.* Instructor: Holladay.

(B) The following courses are open primarily to graduate students.

Ma 205 a. Advanced Numerical Mathematics. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 105 or equivalent.* Discussion of areas of current interest. Each quarter will be treated as a separate unit. Where appropriate, accompanying laboratory periods will be arranged as a separate reading course. Not offered in 1976-77.

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: Kechris.

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. Instructor: Aschbacher.

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. Instructor: O. Todd.

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 1976-77.

Ma 226 ab. Ring Theory. *9 units (3-0-6) Prerequisite: Ma 120 or equivalent.* Selected topics in the structure of rings leading from classical theorems to areas of current research. Not offered in 1976-77.

Ma 238 a. Advanced Complex Variable Theory. *9 units (3-0-6); third term. Prerequisite: Ma 118 or equivalent.* Topics will be selected from: linear spaces of analytic functions, conformal mapping, algebraic functions, Riemann surfaces, functions of several complex variables, singular integral equations. Instructor: J. Todd.

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. Instructors: Staff.

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. (Jointly with UCLA.)* Instructors: Kechris, Schlipf.

Ma 320 abc. Special Topics in Algebra. *9 units. Three terms.*

Ma 324 abc. Seminar in Matrix Theory. *Units to be arranged. Three terms.*

Ma 325 abc. Seminar in Algebra. *6 units. Three terms.*

Ma 340 abc. Special Topics in Analysis. *9 units. Second and third terms.*

Ma 345 abc. Seminar in Analysis. *6 units. Three terms.*

Ma 350 abc. Special Topics in Geometry. *9 units. Three terms.*

Ma 355 abc. Seminar in Geometry. *6 units. Three terms.*

Ma 360 ab. 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

(See Engineering and Applied Science)

MUSIC

Mu 11. Fundamentals of Music. *5 units (2-0-3).* Course content: notation, music reading, chord structures, keys, elementary ear training, basic keyboard harmony. For students with little or no previous music study. Instructors: Staff.

Mu 12. Music History and Music Theory. *9 units (3-0-6). Prerequisite: Mu 11, or successful completion of the Music Fundamentals Test.* Course content, alternate years: history of music during the Renaissance and Baroque periods; analysis of forms and styles. Course content, alternate years: music theory, including diatonic chord progressions, common chord modulations, non-harmonic tones, composition in 2, 3, and 4 parts, harmonic analysis. Instructors: Staff.

Mu 13. Music History and Music Theory. *9 units (3-0-6). Prerequisite: Mu 12.* Course content, alternate years: history of music from 1750 to the present; analysis of forms and styles; music theory, including chromatic progressions and modulations, altered chords, composition in more advanced forms, introduction to counterpoint. Instructors: Staff.

Mu 101. Selected Topics in Music. *Units to be determined by arrangement with the instructor.* Instructors: Staff and visiting lecturers.

PHILOSOPHY

Undergraduate Courses

Pl 7 abc. Introduction to Philosophy. *9 units (3-0-6); first, second, third terms.* A study of the history of philosophy through readings in the sources. The three terms will concentrate, respectively, on ancient, modern, and contemporary philosophy. Instructor: Abrams.

Pl 12. Induction. *9 units (3-0-6).* Inductive logic and the foundations of probability. Investigation of the inductive basis of scientific theories. The course will be built around readings in the contemporary literature. Instructor: Thompson.

Pl 13. Reading in Philosophy. *Elective in any term or for summer reading with consent of specific instructor. Units to be determined by consultation with the instructor.* Reading in philosophy, supplementary to, but not substituted for, courses listed; supervised by members of the department. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

Pl 16. Life Cycles. *9 units (3-0-6); second term.* A study of life patterns, world cultures, and conceptions of human life. Instructors: Staff.

Pl 17 abc. Introductory Philosophy. *9 units (3-0-6).* Topic-oriented examination of selected problems in philosophy. Historical and contemporary readings. Instructors: Staff.

Pl 19. Human Nature and Ethics. *9 units (3-0-6); first term.* A study of ethical values in relation to human nature and culture. Conceptions of human nature provide bases for study of human value systems. All phases of human inquiry which bear on human nature are considered. Instructors: Staff.

Pl 20. The Psychology of Liberation: Laing, Brown, and Marcuse. *9 units (3-0-6); first 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*. Instructor: Abrams.

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. Instructor: Abrams.

HSS 99. See page 316 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); first term.* A study of world views and of the ways in which they are reflected in the literature, art, philosophy, and science of different cultures. Several contrasting views will be selected for detailed study. Instructor: Jones.

Pl 104. Educational Issues and Problems. *9 units (3-0-6); first 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 on 1976-77. 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. Instructor: Abrams.

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, Godel's Theorem and its implications. Instructor: Abrams.

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.* Instructor: Abrams.

Pl 113. Reading in Philosophy. Same as Pl 13 but for graduate credit.

PHYSICS

Undergraduate Courses

Ph 1 abc. Kinematics, Particle Mechanics, and Electric Forces. *9 units (4-0-5); first, second, third terms. Prerequisites: High school physics, algebra, and trigonometry.* The first year of a two-year course in introductory classical and modern physics. Topics to be covered include the kinematics and dynamics of particles, planetary and harmonic motion, geometrical and physical optics, kinetic theory, and thermodynamics. The course is offered in two tracks; track A emphasizes fundamentals, while track B is at a somewhat higher mathematical level and covers more topics. In both tracks, emphasis is placed upon the application of the fundamental principles through the solution of problems. Graded pass/fail. Instructors: Farrar, Gomez, Neugebauer, Werner, and assistants.

Ph 2 abc. Electromagnetism and Quantum Mechanics. *9 units (4-0-5); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or their equivalent.* The second year of a two-year course in introductory classical and modern physics. Topics to be included include electricity and magnetism, Maxwell's equations, electromagnetic waves and elementary quantum mechanics. The course is offered in two tracks, similarly to Ph 1. Track B is taught at a somewhat higher mathematical level and covers more topics. Instructors: Barnes, Cowan, Goodstein, Mathews, and assistants.

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: Mercereau, Pine, 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: Mercereau, Pine, 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: Mercereau, Pine, and assistants.

Ph 6. Physics Laboratory. *6 units; second term. Prerequisites: Ph 1 abc, Ph 2 b (or taken concurrently) and Ph 3 or equivalent.* This laboratory course involves experiments in electromagnetic phenomena such as electromagnetic induction, properties of magnetic materials and high-frequency circuits. The mobility of ions in gases is studied and a precise measurement of the value of e/m of the electron is made. Instructors: Mercereau, Pine, and assistants.

Ph 7. Physics Laboratory. *6 units; third term. Prerequisite: Ph 5 or Ph 6.* In this laboratory course, experiments are performed in atomic and nuclear physics. These include studies of the Balmer series of hydrogen and deuterium, the decay of radioactive nuclei, absorption of X-rays and gamma rays, ratios of abundances of isotopes and the Stern-Gerlach experiment. Instructors: Mercereau, Pine, and assistants.

Ph 10 ab. Special Topics in Introductory Physics. *6 units (2-0-4); second, third terms.* An elective course for first-year students, based upon material covered in Ph 1 abc. The purpose of the course is to provide interested students an opportunity to penetrate more deeply into some of the topics covered earlier in Ph 1. Emphasis will be given to the analysis of problems of broad scientific and technical interest. Topics to be covered will be selected partly on the basis of class preference. Instructor: Tombrello.

Ph 77 ab. Advanced Physics Laboratory. *6 units; first, second, or third terms.* A two-term laboratory course open to junior and senior physics majors. The purpose of the course is to familiarize the student with laboratory equipment and procedures that are used in the research laboratory. The experiments are designed to illustrate fundamental physical phenomena, such as Compton scattering, nuclear and paramagnetic resonance, the photoelectric effect, the interaction of charged particles with matter, etc. Instructor: Whaling.

Ph 78 abc. Senior Thesis Experimental. *9 units; first, second, third terms. Prerequisite: instructor's permission.* This course is intended to provide supervised experimental research experience, and is open only to senior physics majors. Requirements will be set by individual faculty members, but will include a term paper based upon actual laboratory experience. The selection of topics and the final report must be approved by the Physics Undergraduate Committee. Not offered on pass/fail basis. Instructors: Physics Staff.

Ph 79 abc. Senior Thesis Theoretical. *9 units; first, second, third terms. Prerequisite: instructor's permission.* This course is intended to provide supervised theoretical research experience and is open only to senior physics majors. Requirements will be set by individual faculty members, but will include a term paper based on the work performed. The selection of topics and the final report must be approved by the Physics Undergraduate Committee. Not offered on pass/fail basis. Instructors: Physics Staff.

Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with Professor Gomez, 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. Instructors: Garmire, Sciulli.

Ph 93 abc. Topics in Contemporary Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 92 abc or Ph 125 abc, Ph 106 abc.* A series of introductory one-term courses on topics of contemporary physics. In general, students may register for any particular term or terms. In 1976-77 the topics will be (a) astrophysics, (b) low-temperature physics, and (c) nuclear physics. Instructors: Thorne, Mercereau, Tombrello.

Advanced Courses

Ph 106 abc. Topics in Classical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc, Ma 2 abc.* An intermediate course in the application of the basic principles of classical physics to a wide variety of subjects. It is intended that roughly half of the year will be devoted to mechanics, and half to electromagnetism. Topics to be covered include the Lagrangian and Hamiltonian formulations of mechanics, small oscillations and normal modes, boundary value problems, multipole expansions and various applications of electromagnetic theory. Graduate students majoring in physics or astronomy will be given only 6 units credit for this course. Instructor: Kavanagh.

Ph 112 abc. Modern Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 106 abc, Ph 125 abc, or equivalents. Not open to students who have taken Ph 92.* A lecture and problem course on the physics of atoms, nuclei, and elementary particles. Among the topics discussed are: atomic and molecular structure, electromagnetic interactions, quantum statistical mechanics, and an introduction to the physics of nuclei, elementary particles, and condensed matter. Instructor: Boehm.

Ph 118 abc. Electronic Circuits and Their Application to Physical Research. *9 units (3-3-3); first, second, third terms.* A course on the fundamentals of analog and digital electronics with emphasis on proven techniques of instrumentation for scientific research. The first two terms will deal with the physical principles and properties of electronic components and circuits and the last will discuss the logical design of digital systems. 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 1976-77.

Ph 125 abc. Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 abc. Recommended: Ph 92 abc, and either AMa 95 abc or Ma 108 abc. Available to juniors only by permission of instructor.* A fundamental course in quantum mechanics aimed at understanding the mathematical structure of the theory and its application to physical phenomena at the atomic and nuclear levels. The subject matter will include the various formulations of quantum mechanics, properties of operators, one-dimensional and central potentials, angular momentum and spin, scattering theory, perturbation theory, identical particles, and introductory relativistic quantum theory. Instructor: Walker.

Ph 127 abc. Statistical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 92 abc, Ph 106 abc.* This course will present a thorough introduction to problems in physics which are fundamentally statistical. Topics to be covered will include; fundamental laws and concepts of thermodynamics, kinetic theory and transport phenomena, statistical mechanics and the connection between macroscopic and atomic laws. Instructor: Fox.

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 171. Reading and Independent Study. Occasionally, advanced work involving reading, special problems, or independent study is carried out under the supervision of an instructor. Units in accordance with work accomplished. Approval of the instructor and of the student's departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 172. Experimental Research in Physics. *Units in accordance with the work accomplished.* Approval of the student's research supervisor and of his department adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 173. Theoretical Research in Physics. *Units in accordance with the work accomplished.* Approval of the student's research supervisor and of his departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 203 abc. Nuclear Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 92 abc and Ph 125 abc or equivalents.* A problem and lecture course in nuclear physics concerning experimental and theoretical methods for the study of nuclear structure and reactions. Topics discussed include: systematics of nuclear properties, experimental techniques of nuclear physics, radioactive decay modes, radiative transitions, liquid-drop, shell and collective models, and simple reaction theories applied to nuclear systems. Offered in alternate years with Ph 237. Instructor: Sierk.

Ph 205 abc. Advanced Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125 abc, Ph 92 abc.* The course will cover advanced nonrelativistic quantum mechanics and relativistic quantum mechanics with an introduction to field theory. Topics covered include angular momentum, transition probabilities, scattering theory, Dirac equation, Feynman diagrams, quantum electrodynamics, and other applications of field theory. Instructor: Zachariasen.

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: Davis.

Ph 213 ab. Nuclear Astrophysics. *9 units (3-0-6); first, second terms.* A lecture or reading course in the applications of nuclear physics to astronomy, geochronology, cosmochronology and other fields. 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. Not offered in 1976-77.

Ph 221. Topics in Solid-State Physics. *9 units (3-0-6); third term. Prerequisite: APh 114 abc or equivalent.* A course on selected topics in solid-state physics, with different subjects being presented each year. Not offered in 1976-77.

Ph 224 abc. Space Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 92, Ph 106 or equivalent.* The first term will be devoted to the experimental techniques employed in measurements made in space with applications to UV, X-ray, and gamma ray astronomy. A comprehensive review of X-ray and gamma ray astronomy will complete the term. The second term will be devoted to plasma physics, with applications to planetary radiation belts and the solar wind. The third term will be devoted to a thorough review of cosmic ray research. Not offered in 1976-77.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205 abc (may be taken concurrently).* A course in advanced techniques of elementary particle theory, including field theory, renormalization, groups and symmetries, gauge theories, current algebra, dispersion theory, and other approaches of current interest. Instructor: Frautschi.

Ph 231 abc. High Energy Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125 abc or equivalent.* An introductory course covering the properties of elementary particles and their interactions, especially at high energies. Emphasis will be on discussion of problems of current experimental interest. Topics discussed include the classification of particles and their symmetries, experimental detection of particle properties, strong interactions at low and high energies, weak decays of strange and non-strange particles, problems associated with very high energy interactions. Instructor: Barish.

Ph 234 abc. Topics in Theoretical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 205 abc and Ph 231 abc, or instructor's permission.* Current topics of research in high energy physics will be presented. Independent study and research will be encouraged. The detailed content of this course may vary from quarter to quarter. Not offered in 1976-77.

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: Detweiler.

Ph 237. Theoretical Nuclear Physics. *9 units (3-0-6); first term. Prerequisite: Ph 205 or equivalent.* A lecture course on non-relativistic scattering and reaction theory. The emphasis will be on various approximation methods for inelastic scattering and rearrangement collisions, with applications in several areas of physics. Not offered in 1976-77.

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. Instructor: Gell-Mann.

Ph 241. Research Conference in Physics. *No credit; first, second, third terms.* Meets once a week for a report and discussion of the work appearing in the literature and that in progress in the laboratory. Advanced students in physics and members of the physics staff take part.

Ph 300. Research in Physics. *Units in accordance with work accomplished.* Ph 300 is elected in placed of Ph 172 when the student has progressed to the point where his research leads directly toward the thesis of the degree of Doctor of Philosophy. Approval of the student's research supervisor and of his department adviser or registration representative must be obtained before registering. Graded pass/fail.

POLITICAL SCIENCE

PS 1 abc. Introduction to Political Science. *9 units (3-0-6); first, second, third terms.* Introduction to behavioral and analytical political science. Instructors: Staff.

HSS 99. See page 316 for description.

Advanced Courses

PS 101. Selected Topics in Political Science. *Units to be determined by arrangement with the instructor.* Instructors: Staff and visiting lecturers.

PS 102. Black Africa 800 A.D. to the Present. *9 units (2-0-7).* Topics relating to the origins of Americans of African descent, including African empires such as Ghana and Songhai, the Slave Trade, and the emergence of independent nations. Instructors: Munger, in collaboration with Scudder and Bates.

PS 110 ab. Political Modernization and Development. *9 units (3-0-6); second, third terms.* The first term is devoted to the general literature in the field; the second, to case studies of African nations; e.g., Nigeria and Zaire. 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 118. Democratic Theory. *9 units (3-0-6); third term.* This course will raise several types of questions and answer none. Is it possible to have a democracy; how ought citizens to act in a democracy; how do democratic governments and citizens of democratic politics actually behave; and is a democratic government necessarily just? Instructor: Ferejohn.

PS 120 ab. American Electoral Behavior and Party Strategy. *9 units (3-0-6); first, second terms.* A consideration of existing literature on the voting behavior of the citizen, moving to an examination of theoretical and empirical views of the strategies followed by the parties. Instructors: Fiorina, Ferejohn.

PS 121. Congressional Policy Formation and Legislative Process. *9 units (3-0-6); second term.* An analysis of decision-making in legislative bodies with major emphasis on the American Congress. It also includes an investigation into the impact of Congressional structure and practices on the policies adopted by the Federal Government. Instructors: Fiorina, Ferejohn.

PS/SS 122. Formal Theories in Political Science. *9 units (3-0-6). Prerequisite: Ec/SS 11 b.* An examination of the axiomatic structure and the behavioral interpretations of game theoretic and social choice models, and selected political models based on them. Instructors: Ferejohn, Fiorina, Plott.

PS 125. Peasant Politics. *9 units (3-0-6); third 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. Instructor: Bates.

PS 132. Strategy in Politics. *9 units (3-0-6); first term. Prerequisite: Ec/SS 11 a.* Game theory examined on a non-technical level, considering experimental work and political applications, with a focus on applications. Instructors: Fiorina, Ferejohn.

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 140. Seminar in Foreign Area Problems. *9 units (3-0-6).* The object of this course is to give students an opportunity to study in some detail problems current in certain selected foreign areas. Three or four areas will be considered each time the course is given, and the selection will normally vary from year to year. Instruction will be given mainly by area specialists of the American Universities Field Staff. Instructors: Staff and members of AUFS.

PS 141 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. Instructors: Fiorina, Ferejohn.

PS 151. Justice and Obligation. *9 units (3-0-6); third term.* An analysis of the concepts of justice and obligation primarily within a social contract framework but with some comparative study of utilitarian, Kantian, and other ethical schemes. Other normative concepts such as that of "the public interest," "rights," and "duty," will be examined as well. Instructors: Fiorina, Ferejohn.

PSYCHOLOGY

Undergraduate Courses

Psy 11. Introduction to Psychology. *9 units (3-0-6); first term.* A relatively free exploration of the variety of topics that comprise psychology. Topics can include, but are not limited to: historical background, development of personality and intellect, biological-evolutionary factors, issues in motivation, learning, social and abnormal psychology. Instructor: Breger.

Psy 12. Introduction to Abnormal Psychology. *9 units (3-0-6); second term.* An introduction to the development of mental and emotional disturbances. Basic theory will be reviewed in relation to selected case material and relevant research. Instructors: Staff.

Psy 13. Introduction to Social Psychology. *9 units (3-0-6); third term.* A survey of background and current areas in social psychology. Instructor: Beakel.

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); second, third 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. Psychohistory. *9 units (3-0-6); third term.* An examination of the interaction of psychological factors on the course of history; and of historical forces in the shaping of individual psychology. Instructors: Breger, Rosenstone.

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: Staff.

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.* This course concentrates on non-market decisions. It focuses on committee and legislative decision-making as well as providing an introduction to recent work in the theory of voting and the political process. Instructors: Staff.

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.* 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. Instructors: Staff.

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 1976-77. 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; first offered in 1976-77. Instructors: B. Thompson, F. Thompson.

Advanced Courses

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 122. Formal Theories in Political Science. *9 units (3-0-6);. Prerequisite: Ec/SS 11 b.* An examination of the axiomatic structure and the behavioral interpretations of game theoretic and social choice models, and selected political models based on them. Instructors: Ferejohn, Fiorina, Plott.

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.*

SS 140. Laboratory Experiments in the Social Sciences. *9 units (3-0-6).* An examination of recent work in laboratory testing in the social sciences with particular reference to work done in social psychology, economics, and political science. Instructors: Breger, Ferejohn, Thompson.

SS 141. Field Research in the Social Sciences. *9 units (3-0-6).* An examination of the uses for census and social statistics, an introduction to survey techniques and an evaluation of recent work in the area. Instructors: Bates, Scudder.

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. Taught in alternate years; not offered in 1976-77. Instructor: Thompson.

SS 150 abc. Social Science Aspects of Technology. *9 units (3-0-6).* This course is especially oriented toward engineering seniors and graduate students. The first term will present the theory of the operation of a competitive price system. The second term will deal with problems related to distortions of the competitive market mechanism. The third term will focus on specific problems involving substantial overlap between engineering and social science. Instructors: Staff.

SS 151. Research Seminar in Social Science Aspects of Technology. *9 units (3-0-6).* This course is especially oriented toward engineering seniors and graduate students. It will deal with current engineering research with strong social science implications. Instructors: Social Science and Engineering Staff.

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.

SS 201 abc. Microeconomics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ec 121 a or equivalent.* The first quarter covers classical consumption theory, the theory of production and markets, externalities and the question of public goods. The second quarter deals with modern economic theory, including decision theory, game theory, the role of uncertainty, and investment theory; the third quarter deals with dynamics. Instructors: Staff.

SS 202. Behavioral Perspectives in Political Science. *9 units (3-0-6); first term.* This course will focus on the influence of psychological and sociological theories upon the analysis of political behavior. Instructor: Bates.

SS 203. Game and Decision Theoretic Applications in Political Science. *9 units (3-0-6); second term.* The course examines recent attempts to apply game and decision theoretic models to politics, particularly legislative and electoral processes. A level of knowledge equivalent to PS/SS 122 is presumed. Instructors: Ferejohn, Fiorina.

SS 204. Social Choice Theories in Political Science. *9 units (3-0-6); third term.* Mathematical theories of individual and social choice are introduced as an approach to the classic problems of welfare economics and economic policy. Instructors: Ferejohn, Plott.

SS 206. Economic Foundations of Property, Exchange, and Liability Law. *9 units (3-0-6); second term.* Property, contract, and tort law will be introduced and examined as legal mechanisms for maximizing the value of production, controlling externalities, and distributing wealth. Instructor: Levine.

SS 207. Experimental Foundations of Social Problems. *9 units (3-0-6); second term.* The course is concerned with the design of experiments in social problems. The work will cover, for example, problems of competitive markets, cartel behavior, spatial models and politics. Instructor: Plott.

SS 210 ab. Foundations of Political Economy. *9 units (3-0-6).* Mathematical theories of individual and social choice applied to problems of welfare economics and political decision-making as well as construction of political economic processes consistent with stipulated ethical postulates, political platform formulation, the theory of political coalitions and decision-making in political organizations. Instructors: Plott, Ferejohn.

SS 211. Advanced Economic Theory. *9 units (3-0-6).* Advanced work in a specializing area of economic theory, with topics varying from year to year according to the interests of students. Instructors: Staff. *Can be repeated for credit.*

SS 212. 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: Staff. *Can be repeated for credit.*

SS 213. Competition and Antitrust Policy. *9 units (3-0-6); second term. Prerequisite: Ec 128.* This course is concerned with the differences in antitrust policies which would result from taking static as opposed to dynamic points of view. Instructor: Klein.

SS 214. Legal Aspects of the Economics and Politics of Regulation. *9 units (3-0-6); first term.* 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: Levine and staff.

SS 222 ab. Econometrics. *9 units (3-0-6). Prerequisites: Mathematical Statistics, 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. Instructors: Staff.

SS 223 abc. Special Topics in Econometrics. *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. The content will vary from term to term. Instructors: Grether, Nelson.

SS 229 ab. Historical Dimensions of Economic Analysis. *9 units (3-0-6); first, second terms.* 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. Instructor: Davis.

SS 230. Psychology and Organizational Behavior. *9 units (3-0-6).* Psychological theories of decision-making, small-group and organizational behavior, uncertainty and the tolerance for ambiguity and stress and change. Instructors: Staff.

SS 231 abc. American Politics. *9 units (3-0-6).* A three-term course in American politics and political behavior. While drawing from contemporary materials, the course will emphasize the historical background of American political institutions. Instructors: Staff.

SS 232 abc. Historical and Comparative Perspectives in Political Analysis. *9 units (3-0-6).* The course will provide an introduction to selected problems in American political history and quantitative analyses which have been made of them. Instructors: Bates, Kousser.

SS 233 abc. Public Policy Making. *9 units (3-0-6).* An examination of the policy-making processes in national, state, and local goverments and how various institutions affect policy choices. Instructors: Fiorina, Ferejohn.

SS 234. Research Seminar in Modern Political Science. *9 units (3-0-6); third term.*

SS 240. Techniques of Policy Research. *9 units (3-0-6); first term. Prerequisites: SS 201 abc, SS 202, SS 203, SS 204, SS 222 ab.* 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. Instructor: Noll.

SS 300. Research in Social Science. *9 units (3-0-6).* Instructors: Staff.