# INFORMATION FOR STUDENTS Galdeen

The cover illustrations symbolize the new emphasis on cell biology and chemistry in Callech's Divisions of Biology and Chemistry and Chemical Engineering, whose current research shows that the chemical and biological nature and behavior of the cell surface play major roles in human health and disease. Top: Two artist's renderings of (left) a cell-like fossil in a meteorite and (right) a fossilized cell from early earth. Bottom: Dried, thinly coated with gold, magnified 15,000 times actual size, and photographed by a scanning electron microscope, a baby hamster's kidney cell ruffles its way across a petri disb.

## INFORMATION FOR STUDENTS 1978-1979

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

September 1978

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KEY TO ABBREVIA	ATIONS
Aeronautics Ae En	vironmental Engineering
Anthropology An E	Delence Env

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 & Applied Science E & AS
Engineering Graphics Gr
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 1978-79

1978	First Term
September 20	Registration of entering freshmen - 1:00 p.m4:30 p.m.
September 21-23	New Student Orientation
September 25	General Registration 8:30 a.m4:30 p.m.
September 25	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
September 26	Beginning of instruction — 8:00 a.m.
October 13	Last day for adding courses and for removing conditions and incompletes
October 30-	Mid-Term week
November 3	
November 3	Last day for admission to candidacy for Master's and Engineer's degrees
November 6	Mid-Term deficiency notices due - 9:00 a.m.
November 13-17	Pre-registration for second term, 1978-79
November 23-26	Thanksgiving recess
November 23-24	Thanksgiving holidays
December 1	Last day for dropping courses, changing sections, and track changes
December 9-15	Final examinations, first term, 1978-79
December 16	End of first term, 1978-79
December 17-	Christmas recess
January 1	
December 18	Instructors' final grade reports due — 9:00 a.m.
December 22-26	Christmas holidays

#### 1979

### Second Term

January 1	New Year's Day holiday
January 2	General Registration - 8:30 a.m4:30 p.m.
January 2	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
January 3	Beginning of instruction — 8:00 a.m.
January 19	Last day for adding courses and for removing conditions and incompletes
February 5-9	Mid-Term week
February 12	Mid-Term deficiency notices due — 9:00 a.m.
February 19-23	Pre-registration for third term, 1978-79
March 2	Last day for dropping courses, changing sections, and track changes
March 10-16	Final examinations, second term, 1978-79
March 16	Last day for obtaining admission to candidacy for the degree of Doctor of Philosophy
March 17	End of second term, 1978-79
March 18-25	Spring recess
March 19	Instructors' final grade reports due — 9:00 a.m.

1979	Third Term
March 26	General registration - 8:30 a.m4:30 p.m.
March 26	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
March 27	Beginning of instruction — 8:00 a.m.
April 13	Last day for adding courses and for removing conditions and incompletes
April 23-27	Mid-Term week
April 30	Mid-Term deficiency notices due — 9:00 a.m.
May 4-5	Examinations for admission to upper classes, September 1979
May 14-18	Pre-registration for first term, 1979-80, and registration for summer research (graduate and undergraduate)
May 18	Last day for dropping courses, changing sections, and track changes
May 25	Last day for presenting theses for the degrees
	of Doctor of Philosophy and of Engineer
May 26-	Final examinations for senior and graduate students,
June 1	third term, 1978-79
May 28	Memorial Day holiday
June 2-8	Final examinations for undergraduate students, third term, 1978-79
June 4	Instructors' final grade reports due for senior and graduate students — 9:00 a.m.
June 6	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
June 6	Curriculum Committee Meeting — 10:00 a.m.
June 6	Faculty Meeting — 2:00 p.m.
June 8	Commencement
June 9	End of third term, 1978-79
June 11	Instructors' final grade reports due for undergraduate students — 9:00 a.m.
June 20	Undergraduate Academic Standards and Honors Committee — 9:00 a.m.
July 4	Independence Day Holiday
September 3	Labor Day holiday
	First Term 1979-80
September 19	Registration of entering freshmen, 1:00 p.m4:30 p.m.
ptember 20-22	New Student Orientation

- New Student Orientation General Registration 8:30 a.m.-4:30 p.m. Beginning of instruction 8:00 a.m.
- September 20-22 September 24 September 25



## 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)
- 82. Grounds Operations Office
- 45. Guggenheim Laboratory (Aeronautics and Applied Physics)
- 56. Housing Office
- 90. Industrial Relations Center
- 35. Isotope Handling Laboratory
- 80. Jorgensen Laboratory (Computer Science and Bioinformation Systems)
- Karman Laboratory (Fluid Mechanics and Jet Propulsion)

- 86. Keck House (Graduate Residence)
- 78. Keck Laboratories (Environmental Engineering and Materials Science)
- 38. Kellogg Radiation Laboratory
- 27. Kerckhoff Laboratory (Biological Sciences)
- 48. Lauritsen Laboratory (High Energy Physics)
- 54. Lloyd House (Undergraduate Residence)
- 89. Marks House (Graduate Residence)
- 32. Millikan (Library and Administration)
- 87. Mosher-Jorgensen House (Graduate Residence)
- 23. Mudd, North (Geology and Geochemistry)
- 21. Mudd, South (Geophysics and Planetary Sciences)
- 72. Noyes Laboratory (Chemical Physics)
- 53. Page House (Undergraduate Residence)
- 4, 5, 82, 83, 84. Physical Plant
- 92. Public Events Office
- 71. Public Relations and Publications
- 77. Ramo Auditorium
- 59. Ricketts House (Undergraduate Residence)
- 24. Robinson Laboratory (Astrophysics)
- 55. Ruddock House (Undergraduate Residence)
- Sloan Laboratory (Mathematics and Physics)
- 6. Spalding Building (Business Services)
- 41. Spalding Laboratory (Chemical Engineering)
- 94. Steele House (Residence, Master of Student Houses)
- Steele Laboratory (Applied Physics and Electrical Engineering)
- 44. Thomas Laboratory (Civil and Mechanical Engineering)
- 92. Ticket Office
- 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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#### FACULTY OFFICERS AND COMMITTEES

#### 1978-1979

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Term expires June 30, 1979	Term expires June 30, 1980
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S. Epstein	N. R. Corngold

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In residence 1977-78 <sup>1</sup>In residence <sup>19/7-78</sup> <sup>2</sup>U. S. Public Health Service Fellow <sup>3</sup>U. S. Public Health Service Postdoctoral Trainee <sup>4</sup>Chaim Weizmann Research Fellow <sup>4</sup>Consiglio Nazionale delli Richerche Fellow <sup>6</sup>American Cancer Society Fellow <sup>7</sup>Damon Runyon Memorial Fund Fellow <sup>8</sup>Helen Hay Whitney Foundation Fellow

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Paul D. Arthur, Ph.D. <sup>1</sup>	Aeronautics
James A. Boa, Ph.D. <sup>1</sup>	Applied Mathematics
Stephen H. Caine	Computer Science
Sebastien M. Candel, Ph.D. <sup>1</sup>	Jet Propulsion
Gordon E. Chapman, D.Phil.	Applied Physics
Vincent H. Chu, Ph.D.	
L. Pamela Cook-Ioannidis, Ph.D. <sup>1</sup>	Applied Mathematics
Bruno Crosignani, Lib.Doc. <sup>1</sup>	Electrical Engineering
Nicholas A. Cumpsty, Ph.D.	Jet Propulsion
Kamalaksha Das Gupta, Ph.D.	
Ellen R. Domb, Ph.D.	Applied Physics
Vjatsheslav A. Dudkin, Ph.D. <sup>1</sup>	Jet Propulsion
Sverre T. Eng., Dr.Tech.	Electrical Engineering
Giorgio Franceschetti, Ph.D.	Electrical Engineering
Laszlo Gal, Dr.Eng. <sup>1</sup>	Applied Physics
E. Kent Gordon, B.S.	Computer Science
Alten F. Grandt, Jr., Ph.D. <sup>1</sup>	Aeronautics
Rudolf Grossmayer, Dr.Tech.Sci. <sup>2</sup>	Applied Mechanics
<sup>1</sup> In residence 1977-78	

<sup>2</sup>Max Kade Postdoctoral Research Exchange Scholar

William F. Hunt, M.S. <sup>1</sup>	. Environmental Engineering Science
Herbert E. Huppert, Ph.D	. Environmental Engineering Science
Edward F. Kennedy, Ph.D. <sup>1</sup>	Applied Physics
Ramaz A. Khurodze, Cand.Tech.Sci. <sup>1</sup>	Electrical Engineering
Akira Kobayashi, D.Eng. <sup>1</sup>	Aeronautics
Tsutomu Kobayashi, Ph.D.	Electrical Engineering
Kazunari Komenou, D.Eng	Applied Physics
Hiroshi Kosaka, M.S. <sup>1</sup>	Environmental Engineering
Vladimir N. Kuzmin, Docent	Applied Physics
Rachmiel Levine, M.D.	Biomedical Engineering
Thomas E. Ogden, M.D., Ph.D.	Biomedical Engineering
Makoto Okusu, D.Eng.	Engineering Science
Nick D. Panagiotacopulos, M.S	Aeronautics
Ruggero L. Pierantoni, Ph.D.	Biomedical Engineering
Simon Ramo, Ph.D.	Engineering
Avigdor V. Rutenberg, D.Sc.	Civil Engineering
C. Hunter Shelden, M.D.	Biomedical Engineering
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Robert F. Sproull, Ph.D. <sup>1</sup>	Computer Science
Ernest O. Tuck, Ph.D. <sup>1</sup>	Engineering Science
Billy J. Walker, Ph.D.	Aeronautics and Applied Mathematics
Martin F. von Allmen, Ph.D.	Applied Physics
Iwao Watanabe, M.E.	Engineering Science
Kenneth T. Whitby, Ph.D. <sup>1</sup>	Environmental Engineering Science
Bernhard Wielke, Ph.D. <sup>2</sup>	
Howard Winet, Ph.D.	Engineering Science
Dean E. Wooldridge, Ph.D	Engineering
James H. T. Wu, Ph.D	Aeronautics
James T. P. Yao, Ph.D. <sup>1</sup>	Earthquake Engineering
Sergey Yevgenyevich Yurchenko, Ph.D. <sup>1</sup>	Applied Physics
Moshe Yust, M.Sc.	Applied Physics
George J. Zimmer, Dipl. <sup>1</sup>	Applied Physics

#### **Associate Professors**

Christopher Brennen, Ph.D.	
Francis S. Buffington, Sc.D.	
Hardy C. Martel, Ph.D	Electrical Engineering
David F. Welch, I.D.	Engineering Design

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Craig Mudge, Ph.D	Computer Science
Edward C. Posner, Ph.D	Electrical Engineering
Martin Rem, Ph.D. <sup>1</sup>	Computer Science
Lincoln J. Wood, Ph.D	Systems Engineering

#### **Research Associates**

James E. Broadwell, Ph.D	Aeronautics
John P. Gray, Ph.D.	Computer Science
Robert C. Y. Koh, Ph.D.	Environmental Engineering Science
Charles L. Seitz, Ph.D	Computer Science

<sup>1</sup>In residence 1977-78 <sup>2</sup>Max Kade Postdoctoral Research Exchange Scholar

#### Assistant Professors

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Slobodan M. Cuk, Ph.D.	Electrical Engineering
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
William L. Johnson, Ph.D.	Materials Science
James T. Kajiya, Ph.D.	Computer Science
Charles R. Minter, Ph.D.	Computer Science
Darryl L. Smith, Ph.D.	Applied Physics

#### Senior Research Fellows

Glen R. Cass, Ph.D. <sup>1</sup>	. Environmental Engineering Science
Anthony T. W. Cheung, Ph.D.	Engineering Science
Vernal H. Kenner, Ph.D.	Aeronautics
Vijay Kulkarny, Ph.D. <sup>2</sup>	Aeronautics
Aurora M. Landel, Ph.D.	Biomedical Engineering
Silvanus S . Lau, Ph.D. <sup>3</sup>	Applied Physics
Nicholas R. Moore, Ph.D.	Engineering

#### Instructors

Anastassios C. B	ountis,	Ph.D.	Bateman	Research	Instructor in	1 Applied	Mathematics
James C. Long, I	Ph.D.					Electrical	Engineering

#### Lecturers

Stanley H. Bacon	Electrical Engineering
Stephen R. McReynolds, Ph.D. <sup>2</sup>	Systems Engineering
Amr M. Mohsen, Ph.D.	Electrical Engineering
Marc H. Raibert, Ph.D	Computer Science
Charles B. Ray, M.S.	Computer Science
Stanley T. Wolfberg, M.B.A.	Engineering

#### **Research Fellows**

Michael J. Barcelona, Ph.D.	.Environmental Engineering Science
James F. Blinn, Ph.D.	Computer Science
Brian J. Cantwell, Ph.D	Aeronautics
Tony Fan-cheong Chan, Ph.D.	Applied Mathematics
Martin Chen, Ph.D. <sup>2</sup>	Applied Physics
Cliff I. Davidson, Ph.D. <sup>2</sup>	.Environmental Health Engineering
Walter K. De Logi, Ph.D	Electrical Engineering
Dan Fekete, Ph.D. <sup>5</sup>	Applied Physics
Gregory Gartrell, Jr., Ph.D. <sup>5</sup>	Environmental Engineering Science
Ilan Golecki, Ph.D.	Applied Physics
Crockett L. Grabbe, Ph.D. <sup>2</sup>	Applied Physics
Lambertus Hesselink, Ph.D. <sup>4</sup>	Fluid Mechanics

<sup>1</sup>Also part-time Instructor in Environmental Engineering Science <sup>2</sup>In residence 1977-78 <sup>3</sup>Also part-time Lecturer in Applied Physics <sup>4</sup>Also part-time Lecturer in Applied Physics <sup>5</sup>Chaim Weizmann Research Fellow

Robert E. Johnson, Ph.D. <sup>1</sup>	Engineering Science and Biology
Keiichiro Koga, M.E.E. <sup>1</sup>	Electrical Engineering
John P. Kroeker, Ph.D	Bioinformation Systems
David M. Lee, Ph.D.	Earthquake Engineering
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Peter H. McMurry, Ph.D. <sup>1</sup>	Environmental Health Engineering
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Robert D. Shull, Ph.D.	Materials Science
Roque Kwok-Hung Szeto, Ph.D.	Applied Mathematics
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Marc F. Wittmer, Ph.D. <sup>1</sup>	Applied Physics
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<sup>1</sup>In residence 1977-78 <sup>2</sup>Chaim Weizmann Research Fellow

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William H. Bettes, Manager GALCIT

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## Division of Geological and Planetary Sciences

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Charles F.	Richter, Ph.D.	.Seismology

#### Professors

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Arden L. Albee, Ph.D.	Geology
Clarence R. Allen, Ph.D	Geology and Geophysics
Don L. Anderson, Ph.D.	Geophysics
Donald S. Burnett, Ph.D.	Nuclear Geochemistry
Samuel Epstein, Ph.D.	Geochemistry
Peter Goldreich, Ph.D.	. Planetary Science and Astronomy
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

Anton L. Hales, Ph.D	Geophysics
Vladimir I. Keilis-Borok	Geophysics
Frank M. Richter, Ph.D.	Geophysics
Ronald L. Shreve, Ph.D.	
Anthony Turkevich, Ph.D.	Geochemistry
# **Visiting Professors**

C. Bernard Farmer, Ph.D	.Planetary Science
Alexander R. McBirney, Ph.D.	Geology

### Senior Research Associate

Clair	C.	Patterson,	Ph.D.,	D.Sc	Geochemistry
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### **Visiting Associates**

Georg Amthauer, Ph.D.	Mineralogy
Donald E. Brownlee, Ph.D.	Geochemistry
Giuseppe Colombo, Ph.D.	lanetary Science
Osamu Matsubaya, Ph.D.	Geochemistry
John D. O'Keefe, Ph.D	lanetary Science
John A. Orcutt, Ph.D.	Geophysics
David A. Wark, Ph.D.	Geochemistry
Ralph A. Wiggins, Ph.D.	Geophysics
Dorothy S. Woolum, Ph.D.	Geochemistry

# **Associate Professors**

David G. Harkrider, Ph.D.	Geophysics
Donald V. Helmberger, Ph.D.	Geophysics
George R. Rossman, Ph.D.	Mineralogy
Jason Saleeby, Ph.D.	Geology

# **Research Associates**

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

# **Assistant Professors**

H. Jay Melosh, Ph.D.	Planetary Science
Jean-Bernard H. Minster, Ph.D	Geophysics
Kerry E. Sieh, Ph.D.	Geology
Yuk L. Yung, Ph.D	Planetary Science

# Senior Research Fellows

Richard H. Becker, Ph.D.	.Geochemistry
Hermann F. Engelhardt, Ph.D.	Geophysics
Karen C. McNally, Ph.D.	Geophysics
Maureen B. Steiner, Ph.D.	Geology
John T. Trauger, Ph.DPla	netary Science
James H. Whitcomb, Ph.D.	Geophysics

# Lecturer

David T. Burhans, Ph.D	),	.Speech	Communication
------------------------	----	---------	---------------

### **Research Fellows**

Lawrence J. Burdick, Ph.D.	Geophysics
Kazuya Fujita, Ph.D	Geophysics
Michael J. DeNiro, Ph.D.	Geochemistry
Robert S. Hart, Ph.D	Geophysics
Stephen H. Hartzell, Ph.D.	Geophysics
Tai-Lin Hong, Ph.D.	Geophysics
Barry R. Lienert, Ph.D.	Geophysics
Felix Oberli, Ph.D.	. Geology and Geochemistry
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James A. Woodhead, Ph.D	Geology

#### Graduate Students 1978-79

Applied Physics Gregory Allen Lyzenga

Geochemistry Timothy Miller Benjamin Robert Everett Criss Joel Earl Everson Marian Judith Furst Peter L. Gromet

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Roger Deane Aines Warren Scott Baldridge David Wayne Beaty Brian Stuart Brock Melinda Mary Brugman Duane Edwin Champion Michael Paul Charette Josephine Beatrice Way Cimino Charles Brown Douthitt Keith Alan Echelmeyer Alan Reed Gillespie Robert Theodore Gregory Robert Ian Hill Elizabeth Anne Horton Stein Bjornar Jacobsen Raymond Francois Jeanloz

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- John Edward Ebel Jeffrey Wayne Given Thomas Martin Hearn Thomas Harrison Heaton Bruce Martin Jakosky Carl Edward Johnson Richard Paul Keller Thorne Lay Hsui-Lin Liu Kristian Erik Meisling George Robert Mellman
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Alan R. Sweezy, Ph.D.	Economics
Ray E. Untereiner, Ph.D., J.D.	Economics

### Lecturer Emeritus

Charles Newton.	Ph.B.	 English
Charles renton,		 

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David M. Grether, Ph.D.	Economics

Part-time

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Daniel J. Kevles, Ph.D.	History
Burton H. Klein, Ph.D.	Economics
Beach Langston, Ph.D. <sup>2</sup>	English
Michael E. Levine, J.D. <sup>2</sup>	Luce Professor of Law and Social Change
Oscar Mandel, Ph.D.	English
George P. Mayhew, Ph.D. <sup>2</sup>	English
Edwin S. Munger, Ph.D	Geography
Roger G. Noll, Ph.D.	Economics
Robert W. Oliver, Ph.D.	Economics
Rodman W. Paul, Ph.D	Edward S. Harkness Professor of History
Charles R. Plott, Ph.D.	Economics
James P. Quirk, Ph.D.	Economics
Robert A. Rosenstone, Ph.D	History
Thayer Scudder, Ph.D.	Anthropology
Frederick B. Thompson, Ph.D.	Applied Philosophy and Computer Science

# Sherman Fairchild Distinguished Scholars

William A. Brock, Ph.D	Economics
David Cass, Ph.D.	Economics
Richard D. McKelvey, Ph.D Politi	cal Science

# Visiting Associate

David	A. Hamburg,	M.D.	 ial Science

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Simon I	Ramo, Ph.D.		 	 	 . Management	Science

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Louis Breger, Ph.D.	Psychology
Heinz E. Ellersieck, Ph.D	History
Stuart A. Ende, Ph.D.	English
J. Morgan Kousser, Ph.D	History
Jenijoy La Belle, Ph.D	English
David R. Smith, Ph.D.	English

### **Assistant Professors**

Bruce E. Cain, Ph.D.	Political Science
Robert E. Forsythe, Ph.D.	Economics
Holly Jackson, Ph.D. <sup>2</sup>	English
Gary J. Miller, Ph.D	Political Science
Forrest D. Nelson, Ph.D.	Economics
Joyce Penn, Ph.D.	English

<sup>1</sup>Part-time <sup>2</sup>Leave of absence

George W. Pigman III, Ph.D.	English
Martin H. Rubin, Ph.D.	English
Randolph N. Splitter, Ph.D.	English
Louis L. Wilde, Ph.D Ed	onomics

# Visiting Assistant Professor

Ronald Braeutigam,	Ph.D.	<i>L</i>	Economics
--------------------	-------	----------	-----------

# Lecturers

Andreas Aebi, Ph.D.	German
Irving S. Bengelsdorf, Ph.D. <sup>1</sup>	Science Communication
David J. Britton, D.M.A.	Music
Lee F. Browne, M.S. <sup>1</sup>	Education
Klara Carmely, Ph.D	German
Barbara Fass, Ph.D. <sup>1</sup>	Psychology
Stirling L. Huntley, Ph.D.	Drama
Edward Hutchings, Jr., B.A. <sup>1</sup>	Journalism
David W. Morrisroe, M.B.A. <sup>1</sup>	Business Economics
Jon Richard Pariser, M.A.	Russian
Aimée Brown Price, Ph.D.	Art History
Elma Schonbach, B.M.	Music
Annette Smith, Ph.D.	French
Victor V. Veysey, M.B.A. <sup>1</sup>	Business Economics
	and Industrial Relations
Robert R. Wark, Ph.D. <sup>1</sup>	Art
Valentina Zaydman, M.A.	Russian

### **Research Associates**

R. Talbot Page, Ph.D.		Economics
Bozena Henisz-Dostert Thompson, Ph.D.	I	inguistics

### Mellon Postdoctoral Instructors

Gordon Appleby, Ph.D	 Anthropology
Terrence McDonald, Ph.D.	 History

# Graduate Students 1978-79

Social Science	
Joel Abe Balbien	Robert William Hahn
Michael Stanley Becker	Steven Wayne Hashimoto
Donna Hope Berry	Elizabeth Hoffman
Brian Robert Binger	James Takfay Hong
Randall Lee Calvert	Robert Mark Isaac
Cynthia Rae Carlson	Jeffrey Bowman Johnson
Linda Rachel Cohen	Julie Marie Laherty
Gary Walter Cox	Tom Kwan-Yau Lee

<sup>1</sup>Part-time

Carl J. Lydick Mathew Daniel McCubbins Kenneth Frank McCue Thomas Rossman Palfrey III Asha Bhalachandra Paranjape William Paul Rogerson Venkatraman Sadanand John Patrick Schmitz Charles Seymour Slater Lee Ira Sparling Matthew L. Spitzer Mark Edward Stover John Marshall Williamson

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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
, , , <u>_</u>	Professor of Theoretical Physics

Peter Goldreich, Ph.D.	Planetary Science and Astronomy
Ricardo Gomez, Ph.D.	Physics
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.	IBM Professor of Mathematics
Ralph W. Kavanagh, Ph.D.	Physics
Herbert B. Keller, Ph.D.	Applied Mathematics
Heinz-Otto Kreiss, Docent	Applied Mathematics
Robert B. Leighton, Ph.D.	Physics
Gary Lorden, Ph.D.	Mathematics
W. A. J. Luxemburg, Ph.D.	Mathematics
Jon Mathews, Ph.D.	Theoretical Physics
James E. Mercereau, Ph.D., D.Sc.	Physics and Applied Physics
Alan T. Moffet, Ph.D.	Radio Astronomy
Gerry Neugebauer, Ph.D.	Physics
J. Beverley Oke, Ph.D.	Astronomy
Charles W. Peck, Ph.D	Physics
Jerome Pine, Ph.D. <sup>1</sup>	
Herbert J. Ryser, Ph.D.	
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.	Theoretical Physics
John Todd, B.Sc.	Mathematics
Thomas A. Tombrello, Jr., Ph.D.	Physics
Rochus E. Vogt, Ph.D.	Physics
David B. Wales, Ph.D.	
Robert L. Walker, Ph.D.	
Ward Whaling, Ph.D.	Physics
Gerald B. Whitham, Ph.D.	Applied Mathematics
Fredrik Zachariasen, Ph.D. <sup>1</sup>	Theoretical Physics
Harold Zirin, Ph.D.	Astrophysics
George Zweig, Ph.D.	Theoretical Physics
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# Sherman Fairchild Distinguished Scholars

Donald Lynden-Bell, Ph.D.	Astronomy
Alexander Polyakov, Doktorat	Theoretical Physics
Reuven Ramaty, Ph.D.	Astrophysics
Valentine Telegdi, Ph.D	Physics

# Visiting Professors

Per Henrik Enflo, Ph.D	Mathematics
Haim Hanani, Ph.D	Mathematics
Sydney Meshkov, Ph.D Theore	etical Physics
Helmut H. Schaefer, Ph.D	Mathematics

# Visiting Associates

J. L. Alperin, Ph.D.	Mathematics
Jean P. Bibring, These d'Etat	Physics
Paul Bonche, Ph.D	Physics
Felix E. Browder, Ph.D.	Mathematics
Roland Buser, Ph.D.	Astronomy
Frank Calaprice, Ph.D	Physics
Lucy M. Carruthers, Ph.D	Theoretical Physics
Chu-Nan Chang, Ph.D.	Physics
Francis E. Corrigan, Ph.D	Theoretical Physics
Ronald J. Crowley, Ph.D.	Physics
Bibiana Cujec, Ph.D	Physics
Christian A. Engelbrecht, Ph.D	Physics
Pierre Fayet, Ph.D.	Theoretical Physics
George Glauberman, Ph.D.	Mathematics
Stephen F. Gull, Ph.D.	Radio Astronomy
Charles H. Holbrow, Ph.D.	Physics
Sir Fred Hoyle, D.Sc.	Physics
Anthony M. Lane, Ph.D	Physics
Joseph. J. Y. Liang, Ph.D.	Mathematics
David K. Lynch, Ph.D.	Physics
Geoffrey Mason, Ph.D.	Mathematics
H. Richard Miller, Ph.D.	Astronomy
John W. Negele, Ph.D.	Physics
Igor D. Novikov, D.Sc.	Physics
Patrick S. Osmer, Ph.D.	Astronomy
Thomas G. Phillips, Ph.D.	Radio Astronomy
Jorgen Randrup, Lic. Scient	Physics
Douglas O. Richstone, Ph.D.	Astronomy
Simon Rosenblat, Ph.D.	. Applied Mathematics
Denis G. Sargood, Ph.D.	Physics
Ryoichi Seki, Ph.D.	Physics
Luigi Sertorio, Ph.D.	Theoretical Physics
Mark H. Shapiro, Ph.D.	Physics
Arnold J. Sierk, Ph.D.	Physics
Armando Silva Moreira, Ph.D.	Physics
Paula Szkody, Ph.D.	Astronomy
Matilde P. Teleman, Laurea	Physics
Ole Ulfbeck, Ph.D.	Astronomy
Gerard Vauclair, Ph.D.	Astronomy
Sylvie Vauclair-Gueudet, Ph.D.	Astronomy
Marion J. Watson, M.Sc.	Physics
Lester Winsberg, Ph.D.	Physics
C. Gareth Wynn-Williams, Ph.D.	Physics
Amos Yahil, Ph.D.	Physics
Fleur Belle Yano, Ph.D.	Physics

# **Associate Professors**

Judith G. Cohen,	Ph.D	Ast	ronomy
Geoffrey Fox, Ph.I	D	Theoretical	Physics

Alexander S. Kechris, Ph.D. <sup>1</sup> Ma	thematics
Steven E. Koonin, Ph.D.	. Physics
H. David Politzer, Ph.D Theoretical	l Physics

#### **Research Associates**

Richard D. Field, Ph.D. <sup>2</sup>	. Theoretical	Physics
Richard J. Powers, Ph.D.	<i></i> .	Physics
John H. Schwarz, Ph.D. <sup>1</sup>	. Theoretical	Physics
George A. Seielstad, Ph.D	Radio As	tronomy
Petr Vogel, Ph.D.		Physics

#### Assistant Professors

Roger D. Blandford, Ph.D.	Theoretical Astrophysics
Jack F. Conn, Ph.D.	Mathematics
Peter G. Wannier, Ph.D.	Radio Astronomy
Michael Werner, Ph.D.	Physics

### **Visiting Assistant Professor**

James E. Pringle,	. Ph.D	. Astronomy
-------------------	--------	-------------

### Senior Research Fellows

Carl Bromberg, Ph.D.	Physics
John M. Davidson, Ph.D.	Physics
G. John Dick, Ph.D.	Applied Physics
Alan M. Dressler, Ph.D.	Astronomy
Glennys Farrar, Ph.D.	Theoretical Physics
Thomas R. Geballe, Ph.D.	Astronomy
Terrence J. Goldman, Ph.D.	Theoretical Physics
Gillian Knapp, Ph.D.	Radio Astronomy
Kwok-Yung Lo, Ph.D.	Radio Astronomy
Richard A. Mewaldt, Ph.D.	Physics
Ronald L. Moore, Ph.D.	Astrophysics
Harris A. Notarys, Ph.D.	Physics
Pierre Ramond, Ph.D. <sup>3</sup>	Theoretical Physics
Anthony C. S. Readhead, Ph.D.	Radio Astronomy
Douglas Ross, Ph.D.	Theoretical Physics
I-Juliana Sackmann, Ph.D.	Physics
Michael Shaevitz, Ph.D.	Physics
B. Thomas Soifer, Ph.D.	Physics
Robert J. Zinn, Ph.D.	Astronomy

#### Instructors

Sydney Graham,	Ph.D. <sup>4</sup>	Mathematics
Jerrold R. Griggs,	Ph.D. <sup>4</sup>	Mathematics

<sup>1</sup>Leave of absence 1978-79

.

<sup>3</sup>Richard Chace Tolman Research Associate <sup>3</sup>Robert Andrews Millikan Sr. Research Fellow <sup>4</sup>Harry Bateman Research Instructor

Robert M. Guralnick, Ph.D. <sup>3</sup>	Mathematics
Stephen C. Power, Ph.D. <sup>1</sup>	Mathematics
Arden Ruttan, Ph.D.	Mathematics
Anton R. Schep, Ph.D.	Mathematics
Mitchell Spector, Ph.D. <sup>1</sup>	Mathematics
Neculaí S. Teleman, Ph.D. <sup>1</sup>	Mathematics

### **Research Fellows**

Thomas B. Ake III, Ph.D.	Astronomy
Steven Beckwith, Ph.D.	Physics
Bernard J. Carr, Ph.D.	Physics
Andrew L. Chermak, Ph.D.	Mathematics
Thomas J. Chester, Ph.D.	Astrophysics
Brian L. Combridge, Ph.D.	Physics
Gary S. DaCosta, Ph.D.	Astronomy
William M. DeCampli, Ph.D.	Astrophysics
Jean O. Dickey, Ph.D	Physics
Eliahu Dwek, Ph.D.	Physics
Ian Gatley, Ph.D	Physics
Richard F. Green, Ph.D.	Astronomy
Alan Hahn, Ph.D.	Physics
Frank P. Israel, Ph.D.	Radio Astronomy
Robert C. Kennicutt, Jr., Ph.D.	Astronomy
Edward W. Kolb, Ph.D.	Physics
Colin R. Masson, Ph.D.	Radio Astronomy
David L. Meier, Ph.D.	Physics
Robert L. Messner, Ph.D.	Physics
Stefan Mochnacki, Ph.D.	Astronomy
Jeremy Mould, Ph.D.	Astronomy
Henry Norgaard, Cand. Sci	Physics
John A. Nousek, Ph.D	Physics
Timothy J. Pearson, Ph.D.	Radio Astronomy
Frank C. Porter, Ph.D. <sup>2</sup>	Physics
William Priedhorsky, Ph.D.	Physics
Edward J. Rhodes, Jr., Ph.D.	Physics
James A. Rose, Ph.D.	Astronomy
Vernon D. Sandberg, Ph.D.	Physics
Anneila I. Sargent, Ph.D.	Astronomy
Robert A. Schommer, Ph.D.	Astronomy
David L. Tubbs, Ph.D.	Physics
R. Craig Walker, Ph.D.	Radio Astronomy
Stephen V. Weber, Ph.D. <sup>2</sup>	Astrophysics
Robert A. Weller, Jr., Ph.D.	Physics
Mark E. Wiedenbeck, Ph.D.	Physics
Huan-Chen Yen, Ph.D.	Physics

<sup>1</sup>Harry Bateman Research Instructor <sup>2</sup>Chaim Weizmann 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 1978-79

Applied Mathematics David Leslie Brown Benito Chen-Charpentier Pascal Henri Elleaume Anthanassios Fokas Daniel Craig Jay Fai Ma George Joseph Majda John Weidman McLean

Applied Physics George Fox Eric Donald Fredrickson

- Astronomy Graham Berriman Kirk Daniel Borne Menachem Cimerman Boris Gokhman John Greg Hoessel Keith Douglas Horne Stephen Matthew Kent Stephen Morris Lichten Roger Paul Linfield Matthew Arnold Malkan
- Mathematics Richard Paul Anstee Stuart Lynch Blackburn Arthur Robert Calderbank Neville Ray Campbell Leslie Joseph Deutsch Brent Lee Ellerbroek Jeffrey Lee Fordon Philip James Hanlon Dean Robert Hart

Physics Timothy James Alleman Gregory John Ball Alan Voltz Barnes Bertrand Charles Barrois Jon Stuart Bartlett Arthur Ira Metz David Joseph Perozzi Douglas Alan Reinelt Luis Guillermo Maria Reyna Henry Clark Simpson Daniel Herbert Turnbull Daniel Ian Zwillinger

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Howard Louis Berg Robert Eugene Blair Anthony Michael Bloch Norman Bobroff John Richard Bond

Mark John Bowick Hugh Herbert Breneman Richard Laurence Brenner Eugene David Brooks III Kay Wyatt Brown Larry James Carson Carlton Morris Caves Yia-chung Chang Arthur Er-Terg Chiou Yam Ki Chu Joseph Stephens Clapp Christopher Alan Cole Walter Richardson Cook Barbara Hope Cooper France Anne Cordova Vaughn Omer Davidson Brian Ronald Davis Murray Scott Daw Eva Maria Dohrn Mark F. Dumke David James Ennis Richard Alan Flammang Bradley Arnold Flanders Michael David Foote Patrick Michael Frantz George M. Fuller Cornelis Adolf Gehrels James Lawrence Gimlett **Jeffrey Mark Greif** Joseph Edward Griffith Raian Gupta Yekta Gursel Craig Warren Gustafson Jeffrey John Hamilton Michael David Hamrick Steward Russell Hartman Jeffrey A. Harvey Robert Lee Hatch Lowell Eugene Hazelton William Donald Hazelton Mark Hereld Raymond David Hermann Lars Eric Hernquist Andrew Thompson Hunter Thomas Robert Hurd Kenneth Alan Jensen Sarbmeet Singh Kanwal Rosemary Gillian Kennett Jaisam Kim Arieh Konigl Dale Edward Koop Keith E. Krombel Daniel Sai Wah Kwoh

Heemin Kwon Nai-Hang Kwong Warren Yiu-cho Lai Koon Hang Lau James Roy Lee Michael Murdock Lowry Douglas Alan MacDonald David Brian MacFarlane Robert Sullivan Maier Max Marshall Ian Rowland McLenaghan Michael Charles McNab Charles Kenneth Meins, Jr. Geoffrey Blount Mills Donald Paul Mitchell Daniel Nadeau Frank Joseph Nagy Joseph Michael Nilsen John Joseph Nugent Peter Oliver Orland John Lawrence Osborne Gordon Cecil Osbourn Steve William Otto Richard Allan Partridge Robert Charles Pike Milind Vasant Purohit Ian H. Redmount David Benjamin Reiss Charles Edward Riedhauser Leonid Zinovy Rivkin **James William Rohlf** David Arthur Rowe William Armstrong Russell Raghvendra Sahai Conrad Nobushige Sato Joel Nathan Schulman Lucy Elizabeth Seiberling Kristen Sellgren Chun-Ching Shih Eric Ionathan Siskind Robert Thomas Skelton Stephen Avery Slutz John David Spalding Srinivas Sridhar Stuart Reh Stampke John Stager Stemple Gayle Arden Sugiyama Timothy Sean Sullivan Eugene Szedenits, Jr. Peter Taborek Anthony Emerson Terrano Stephen Trentalange Tsun-yan Tse

John Reinhold Valainis Mark Alan Voelker Ken-chung Wang Michael Ben Weimer Martha Carroll Weller Brian David Wilson Harold Stevenson Wilson Daniel Paul Wilt Jack Leach Wisdom Stephen Wolfram Hitoshi Yamamoto Kar Woo Yung Cosmas Kyriacoulis Zachos Mark Edward Zimmermann James Frederick Zumberge John Lehrer Zyskind

#### Owens Valley Radio Observatory Staff Members

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Glenn L. Berge, Ph.D. Marshall H. Cohen, Ph.D. Martin S. Ewing, Ph.D. Gillian R. Knapp, Ph.D. Robert B. Leighton, Ph.D. Alan T. Moffet, Ph.D. Duane O. Muhleman, Ph.D. Thomas G. Phillips, Ph.D. Richard B. Read, Ph.D. Wallace L. W. Sargent, Ph.D. George A. Seielstad, Ph.D.

### Sherman Fairchild Distinguished Scholars

#### 1978-79

Carl F. Ballhausen, Dr. Phil. Professor and Head of Physical Chemistry Department, University of Copenhagen William A. Brock, Ph.D. Professor of Economics, Cornell University David Cass, Ph.D. Professor of Economics, University of Pennsylvania Wladyslaw Fiszdon, D.Sc. Head of Fluid Dynamics Department, Institute of Basic Technological Problems, Polish Academy of Sciences Anton Hales, Ph.D. Professor of Geophysics, The University of Texas at Dallas Jack Halpern, Ph.D. Professor of Chemistry, The University of Chicago William Hayes, Sc.D. Professor of Genetics, Australian National University Vladimir I. Keilis-Borok, Ph.D. Professor and Head of the Department of Methods of Interpretation, Institute of the Physics of the Earth, Academy of Sciences, USSR Donald Lynden-Bell, Ph.D. Professor of Astrophysics, Institute of Astronomy, The Observatories, University of Cambridge Richard D. McKelvey, Ph.D. Assistant Professor of Economics, Carnegie-Mellon University Robert P. Merrill, Sc.D. Herbert Fisk Johnson Professor of Chemical Engineering, Cornell University

Matthew Meselson, Ph.D.
Thomas Dudley Cabot Professor of the Natural Sciences, Harvard University
Walter Munk, Ph.D.
Professor and Director, Institute of Geophysics, University of California at San Diego
J. R. Anthony Pearson, Sc.D.
Professor of Chemical Engineering, Imperial College
Alexander M. Polyakov, Ph.D.
Senior Research Scientist, Landau Institute of Theoretical Physics, All-Union Academy
of Sciences, USSR
Reuven Ramaty, Ph.D.
Head, Theoretical Section, AST Fields and Particles Laboratory for High Energy
Astrophysics, Goddard Space Flight Center
Stuart A. Rice, Ph.D.
Louis Block Professor and Chairman, Department of Chemistry, The University
of Chicago
Frank M. Richter, Ph.D.
Assistant Professor of Geophysics, The University of Chicago
Ronald Shreve, Ph.D.
Professor of Geology and Geophysics, University of California at Los Angeles
Valentine L. Telegdi, Ph.D.
Professor of Physics, The University of Chicago

### **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.

Part-time Staff David E. Beck, B.A. Dean G. Bond, B.A. Donald R. Cameron, B.Sc. Harold G. Cassriel, B.S. George Clovis Edward T. Preisler, B.A. Edwin Spencer, B.S.

Jack Giles John L. Lamb Elizabeth Oberstein, M.A. 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.

# Willis H. Booth Computing Center

Charles B. Ray, Director Kiku Matsumoto, Deputy Director

### **Environmental Quality Laboratory**

Norman H. Brooks, Director

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<sup>1</sup>Executive Committee <sup>2</sup>On leave, Fall term, 1978-79

#### **Research Staff**

Ronald Braeutigam, Visiting Assistant Professor of Economics Norman H. Brooks, Director; James Irvine Professor of Environmental and Civil Engineering William M. Brown III, Hydrologist (on assignment to EQL by U.S. Geological Survey) Glen R. Cass, Senior Research Fellow and Instructor in Environmental Engineering Science John Ferejohn, Professor of Political Science Richard C. Flagan, Assistant Professor of Environmental Engineering Science Robert E. Forsythe, Assistant Professor of Economics Morton Isaacson, Research Engineer Robert C. Y. Koh, Research Associate in Environmental Engineering Science Lester Lees, Professor of Environmental Engineering Science and Aeronautics E. John List, Professor of Environmental Engineering Science James J. Morgan, Professor of Environmental Engineering Science Roger G. Noll, Professor of Economics R. Talbot Page, Visiting Associate in Economics James P. Quirk, Professor of Economics John H. Seinfeld, Professor of Chemical Engineering Frederick H. Shair, Professor of Chemical Engineering Brent D. Taylor, Senior Research Engineer Wade Wells, Hydrologist (on assignment to EQL by U.S. Forest Service)

#### Consultant

James E. Krier, Professor of Law, Stanford University

#### Graduate Students 1977-78

Joel A. Balbien (Social Science) William Brownlie (Engineering) Edward W. Fall (Geology) Robert Hahn (Social Science) James E. Houseworth (Engineering) Mark Isaac (Social Science) Gregory John McRae (Engineering) John P. Schmitz (Social Science) Lee Sparling (Social Science) Lloyd Townley (Engineering)

### Hale Observatories

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Allan R. Sandage Wallace L. W. Sargent Maarten Schmidt, Chairman

## **Staff Members**

Halton C. Arp, Ph.D.	S. Eric Persson, Ph.D.
Horace W. Babcock, Ph.D., Sc.D.	George W. Preston, Ph.D.
Judith G. Cohen, Ph.D.	Allan R. Sandage, Ph.D., Sc.D., D.Sc., LL.D.
Jesse L. Greenstein, Ph.D.	Wallace L. W. Sargent, Ph.D.
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Robert F. Howard, Ph.D.	Leonard Searle, Ph.D.
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Gerry Neugebauer, Ph.D.	James A. Westphal, B.S.
J. Beverley Oke, Ph.D.	Harold Zirin, Ph.D.

#### **Staff Associates**

Robert J. Brucato, Ph.D. B. Thomas Soifer, Ph.D. Michael W. Werner, Ph.D.

#### Senior Research Fellows

Alan M. Dressler, Ph.D. Thomas R. Geballe, Ph.D. Ronald Moore, Ph.D. Robert J. Zinn, Ph.D.

#### **Research Fellows**

Thomas B. Ake III, Ph.D. Gary S. Da Costa, Ph.D. Richard F. Green, Ph.D. Robert C. Kennicutt, Jr., Ph.D. Barry J. LaBonte, Ph.D. Stefan Mochnacki, Ph.D. Jeremy R. Mould, Ph.D. James A. Rose, Ph.D. Anneila I. Sargent, Ph.D. Robert A. Schommer, Ph.D.

# **Health Center**

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

# **Industrial Relations Center**

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

# Jet Propulsion Laboratory

Administered by Caltech for the National Aeronautics and Space Administration

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

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Trustee, Caltech	Development, Hewlett-Packard	
Dr. Eugene G. Fubini	Company	
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Dr. John Gardner	Professor of Biology, Dean of	
Chairman, President's Commission on	Students, and Vice President for	
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William R. Kenan, Jr. Professor and	Co-Director, Stanford Center for Radar	
Professor of Chemistry, and Chairman	Astronomy, Stanford University	
of the Division of Chemistry and	Dr. John R. Pierce	
Chemical Engineering Caltech	Professor of Engineering, Caltech	

 Mr. Stanley R. Rawn, Jr.
 Dr.

 Caltech Trustee, and President,
 Marline Resources Company, Inc.

 Mary L. Scranton
 Dr.

 Caltech Trustee
 Dr.

 Dr. Robert P. Sharp
 Professor of Geology, Caltech

Dr. John M. Teem President, Association of Universities for Research in Astronomy, Inc. (AURA) Dr. Rochus E. Vogt Professor of Physics, Chairman of the Division of Physics, Mathematics and Astronomy, Caltech

# **Institute Libraries**

Johanna E. Tallman, Director

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

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# **Musical Activities**

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

# OFFICERS AND FACULTY

- Marvin Leonard Goldberger, Ph.D., President; Professor of Physics B.S., Carnegie Institute of Technology, 1943; Ph.D., The University of Chicago, 1948. California Institute, 1978-.
- Ahmed Mansour Abdel-Ghaffar, Ph.D., Research Fellow in Civil Engineering B.Sc., Cairo University, 1970; M.S., California Institute, 1973; Ph.D., 1976. Research Fellow, 1976-.
- Katsuyuki Abe, Ph.D., Senior Research Fellow in Geophysics B.S., University of Tokyo, 1968; Ph.D., 1973. California Institute, 1977.
- Allan James Acosta, Ph.D., Professor of Mechanical Engineering B.S., California Institute, 1945; M.S., 1949; Ph.D., 1952. Assistant Professor, 1954-58; Associate Professor, 1958-66; Professor, 1966-.
- Gerald S. Adams, Ph.D., Visiting Associate in Chemistry B.S., University of Washington, 1966; Ph.D., Oregon State University, 1970. Professor, Whittier College, 1976-. California Institute, 1978.
- Andreas Aebi, Ph.D., Lecturer in German M.A., University of Southern California, 1970; Ph.D., 1974. Lecturer in French, California Institute, 1978; Lecturer in German, 1978-79.
- William Scott Agnew, Ph.D., Research Fellow in Chemistry A.B., University of California (Los Angeles), 1968; Ph.D., 1976. California Institute, 1976-.
- Thomas J. Ahrens, Ph.D., Professor of Geophysics B.S., Massachusetts Institute of Technology, 1957; M.S., California Institute, 1958; Ph.D., Rensselaer Polytechnic Institute, 1962. Associate Professor, California Institute, 1967-76; Professor, 1976.
- Makoto Aihara, Ph.D., Visiting Associate in Chemistry B.S., Kyushu University, 1963; M.S., 1965; Ph.D., 1971. Associate Professor, Fukuoka Women's University, 1974-. California Institute, 1977-78.
- Thomas Bellis Ake III, Ph.D., Research Fellow in Astronomy B.S., Case Western Reserve University, 1971; M.S., 1974; Ph.D., 1977. California Institute, 1978-79.
- J. Edward Akin, Ph.D., Visiting Associate in Applied Mechanics B.S., Tennessee Polytechnic Institute, 1964; M.S., 1966; Ph.D., Virginia Polytechnic Institute, 1968. Professor, University of Tennessee, 1968. California Institute, 1978.
- Francis C. A. Albarede, Ph.D., Research Fellow in Geochemistry B.A., Université de Montpellier, 1964; M.S., 1971; Ph.D., Université de Paris, 1976. California Institute, 1977-.
- Arden Leroy Albee, Ph.D., Professor of Geology; Academic Officer, Geological and Planetary Sciences

A.B., Harvard College, 1950; A.M., Harvard University, 1951; Ph.D., 1957. Visiting Assistant Professor, California Institute, 1959-60; Associate Professor, 1969-66; Professor, 1966-; Academic Officer, 1971-.

- Clarence Roderic Allen, Ph.D., Professor of Geology and Geophysics B.A., Reed College, 1949; M.S., California Institute, 1951; Ph.D., 1954. Assistant Professor, 1955-59; Associate Professor, 1959-64; Professor, 1964.. Interim Director of Seismological Laboratory, 1965-67; Acting Chairman, Division of Geology. 1967-68.
- John Morgan Allman, Ph.D., Associate Professor of Biology B.A., University of Virginia, 1965; A.M., The University of Chicago, 1968; Ph.D., 1971. Assistant Professor, California Institute, 1974-77; Associate Professor, 1977-.
- J. L. Alperin, Ph.D., Visiting Associate in Mathematics A.B., Harvard University, 1959; A.M., Princeton University, 1960; Ph.D., 1961. Professor, The University of Chicago, 1970-. California Institute, 1978-79.
- Ralph Leonard Amey, Ph.D., Visiting Associate in Chemistry A.B., Pomona College, 1959; Ph.D., Brown University, 1963. Associate Professor, Occidental College, 1965-. California Institute, 1977-78.
- (KF) Supported by the Koepfli Fund (LOA) Leave of Absence (PT) Part Time

of Physics, Emeritus

B.S., California Institute, 1927; Ph.D., 1930. Research Fellow, 1930-33; Assistant Professor, 1933-37; Associate Professor, 1937-39; Professor, 1939-76; Chairman, Division of Physics, Mathematics and Astronomy, 1962-70; Board of Trustees Professor Emeritus, 1976-. David Maurice Anderson, Ph.D., Research Fellow in Biology B.A., California State University (Fresno), 1970; M.A., 1972; Ph.D., Purdue University, 1977. California Institute, 1977-. Don Lynn Anderson, Ph.D., Professor of Geophysics; Director, Seismological Laboratory B.S., Rensselaer Polytechnic Institute, 1955; M.S., California Institute, 1958; Ph.D., 1962. Research Fellow, 1962-63; Assistant Professor, 1963-64; Associate Professor, 1964-68; Professor, 1968-; Director, 1967-. Fred Colvig Anson, Ph.D., Professor of Chemistry B.S., California Institute, 1954; Ph.D., Harvard University, 1957. Instructor, California Institute, 1957-58; Assistant Professor, 1958-62; Associate Professor, 1962-68; Professor, 1968-; Executive Officer for Chemistry, 1973-Tom M. Apostol, Ph.D., Professor of Mathematics B.S., University of Washington, 1944; M.S., 1946; Ph.D., University of California, 1948. Assistant Professor, California Institute, 1950-56; Associate Professor, 1956-62; Professor, 1962-. Gordon Appleby, Ph.D., Mellon Postdoctoral Instructor in Anthropology A.B., Middlebury College, 1967; M.A., Stanford University, 1969; Ph.D., 1978. California Institute, 1978-. Johann Arbocz, Ph.D., Visiting Associate in Aeronautics B.S.A.E., Northrop Institute of Technology, 1963; M.S., California Institute, 1964; Ph.D., 1968. Professor of Aircraft Structures, Delft University of Technology, 1976-. Research Fellow, California Institute, 1968-71; Senior Research Fellow, 1971-75; Visiting Associate, 1977. Halton Christian Arp, Ph.D., Staff Member, Hale Observatories A.B., Harvard College, 1949; Ph.D., California Institute, 1953. Staff Member, Hale Observatories, 1957-. Paul D. Arthur, Ph.D., Visiting Associate in Aeronautics (PT) B.S., University of Maryland, 1944; M.S., 1944; Ph.D., California Institute, 1952. Professor, University of California (Irvine), 1968-. Visiting Associate, California Institute, 1978. James Patrick Ary, Ph.D., Research Fellow in Biology B.S., St. Mary's College of California, 1969; Ph.D., The Ohio State University, 1976. California Institute, 1976-. Marylouise Ary, Ph.D., Research Fellow in Biology B.A., Immaculate Heart College, 1969; Ph.D., University of California (Los Angeles), 1977. California Institute, 1977-78 Michael Aschbacher, Ph.D., Professor of Mathematics (LOA) B.S., California Institute, 1966; Ph.D., University of Wisconsin, 1969. Bateman Research Instructor, California Institute, 1970-72; Assistant Professor, 1972-74; Associate Professor, 1974-76; Professor, 1976-. Giuseppe Attardi, M.D., Professor of Biology M.D., University of Padua, 1947. Research Fellow, California Institute, 1959-60; Assistant Professor, 1963; Associate Professor, 1963-67; Professor, 1967-Charles Dwight Babcock, Jr., Ph.D., Professor of Aeronautics B.S., Purdue University, 1957; M.S., California Institute, 1958; Ph.D., 1962. Research Fellow, 1962-63; Assistant Professor, 1963-68; Associate Professor, 1968-74; Professor, 1974-. Horace Welcome Babcock, Ph.D., Sc.D., Staff Member, Hale Observatories B.S., California Institute, 1934; Ph.D., University of California, 1938. Staff Member, Hale Observatories, 1946-; Assistant Director, 1956-63; Associate Director, 1963-64; Director, 1964-78. Robert Fox Bacher, Ph.D., Sc.D., LL.D., Professor of Physics, Emeritus B.S., The University of Michigan, 1926; Ph.D., 1930; Sc.D., 1948. Professor of Physics, California Institute, 1949-76; Chairman, Division of Physics, Mathematics and Astronomy; Director, Norman Bridge Laboratory of Physics, 1949-62; Provost, 1962-70; Vice President and Provost, 1969-70; Professor Emeritus, 1976-. Stanley H. Bacon, Lecturer in Electrical Engineering (PT)California Institute, 1977-. James Frank Baker, Ph.D., Research Fellow in Biology B.S., Florida State University, 1972; Ph.D., Brown University, 1977. California Institute, 1976-.

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- Paul Bowerman, A.M., Professor of Modern Languages, Emeritus A.B., Dartmouth College, 1920; A.M., The University of Michigan, 1936. Instructor, California Institute, 1942-45; Assistant Professor, 1945-47; Associate Professor, 1947-69; Professor Emeritus, 1969-.
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- Bibiana Cujec, Ph.D., Visiting Associate in Physics Dipl., University of Ljubljana, 1950; Ph.D., 1959. Professor, Laval University, 1970-. California Institute, 1978-79.
- Slobodan M. Cuk, Ph.D., Assistant Professor of Electrical Engineering Dipl. Ing., Belgrade University, 1970; M.S.E.E., University of Santa Clara, 1974; Ph.D., California Institute, 1977. Lecturer (PT), 1977; Research Fellow, 1977; Assistant Professor, 1977-.
- Fred E. C. Culick, Ph.D., Professor of Applied Physics and Jet Propulsion (LOA) S.B., S.M., Massachusetts Institute of Technology, 1957; Ph.D., 1961. Research Fellow in Jet Propulsion, California Institute, 1961-63; Assistant Professor, 1963-66; Associate Professor, 1966-71; Professor, 1971-78; Professor of Applied Physics and Jet Propulsion, 1978.
- Nicholas A. Cumpsty, Ph.D., Visiting Associate in Jet Propulsion B.Sc., Imperial College (London), 1964; M.A., University of Cambridge, 1966; Ph.D., 1967. Senior Lecturer in Engineering and Senior Research Fellow, Turbomachinery Laboratory, 1976-. California Institute, 1974; 1978-79.
- Gary S. Da Costa, Ph.D., Research Fellow in Astronomy Ph.D., Australian National University, 1973. California Institute, 1977-78. Carnegie Fellow, Hale Observatories, 1977-.
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- Robert Long Daugherty, M.E., Professor of Mechanical and Hydraulic Engineering, Emeritus

A.B., Stanford University, 1909; M.E., 1914. California Institute. 1919-56; Professor Emeritus, 1956-.

- Cliff Ian Davidson, Ph.D., Research Fellow in Environmental Health Engineering B.S., Carnegie-Mellon University, 1972; M.S., California Institute, 1973; Ph.D., 1977. Research Fellow, 1977.
- Eric Harris Davidson, Ph.D., Professor of Biology
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- John Michael Davidson, Ph.D., Research Fellow in Physics A.B., University of California, 1966; M.S., University of Maryland, 1970; Ph.D., 1973. California Institute, 1976.
- Norman Ralph Davidson, Ph.D., Professor of Chemistry B.S., University of Chicago, 1937; B.Sc., Oxford University, 1938; Ph.D., University of Chicago, 1941. Instructor, California Institute, 1946-49, Assistant Professor, 1949-52; Associate Professor, 1952-57; Professor, 1957--Executive Officer for Chemistry, 1967-73.
- Lance Edwin Davis, Ph.D., Professor of Economics B.A., University of Washington, 1950; Ph.D., The Johns Hopkins University, 1956. California Institute, 1968-.
- Leverett Davis, Jr., Ph.D., Professor of Theoretical Physics B.S., Oregon State College, 1936; M.S., California Institute, 1938; Ph.D., 1941. Instructor, 1941-46; Assistant Professor, 1946-50; Associate Professor, 1950-56; Professor, 1956-.
- John Harold Dawson, Ph.D., Research Fellow in Chemistry A.B., Columbia University, 1972; Ph.D., Stanford University, 1976. California Institute, 1976.
- Richard Albert Dean, Ph.D., Professor of Mathematics B.S., California Institute, 1945; A.B., Denison University, 1947; M.S., The Ohio State University, 1948; Ph.D., 1953. Harry Bateman Research Fellow, California Institute, 1954-55; Assistant Professor, 1955-59; Associate Professor, 1959-66; Professor, 1966.
- Antonius Gerardus de Bruyn, Ph.D., Research Fellow in Astronomy Ph.D., State University, Leiden (The Netherlands), 1976. California Institute, 1976-77. Carnegie Fellow, Hale Observatories, 1976-.
- William Michael DeCampli, Ph.D., Research Fellow in Astrophysics B.S., Massachusetts Institute of Technology, 1973; M.A., Harvard University, 1974; Ph.D., 1978. California Institute, 1978-79.

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Max Delbrück, Ph.D., Sc.D., Nobel Laureate, Board of Trustees Professor of Biology, Emeritus

Ph.D., University of Göttingen, 1931. Research Fellow, California Institute, 1937-39; Professor, 1947-71; Albert Billings Ruddock Professor of Biology, 1971-77; Board of Trustees Professor Emeritus, 1977-.

- Walter Kamiel De Logi, Ph.D., Research Fellow in Electrical Engineering Ing., State University (Ghent, Belgium), 1973; M.S., California Institute, 1974; Ph.D., 1978. California Institute, 1978-79.
- Chang Chun-Tsan Deng, Ph.D., Research Fellow in Chemistry A.M., Duke University, 1971; Ph.D., University of California (San Francisco), 1976. California Institute, 1977-78.
- Michael Joseph DeNiro, Ph.D., Research Fellow in Geochemistry B.S., University of Notre Dame, 1970; Ph.D., California Institute, 1977. Research Fellow, 1977.
- Charles Raymond De Prima, Ph.D., Professor of Mathematics B.A., New York University, 1940; Ph.D., 1943. Assistant Professor of Applied Mechanics, California Institute, 1946-51; Associate Professor, 1951-56; Professor, 1956-64; Professor of Mathematics, 1964-.
- Peter B. Dervan, Ph.D., Assistant Professor of Chemistry B.S., Boston College, 1967; Ph.D., Yale University, 1972. California Institute, 1973-.
- John E. Dever, Jr., Ph.D., Visiting Associate in Biology B.A., Rutgers University, 1960; M.S., Oregon State University, 1962; Ph.D., Michigan State University, 1967. Associate Professor, Fort Lewis College, 1972-. California Institute, 1976-.
- George John Dick, Ph.D., Senior Research Fellow in Applied Physics A.B., Bethel College, 1961; Ph.D., University of California, 1969. Research Fellow, California Institute, 1969-73; Senior Research Fellow in Physics, 1973-75; Senior Research Fellow in Applied Physics, 1975-.
- Richard Earl Dickerson, Ph.D., Professor of Physical Chemistry B.S., Carnegie Institute of Technology, 1953; Ph.D., University of Minnesota, 1957. Associate Professor, California Institute, 1963-68; Professor, 1968.

- Jean O. Dickey, Ph.D., Research Fellow in Physics B.S., St. Francis College, 1967; M.S., Rutgers University, 1975; Ph.D., 1976. California Institute, 1977-.
- Robert Palmer Dilworth, Ph.D., Professor of Mathematics B.S., California Institute, 1936; Ph.D., 1939. Assistant Professor, 1943-45; Associate Professor, 1945-51; Professor, 1951-.
- Paul Emmanuel Dimotakis, Ph.D., Assistant Professor of Aeronautics and Applied Physics B.S., California Institute, 1968; M.S., 1969; Ph.D., 1973. Research Fellow, 1973-74; Research Fellow and Lecturer, 1974-75; Assistant Professor, 1975-.
- Douglas B. Dirks, Ph.D., Instructor in Asian History B.A., Wesleyan University, 1972; M.A., The University of Chicago, 1974; Ph.D., 1978. California Institute, 1978-79.
- Charles Hewitt Dix, Ph.D., Professor of Geophysics, Emeritus B.S., California Institute, 1927; A.M., Rice Institute, 1928; Ph.D., 1931. Associate Professor, California Institute, 1948-54; Professor, 1954-73; Professor Emeritus, 1973.
- Anthony G. Dixon, Ph.D., Research Fellow in Chemical Engineering B.Sc., Edinburgh University, 1975; Ph.D., 1978. California Institute, 1978-79.
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- William Jakob Dreyer, Ph.D., Professor of Biology B.A., Reed College, 1952; Ph.D., University of Washington, 1956. California Institute, 1963-.
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- Pol Edgard Duwez, D.Sc., Professor of Applied Physics and Materials Science, Emeritus Metallurgical Engineer, School of Mines, (Mons, Belgium), 1932; D.Sc., University of Brussels, 1933. Research Engineer, California Institute, 1942-47; Associate Professor, 1947-52; Professor, 1952-78; Professor Emeritus, 1978.
- Eliahu Dwek, Ph.D., Research Fellow in Physics M.Sc., The Hebrew University, 1973; Ph.D., Rice University, 1977. California Institute, 1977.

- Ranier Dyllick-Brenzinger, Ph.D., Research Fellow in Chemistry Dipl., Freiberg University, 1973; Ph.D., Swiss Federal Institute of Technology, 1977. California Institute, 1978-79.
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- Steven Edward Ealick, Ph.D., Research Fellow in Chemistry B.S., Oklahoma State University, 1972; Ph.D., University of Oklahoma, 1976. California Institute, 1978-79.
- William H. Eberhardt, Ph.D., Visiting Professor of Chemistry A.B., The Johns Hopkins University, 1941; Ph.D., California Institute, 1945. Regents Professor, Georgia Institute of Technology, 1955-. Visiting Professor, California Institute, 1978.
- Heinz E. Ellersieck, Ph.D., Associate Professor of History A.B., University of California (Los Angeles), 1942; M.A., 1948; Ph.D., 1955. Instructor, California Institute, 1950-55; Assistant Professor, 1955-60; Associate Professor, 1960-.
- David Clephan Elliot, Ph.D., Professor of History M.A., 5t. Andrew's University, 1939; A.M., Harvard University, 1948; Ph.D., 1951; M.A., Oxford University, 1956. Assistant Professor, California Institute, 1950-53; Associate Professor, 1953-60; Professor, 1960-; Executive Officer for the Humanities and Social Sciences, 1967-71.
- Sterling Emerson, Ph.D., Professor of Genetics, Emeritus B.Sc., Cornell University, 1922; M.A., University of Michigan, 1924; Ph.D., 1928. Assistant Professor, California Institute, 1928-37; Associate Professor, 1937-46; Professor, 1946-71; Professor Ementus, 1971-.
- Warren G. Emery, M.S., Director of Physical Education and Athletics B.S., University of Nebraska, 1948; M.S., University of California (Los Angeles), 1959. Coach, California Institute, 1955; Assistant Director of Physical Education and Athletics, 1963-64; Director, 1964-.
- Stuart Alan Ende, Ph.D., Associate Professor of English A.B., Cornell University, 1965; M.A., New York University, 1966; Ph.D., Cornell University, 1970. Assistant Professor, California Institute, 1970-74; Associate Professor, 1974-.
- Susan K. Ende, A.M., Lecturer in English A.B., Cornell University, 1965; A.M., 1970. Lecturer, California State University (PT), 1975-. California Institute, 1974-75; 1978.
- Per Henrik Enflo, Ph.D., Visiting Professor of Mathematics M.A., University of Stockholm, 1967; Ph.D., 1970. Professor, Stanford University, 1974-. California Institute, 1977.
- Sverre T. Eng, Dr.Tech., Visiting Associate in Electrical Engineering (PT) Dr.Tech., Chalmers University (Sweden), 1967. Professor, 1971-. California Institute, 1978.
- James Douglas Engel, Ph.D., Research Fellow in Chemistry B.A., University of California (San Diego), 1970; Ph.D., University of Oregon, 1975. California Institute, 1975.
- Christian Albertus Engelbrecht, Ph.D., Visiting Associate in Physics B.Sc., University of Pretoria, 1954; M.Sc., 1956; Ph.D., California Institute, 1960. Research Scientist, South African Atomic Energy Board, 1961-. Visiting Associate, California Institute, 1977-78.
- Hermann F. Engelhardt, Ph.D., Senior Research Fellow in Geophysics B.S., Munich Technical University, 1957; M.A., 1957; Ph.D., 1964. California Institute, 1976-
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- Susan Gwenn Ernst, Ph.D., Research Fellow in Biology M.S., Louisiana State University, 1969; Ph.D., University of Massachusetts, 1975. California Institute, 1975.
- Tezer Mehmet Esat, Ph.D., Research Fellow in Physics B.Sc., University College (London), 1971; M.Sc., Queen's University (Kingston), 1972; Ph.D., Australian National University, 1976. California Institute, 1976.
- Arturo P. Eslava, Ph.D., Visiting Associate in Biology Ph.D., University of Sevilla (Spain), 1973. Department of Genetics, Facultad de Biologia (Leon, Spain), 1977-. Research Fellow, California Institute, 1973-75; Visiting Associate, 1978.

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- Martin S. Ewing, Ph.D., Staff Member, Owens Valley Radio Observatory B.A., Swarthmore College, 1966. Ph.D., Massachusetts Institute of Technology, 1971. Research Fellow, California Institute, 1971-73; Staff Member, 1975-.
- C. Bernard Farmer, Ph.D., Visiting Professor of Planetary Science B.Sc., University of London, 1952; Ph.D., 1958. Sensor Member, Technical Staff, Jet Propulsion Laboratory, 1974-. California Institute, 1978-.
- Glennys R. Farrar, Ph.D., Senior Research Fellow in Theoretical Physics B.A., University of California, 1967; Ph.D., Princeton University, 1970. Senior Research Fellow, California Institute, 1973-74; Assistant Professor, 1974-78; Senior Research Fellow, 1978-79.
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   B.A., Queens College of the City of New York, 1964; M.A., The University of Wisconsin, 1966; Ph.D., California School of Professional Psychology, 1976. California Institute, 1978.
- Peter Ward Fay, Ph.D., Professor of History A.B., Harvard College, 1947; B.A., Oxford University, 1949; Ph.D., Harvard University, 1954. Assistant Professor, California Institute, 1955-60; Associate Professor, 1960-70; Professor, 1970-.
- Pierre Fayet, Ph.D., Visiting Associate in Theoretical Physics Ph.D., École Normale Supérieure, 1972. Centre National de la Recherche Scientifique, 1972-. California Institute, 1977-.
- Dan Fekete, Ph.D., Weizmann Research Fellow in Applied Physics B.Sc., Hebrew University of Jerusalem, 1968; M.Sc., 1971; Ph.D., 1977. California Institute, 1977-.
- Thomas E. Felter, Ph.D., Research Fellow in Chemical Engineering B.S., University of California (Santa Cruz), 1970; M.Sc., Brown University, 1973; Ph.D., 1977. California Institute, 1978-79.
- Derek Henry Fender, Ph.D., Professor of Biology and Applied Science B.Sc. Reading University (England), 1939; M.Sc., 1946; Ph.D., 1956. Senior Research Fellow in Engineering, California Institute, 1961-62; Associate Professor of Biology and Electrical Engineering, 1962-66; Professor of Biology and Applied Science, 1966-.
- John Ferejohn, Ph.D., Professor of Political Science B.A., San Fernando Valley State College, 1966; Ph.D., Stanford University, 1971. Assistant Professor, California Institute, 1971-74; Associate Professor, 1974-77; Professor, 1977-.
- John R. Ferron, Ph.D., Visiting Professor in Chemical Engineering (KF) B.ChE., University of Minnesota, 1948; M.S., 1950; Ph.D., The University of Wisconsin, 1958. Professor, University of Delaware, 1969-. California Institute, 1978-79.
- Richard Phillips Feynman, Ph.D., Nobel Laureate, Richard Chace Tolman Professor of Theoretical Physics

B.S., Massachusetts Institute of Technology, 1939; Ph.D., Princeton University, 1942. Visiting Professor, California Institute, 1950; Professor, 1950-59; Tolman Professor, 1959-.

- Richard D. Field, Jr., Ph.D., Research Associate in Theoretical Physics B.S., University of California, 1966; Ph.D., 1971. Research Fellow, California Institute, 1973-75; Senior Research Fellow, 1975-78; Research Associate, 1978-.
- Timothy David Field, Ph.D., Spencer Research Fellow in Biology B.S., The Ohio State University, 1974; Ph.D., University of Southern California, 1977. California Institute, 1977-78.
- Malcolm Edwin Finbow, Ph.D., Research Fellow in Biology B.Sc., Heriot-Watt University (Edinburgh), 1973; Ph.D., University of Glasgow, 1976. California Institute, 1976-.

- Morris P. Fiorina, Ph.D., Professor of Political Science
  - B.A., Allegheny College, 1968; Ph.D., The University of Rochester, 1972. Assistant Professor, California Institute, 1972-74; Associate Professor, 1974-77; Professor, 1977-.
- Wladyslaw Fiszdon, D.Sc., Sherman Fairchild Distinguished Scholar D.Sc., Technical University of Warsaw, 1951. Head of Fluid Dynamics Department, Institute of Basic Technological Problems, Polish Academy of Sciences, 1962-; Professor of Mathematics and Mechanics, University of Warsaw, 1970-. Visiting Professor, California Institute, 1966-67; Sherman Fairchild Distinguished Scholar, 1978-79.
- Richard Charles Flagan, Ph.D., Assistant Professor of Environmental Engineering Science B.S.E., The University of Michigan, 1969; S.M., Massachusetts Institute of Technology, 1971; Ph.D., 1973. California Institute, 1975.
- Arne Woolsey Fliflet, Ph.D., Research Fellow in Chemistry B.Sc., Duke University, 1970; Ph.D., University of Virginia, 1975. California Institute, 1975.
- Richard M. Foote, Ph.D., Bateman Research Instructor in Mathematics B.Sc., University of Toronto, 1972; Ph.D., University of Cambridge, 1976. California Institute, 1976-.
- Bengt Fornberg, Ph.D., Assistant Professor of Applied Mathematics B.S., Uppsala University, 1969; Ph.D., 1972. Bateman Research Instructor, California Institute, 1974-75; Assistant Professor, 1975-.
- Robert Elliott Forsythe, Ph.D., Assistant Professor of Economics B.S., The Pennsylvania State University, 1970; M.S., Carnegie Institute of Technology, 1972; M.S., Graduate School of Industrial Administration, Carnegie-Mellon University, 1974; Ph.D., 1975. California Institute, 1975.
- William Alfred Fowler, Ph.D., D.Sc., Institute Professor of Physics B.Eng., The Ohio State University, 1933; Ph.D., California Institute, 1936. Research Fellow, 1936-39; Assistant Professor, 1939-42; Associate Professor, 1942-46; Professor, 1946-70; Institute Professor, 1970-.
- Geoffrey Charles Fox, Ph.D., Associate Professor of Theoretical Physics
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- Giorgio Franceschetti, Ph.D., Visiting Associate in Electrical Engineering
   B.S., University of Naples, 1959; M.S., Higher Institute for Telecommunications (Rome), 1961; Ph.D., University of Naples, 1965. Professor, 1968-. California Institute, 1973-74; 1978.
- Joel N. Franklin, Ph.D., Professor of Applied Mathematics B.S., Stanford University, 1950; Ph.D., 1953. Associate Professor of Applied Mechanics, California Institute, 1957-65; Professor of Applied Science, 1965-69; Professor of Applied Mathematics, 1969-.
- Steven Clark Frautschi, Ph.D., Professor of Theoretical Physics A.B., Harvard College, 1954; Ph.D., Stanford University, 1958. Assistant Professor, California Institute, 1962-64; Associate Professor, 1964-66; Professor, 1966.
- Henry Freiser, Ph.D., Visiting Associate in Chemistry
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- Patrice L. French, Ph.D., Visiting Associate in Biology (PT)
   B.A., Vanderbilt University, 1971; Ph.D., University of Illinois (Champaign), 1974. Assistant Professor of Psychology, University of California (Los Angeles), 1977-. California Institute, 1978-79.
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Francis Brock Fuller, Ph.D., Professor of Mathematics A.B., Princeton University, 1949; M.A., 1950; Ph.D., 1952. Research Fellow, California Institute, 1952-55; Assistant Professor, 1955-59; Associate Professor, 1959-66; Professor, 1966-. Eric A. Fyrberg, Ph.D., Research Fellow in Chemistry

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- Robert R. Gagné, Ph.D., Assistant Professor of Chemistry B.S., Worcester Polytechnic Institute, 1969; Ph.D., Stanford University, 1974. Arthur Amos Noyes Research Instructor in Chemistry, California Institute, 1974-76; Assistant Professor, 1976.
- Laszlo Gal, Dr.Eng., Visiting Associate in Applied Physics Dr.Eng., Budapest Technical University, 1975. Magnetics Group, Central Research Institute for Physics, Hungarian Academy of Sciences, 1975-. California Institute, 1977.
- Barry Stuart Ganetzky, Ph.D., Research Fellow in Biology B.S., University of Illinois, 1971; Ph.D., University of Washington, 1976. California Institute, 1976-.
- Gordon Paul Garmire, Ph.D., Professor of Physics A.B., Harvard College, 1959; Ph.D., Massachusetts Institute of Technology, 1962. Senior Research Fellow, California Institute, 1966-68; Associate Professor, 1968-72; Professor, 1972-.
- Gregory Gartrell, Jr., Ph.D., Weizmann Research Fellow in Environmental Engineering Science

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- Ian Gatley, Ph.D., Research Fellow in Physics B.S., Imperial College, University of London, 1972; Ph.D., California Institute, 1978. Research Fellow, 1977-78.
- George Rousetos Gavalas, Ph.D., Professor of Chemical Engineering B.S., Technical University of Athens, 1958; M.S., University of Minnesota, 1962; Ph.D., 1964. Assistant Professor, California Institute, 1964-67; Associate Professor, 1967-75; Professor, 1975.
- Thomas R. Geballe, Ph.D., Senior Research Fellow in Astronomy Ph.D., University of California, 1974. Research Fellow, California Institute, 1977-78; Senior Research Fellow, 1978-; Hale Observatories, 1978-; Carnegie Fellow, Las Campanas Observatory, 1977.
- Robert James Geller, Ph.D., Research Fellow in Geophysics B.S., California Institute, 1973; M.S., 1975; Ph.D., 1977. Research Fellow, 1977-78.
- Murray Gell-Mann, Ph.D., Sc.D., D.Sc., Nobel Laureate, Robert Andrews Millikan Professor of Theoretical Physics
   B.S., Yale University, 1948; Ph.D., Massachusetts Institute of Technology, 1950. Associate Professor, California Institute, 1955-56; Professor, 1956-67; Millikan Professor, 1967-.
- Howard Gest, Ph.D., Visiting Associate in Biology B.A., University of California (Los Angeles), 1942; Ph.D., Washington University, 1949. Professor, Indiana University (Bloomington), 1966-. Research Fellow, California Institute, 1956-57; Visiting Associate, 1978.
- Horace Nathaniel Gilbert, M.B.A., D.B.A., Professor of Business Economics, Emeritus A.B., University of Washington, 1923; M.B.A., Harvard University, 1926. Assistant Professor, California Institute, 1929-30; Associate Professor, 1930-47; Professor, 1947-69; Professor Emeritus, 1969-.
- George Glauberman, Ph.D., Visiting Associate in Mathematics B.S., Harvard University, 1961; M.A., The University of Wisconsin, 1962; Ph.D., 1965. Professor, The University of Chicago, 1970-. California Institute, 1978.
- M. Michael Glovsky, M.D., Visiting Associate in Chemistry B.S., Tufts University, 1957; M.D., Tufts Medical School, 1962. Chief, Department of Allergy and Clinical Immunology, Kaiser Permanente Medical Group, 1974-; Associate Clinical Professor of Medicine, University of California (Los Angeles), 1976-. California Institute, 1977-.
- William Andrew Goddard III, Ph.D., Professor of Chemistry and Applied Physics B.S., University of California (Los Angeles), 1960; Ph.D., California Institute, 1965. Noyes Research Fellow in Chemistry, 1964-66; Noyes Research Instructor, 1966-67; Assistant Professor of Theoretical Chemistry, 1967-71; Associate Professor, 1971-74; Professor, 1974-78; Professor of Chemistry and Applied Physics, 1978-.
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- David Louis Goodstein, Ph.D., Professor of Physics and Applied Physics B.S., Brooklyn College, 1960; Ph.D., University of Washington, 1965. Research Fellow, California Institute, 1966-67; Assistant Professor of Physics, 1967-71; Associate Professor, 1971-75; Associate Professor of Physics and Applied Physics, 1975-76; Professor, 1976-.
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- Robert Davis Gray, B.S., Professor of Economics (PT)
   B.S., Wharton School of Finance and Commerce, University of Pennsylvania, 1930. Associate Professor of Economics and Industrial Relations, California Institute, 1940-42; Professor, 1942-78; Professor of Economics, 1978; Director, Industrial Relations Center, 1941-77, Acting Director, 1977-78.
- Richard Frederick Green, Ph.D., Research Fellow in Astronomy A.B., Harvard University, 1971; Ph.D., California Institute, 1977. Research Fellow, 1977.

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- Karen Faye Greif, Ph.D., Research Fellow in Biology A.B., Brown University, 1973; Ph.D., California Institute, 1978; Research Fellow, 1978.
- David M. Grether, Ph.D., Professor of Economics B.S., University of California, 1960, Ph.D., Stanford University, 1969. Associate Professor, California Institute, 1970-74; Professor, 1974-.
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- Rudolf Grossmayer, Dr.Tech.Sci., Max Kade Visiting Associate in Applied Mechanics Dipl.Ing., Technical University of Vienna, 1972; Dr.Tech.Sci., 1975. Assistant Professor, 1972-. California Institute, 1978-79.
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- Alan Andrew Hahn, Ph.D., Research Fellow in Physics B.S., University of Florida, 1972; Ph.D., California Institute, 1977. Research Fellow, 1978-79.
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- Marshall Hall, Jr., Ph.D., IBM Professor of Mathematics B.A., Yale University, 1932; Ph.D., 1936. Professor, California Institute, 1959-73; Executive Officer for Mathematics, 1966-69; IBM Professor, 1973.
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- Eri Heller, Ph.D., Spencer Senior Research Fellow in Biology B.Sc., Israel Institute of Technology, 1964; M.Sc., Hebrew University of Jerusalem, 1965; Ph.D., Weizmann Institute of Science, 1969. Research Fellow, California Institute, 1969-73; Senior Research Fellow, 1973-75; 1977-.
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- Leroy E. Hood, M.D., Ph.D., Ethel Wilson Bowles and Robert Bowles Professor of Biology B.S., California Institute, 1960; M.D., The Johns Hopkins University, 1964; Ph.D., California Institute, 1968. Assistant Professor, 1970-73; Associate Professor, 1973-75; Professor, 1975-77; Bowles Professor, 1977-.
- Norman Harold Horowitz, Ph.D., Professor of Biology; Chairman of the Division of Biology B.S., University of Pittsburgh, 1936; Ph.D., California Institute, 1939. Research Fellow, 1940-42; Senior Research Fellow, 1946-47; Associate Professor, 1947-53; Professor, 1953-; Executive Officer for Biology, 1971-76; Acting Chairman, Divison of Biology, 1973; Chairman, 1977-.
- George William Housner, Ph.D., Carl F Braun Professor of Engineering B.S., The University of Michigan, 1933; M.S., California Institute, 1934; Ph.D., 1941. Assistant Professor, 1945-49; Associate Professor, 1949-53; Professor, 1953-74; Braun Professor, 1974-.
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- Floyd Bernard Humphrey, Ph.D., Professor of Electrical Engineering and Applied Physics B.S., California Institute, 1950; Ph.D., 1956. Senior Research Fellow, 1960-64; Associate Professor of Electrical Engineering, 1964-71; Professor, 1971-74; Professor of Electrical Engineering and Applied Physics, 1974-
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B.A., University of California (Los Angeles), 1945; M.S., 1949; Ph.D., Stanford University, 1956. Associate Dean of Graduate Studies, California Institute, 1971-; Lecturer, 1973-; Director of Admissions and Financial

B.S., Colorado State University, 1958; M.S., California Institute, 1960; Ph.D., 1963. Research Fellow in Civil Engineering, 1965, Assistant Professor of Applied Mechanics, 1966-68; Associate Professor, 1968-72; Professor, 1972-77; Professor of Civil Engineering and Applied Mechanics, 1977-; Executive Officer, 1975-.

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- William Lewis Johnson, Ph.D., Assistant Professor of Materials Science B.A., Hamilton College, 1970; Ph.D., California Institute, 1975. Assistant Professor, 1976-.
- Rolf Hans Joho, Dipl., Visiting Associate in Biology (PT) Dipl., Institute of Molecular Biology, University of Zurich, 1972. Research Fellow, Stanford University Medical Center, 1976-. California Institute, 1977-78.
- Louis Winchester Jones, A.B., Dean of Admissions, Emeritus A.B., Princeton University, 1922. Instructor in English, California Institute, 1925-37; Assistant Professor, 1937-43; Registrar, 1942-52; Associate Professor, 1943-68; Dean of Admissions; Director of Undergraduate Scholarships, 1937-68; Dean Emeritus, 1968.
- William Thomas Jones, Ph.D., Professor of Philosophy
   A.B., Swarthmore College, 1931; B.Litt., Oxford University, 1933; A.M., Princeton University, 1936; Ph.D., 1937. Visiting Professor, California Institute, 1970-72; Andrew W. Mellon Professor, 1972-73; Professor, 1973-.
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- Richard P. Junghans, Ph.D., Research Fellow in Chemistry A.B., Harvard College, 1971; Ph.D., University of California, 1975. California Institute, 1976-.
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- Leonard Konrad Kaczmarek, Ph.D., Spencer Senior Research Fellow in Biology B.Sc., University of London, 1968; M.Sc., D.I.C., 1969; Ph.D., 1971. California Institute, 1976.
- James T. Kajiya, Ph.D., Assistant Professor of Computer Science Ph.D., The University of Utah, 1978. California Institute, 1978-.
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- Arthur Louis Klein, Ph.D., Professor of Aeronautics, Emeritus B.S., California Institute, 1921; M.S., 1924; Ph.D., 1925. Research Fellow in Physics and Aeronautics, 1927-29; Assistant Professor of Aeronautics, 1929-34; Associate Professor, 1934-54; Professor, 1954-68; Professor Emeritus, 1968-.
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- James Kenyon Knowles, Ph.D., Professor of Applied Mechanics B.S., Massachusetts Institute of Technology, 1952; Ph.D., 1957. Assistant Professor, California Institute, 1958-61; Associate Professor, 1961-65; Professor, 1965-; Academic Officer, 1972-75.

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- Heinz-Otto Kreiss, Dr.Tech., Docent, Professor of Applied Mathematics Dipl., University of Hamburg, 1955; Lic., Royal Institute of Technology (Sweden), 1960; Dr.Tech., 1960; Docent, 1960. California Institute, 1978-.
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- Toshi Kubota, Ph.D., Professor of Aeronautics B.E., Tokyo University, 1947; M.S., California Institute, 1952; Ph.D., 1957. Research Fellow, 1957-59; Assistant Professor, 1959-63; Associate Professor, 1963-71; Professor, 1971-.
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- Roger Gordon Noll, Ph.D., Professor of Economics B.S., California Institute, 1962; A.M., Harvard University, 1965; Ph.D., 1967. Instructor, California Institute, 1965-67; Assistant Professor, 1967-69; Associate Professor, 1969-71; Professor, 1973-.
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- Denis G. Sargood, Ph.D., Visiting Associate in Physics B.Sc., University of Melbourne, 1950; M.Sc., 1959; Ph.D., 1965. Senior Lecturer, 1965-. California Institute, 1978.
- Adel F. Sarofim, Sc.D., Visiting Chevron Energy Professor B.A., Oxford University, 1955; S.M., Massachusetts Institute of Technology, 1957; Sc.D., 1962. Professor, 1972-. California Institute, 1979.
- James Donald Satterlee, Ph.D., Research Fellow in Chemistry B.A., Central Washington State College, 1970; M.S., 1971; Ph.D., University of California (Davis), 1975. California Institute, 1975.
- Helmut H. Schaefer, Ph.D., Visiting Professor of Mathematics Ph.D., University of Leipzig, 1951. Professor, University of Tübingen, 1963-. California Institute, 1978-79.
- William Palzer Schaefer, Ph.D., Research Associate in Chemistry B.S., Stanford University, 1952; M.S., University of California (Los Angeles), 1954; Ph.D., 1960. Instructor, California Institute, 1960-62; Assistant Professor, 1962-66; Senior Research Fellow, 1968-77; Research Associate, 1977. Assistant Director of Admissions, 1968-73; Registrar, 1971-77; Director of Financial Aid, 1973-77.
- James Francis Scheimer, Sc.D., Weizmann Research Fellow in Geophysics B.S., M.S., Stanford University, 1973; Sc.D., Massachusetts Institute of Technology, 1978. California Institute, 1978-79.
- Anton Roelof Schep, Ph.D., Instructor in Mathematics B.Sc., University of Leiden, 1974; Ph.D., 1977. California Institute, 1977.
- Michael Ira Schimerlik, Ph.D., Research Fellow in Chemistry B.S., Pennsylvania State University, 1971; Ph.D., University of Wisconsin, 1975. California Institute, 1975-.
- Maarten Schmidt, Ph.D., Sc.D., Professor of Astronomy; Director of the Hale Observatories Ph.D., University of Leiden, 1956; Sc.D., Yale University, 1966. Associate Professor, California Institute, 1959-64; Professor, 1964-; Executive Officer for Astronomy, 1972-75; Chairman, Division of Physics, Mathematics and Astronomy, 1975-78; Carnegie Fellow, Hale Observatories, 1966-58; Staff Member, 1959-; Director, 1978-.
- Raymond L. Schmidt, Ph.D., Visiting Associate in Chemical Engineering B.S., Florida Presbyterian College, 1964; Ph.D., Emory University, 1967. Associate Professor, University of New Orleans, 1972-. Research Fellow, California Institute, 1968-70; Visiting Associate, 1977-78.
- Robert Andrew Schommer, Ph.D., Research Fellow in Astronomy B.A., The University of Chicago, 1970; M.S., 1972; Ph.D., University of Washington, 1977. California Institute, 1977-78.
- Elma Schonbach, B.M., Lecturer in Music
- B.M., Cincinnati Conservatory of Music, 1939. Head of Music Department, Westridge School for Girls (Pasadena), 1971-. California Institute, 1976; 1977; 1978.
- Jonathan F. Schonfeld, Ph.D., Research Fellow in Theoretical Physics B.S., Yale University, 1972; M.A., Princeton University, 1973; Ph.D., 1975. California Institute, 1976-.
- Robert S. Schreiber, Ph.D., Research Fellow in Applied Mathematics A.B., Cornell University, 1972; M.S., Yale University, 1973; Ph.D., 1977. California Institute, 1977-.
- Walter Adolph Schroeder, Ph.D., Research Associate in Chemistry B.Sc., University of Nebraska, 1939; M.A., 1940; Ph.D., California Institute, 1943. Research Fellow, 1943-46; Senior Research Fellow, 1946-56; Research Associate, 1956.
- Joseph R. Schuh, Ph.D., Research Fellow in Chemistry B.S., Manhattan College, 1973; Ph.D., Cornell University, 1978. California Institute, 1978-79.
- Joseph R. Schwartz, Ph.D., Visiting Associate in Chemistry B.S., The University of Chicago, 1941; M.S., 1947; Ph.D., 1948. Professor, Loyola Marymount University, 1953-. California Institute, 1978.
- John Henry Schwarz, Ph.D., Research Associate in Theoretical Physics A.B., Harvard College, 1962; Ph.D., University of California, 1966. California Institute, 1972.
- Martin P. Schweizer, Ph.D., Visiting Associate in Chemistry B.A., University of California (Riverside), 1960; M.A., 1963; Ph.D., The Johns Hopkins University, 1968. Professor, Department of Pharmacological Science, School of Medicine, The University of Utah, 1978. California Institute, 1977-78.

- Frank Joseph Sciulli, Ph.D., Professor of Physics
- A.B., University of Pennsylvania, 1960; M.S., 1961; Ph.D., 1965. Research Fellow, California Institute, 1966-68; Assistant Professor, 1969-71; Associate Professor, 1971-76; Professor, 1976-.
- Margaret Y. Scott, Ph.D., Visiting Associate in Biology Ph.D., California Institute, 1976. Research Fellow, Jules Stein Eye Institute, 1977-. Visiting Associate, California Institute, 1977-.
- Ronald Fraser Scott, Sc.D., Professor of Civil Engineering B.Sc., Glasgow University, 1951; S.M., Massachusetts Institute of Technology, 1953; Sc.D., 1955. Assistant Professor, California Institute, 1958-62; Associate Professor, 1962-67; Professor, 1967-.
- Robert Alan Scranton, Ph.D., Research Fellow in Applied Physics B.S., California Institute, 1974; M.S., University of California, 1975; Ph.D., California Institute, 1978. Research Fellow, 1977-78.
- Thayer Scudder, Ph.D., Professor of Anthropology A.B., Harvard College, 1952; Ph.D., Harvard University, 1960. Assistant Professor, California Institute, 1964-66; Associate Professor, 1966-69; Professor, 1969-.
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- Ryoichi Seki, Ph.D., Visiting Associate in Physics B.S., Waseda University, 1962; Ph.D., Northeastern University, 1968. Professor, California State University (Northridge), 1976. California Institute, 1978.
- Luigi Sertorio, Ph.D., Visiting Associate in Theoretical Physics Professor, University of Turin, 1972. California Institute, 1977.
- Michael Herman Shaevitz, Ph.D., Senior Research Fellow in Physics B.Sc., The Ohio State University, 1969; Ph.D., 1975. Research Fellow, California Institute, 1975-78; Senior Research Fellow, 1978-.
- Rajiv Rajaram Shah, Ph.D., Weizmann Research Fellow in Chemistry B.Sc., University of Poona, 1972; M.S., Rice University, 1974; Ph.D., 1977. California Institute, 1976-.
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- Eugene Merle Shoemaker, Ph.D., Sc.D., Professor of Geology B.S., California Institute, 1947; M.S., 1948; M.S., Princeton University. 1954; Ph.D., 1960. Visiting Professor of Geology, California Institute, 1962; Research Associate in Astrogeology, 1964-68; Professor, 1969-; Chairman, Division of Geology, 1969-72.
- Ronald L. Shreve, Ph.D., Sherman Fairchild Distinguished Scholar B.S., California Institute, 1952; Ph.D., 1959. Professor of Geology and Geophysics, University of California (Los Angeles), 1969-. California Institute, 1978-79.
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- Donald W. Skelton, M.S., Lecturer in Physics B.A., California State College (Los Angeles), 1963; M.S., 1965. California Institute, 1977-.
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- James R. Smith, Ph.D., Research Fellow in Physics B.S., Clemson University, 1968; M.S., University of Virginia, 1971; Ph.D., University of Wyoming, 1976. California Institute, 1976-.
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- William Ralph Smythe, Ph.D., Professor of Physics, Emeritus A.B., Colorado College, 1916; A.M., Dartmouth College, 1919; Ph.D., University of Chicago, 1921. National Research Fellow, California Institute, 1923-26; Research Fellow, 1926-27; Assistant Professor, 1927-34; Associate Professor, 1934-40; Professor, 1940-64; Professor Emeritus, 1964.
- Baruch Thomas Soifer, Ph.D., Senior Research Fellow in Physics B.S., California Institute, 1968; Ph.D., Cornell University, 1972. Assistant Professor, University of California (San Diego), 1976. Senior Research Fellow, California Institute, 1978-; Staff Associate, Hale Observatories, 1978.
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- Roger Wolcott Sperry, Ph.D., D.Sc., Hixon Professor of Psychobiology A.B., Oberlin College, 1935; A.M., 1937; Ph.D., University of Chicago, 1941. California Institute, 1954-.
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- Michael E. Squillacote, Ph.D., Research Fellow in Chemistry B.S., The University of Chicago, 1972; Ph.D., University of California (Los Angeles), 1977. California Institute, 1977-.
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- Gabriel H. Srouji, Ph.D., Research Fellow in Chemistry B.S., Ouachita University, 1972; University of Tennessee (Knoxville), 1975; Ph.D., Emory University, 1978. California Institute, 1978-79.
- Thomas H. Stanton, Ph.D., Senior Research Fellow in Biology B.A., Western Maryland College, 1967; Ph.D., University of Alabama Medical Center, 1974. California Institute, 1977-78.
- Maureen B. Steiner, Ph.D., Senior Research Fellow in Geology and Geophysics
   B.S., Southern Methodist University, 1965; M.S., 1967; Ph.D., The University of Texas (Dallas), 1974. Research Fellow, California Institute, 1977-78; Senior Research Fellow, 1978-.
- Gregory N. Stephanopoulos, Ph.D., Assistant Professor of Chemical Engineering B.S., National Technical University (Athens), 1973; M.Sc., University of Florida, 1975; Ph.D., University of Minnesota, 1978. California Institute, 1978-.
- Alfred Stern, Ph.D., Professor of Philosophy, Emeritus Ph.D., University of Vienna, 1923. Instructor, California Institute, 1947-48; Lecturer, 1948-50; Assistant Professor, 1950-53; Associate Professor, 1953-60; Professor, 1960-68; Professor Emeritus, 1968-.

- Richard B. Stern, Ph.D., Research Fellow in Mathematics (PT) S.B., Massachusetts Institute of Technology, 1969; S.M., 1969; Ph.D., The University of Chicago, 1976. California Institute, 1977-78.
- Eli Sternberg, Ph.D., D.Sc., Professor of Mechanics B.C.E., University of North Carolina, 1941; M.S., Illinois Institute of Technology, 1942; Ph.D., 1945. Professor of Applied Mechanics, California Institute, 1964-70; Professor of Mechanics, 1970-.
- Paul R. Stevens, Ph.D., Senior Research Fellow in Theoretical Physics B.S., University of California (Los Angeles), 1965; M.S., 1966; Ph.D., 1969. Research Fellow, California Institute, 1972; 1974-75; Senior Research Fellow, 1975.
- Homer Joseph Stewart, Ph.D., Professor of Aeronautics B.Aero.E., University of Minnesota, 1936; Ph.D., California Institute, 1940. Instructor, 1939-42; Assistant Professor, 1942-46; Associate Professor, 1946-49; Professor, 1949-.
- Edward Carroll Stone, Jr., Ph.D., Professor of Physics
   M.S., University of Chicago, 1957; Ph.D., 1963. Research Fellow, California Institute, 1964-66; Senior Research Fellow, 1967; Assistant Professor, 1967-71; Associate Professor, 1971-76; Professor, 1976-.
- Ellen Glowacki Strauss, Ph.D., Senior Research Fellow in Biology B.A., Swarthmore College, 1960; Ph.D., California Institute, 1966. Research Fellow, 1969-73; Senior Research Fellow, 1973-.
- James Henry Strauss, Ph.D., Associate Professor of Biology B.S., Saint Mary's University, 1960; Ph.D., California Institute, 1967. Assistant Professor, 1969-75; Associate Professor, 1975-.
- Thomas Foster Strong, M.S., Dean of Freshmen, Emeritus B.S., University of Wisconsin, 1922; M.S., California Institute, 1937. Assistant Professor of Physics, 1944-65; Associate Professor, 1965-69; Dean of Freshmen, 1946-68; Dean Emeritus, 1969-.
- Felix Strumwasser, Ph.D., Professor of Biology B.A., University of California (Los Angeles), 1953; Ph.D., 1957. Associate Professor, California Institute, 1964-69; Professor, 1969.
- Bradford Sturtevant, Ph.D., Professor of Aeronautics B.E., Yale University, 1955; M.S., California Institute, 1956; Ph.D., 1960. Research Fellow, 1960-62; Assistant Professor, 1962-66; Associate Professor, 1966-71; Professor, 1971-; Executive Officer for Aeronautics, 1972-76.
- Jack W. Sulentic, Ph.D., Research Fellow in Astronomy B.S., University of Arizona, 1969; Ph.D., State University of New York (Albany), 1975. California Institute, 1975-76; Carnegie Fellow, Hale Observatories, 1975-.
- Ivan E. Sutherland, Ph.D., Fletcher Jones Professor of Computer Science B.S., Carnegie Institute of Technology, 1959; M.S., California.Institute, 1960; Ph.D., Massachusetts Institute of Technology, 1963. Professor of Computer Science, California Institute, 1976-77; Fletcher Jones Professor, 1977-.
- Henry H. Suzukawa, Jr., Ph.D., Research Fellow in Chemistry
   B.S., California Institute, 1967; Ph.D., University of California (Irvine), 1975. California Institute, 1976-.
- James E. Swartz, Ph.D., Research Fellow in Chemistry B.S., Stanislaus State College, 1973; Ph.D., University of California (Santa Cruz), 1978. California Institute, 1978-79.
- Alan R. Sweezy, Ph.D., Professor of Economics, Emeritus B.A., Harvard College, 1929; Ph.D., 1934. Visiting Professor, California Institute, 1949-50; Professor, 1950-77; Professor Emeritus, 1977.
- Ernest Haywood Swift, Ph.D., LL.D., Professor of Analytical Chemistry, Emeritus B.S., University of Virginia, 1918; M.S., California Institute, 1920; Ph.D., 1924. Instructor, California Institute, 1920-28: Assistant Professor, 1928-39: Associate Professor, 1939-43; Professor, 1943-67; Professor Emeritus, 1967. Chairman, Division of Chemistry and Chemical Engineering, 1958-63.
- Zygmunt Edward Switkowski, Ph.D., Visiting Associate in Physics B.Sc., University of Melbourne, 1969; Ph.D., 1973. Research Fellow, California Institute, 1973-74; Senior Research Fellow, 1974-76; Visiting Associate; 1976; 1977; 1978.
- Roque Kwok-Hung Szeto, Ph.D., Research Fellow in Applied Mathematics B.S., New York University, 1972; Ph.D., California Institute, 1978. Research Fellow, 1978-79.

- Paula Szkody, Ph.D., Visiting Associate in Astronomy B.S., University of Washington, 1970; M.S., 1972; Ph.D., 1975. Research Associate, 1975-. California Institute, 1978.
- Johanna E. Tallman, Certificate in Librarianship, Director of Libraries A.B., University of California, 1936; Certificate in Librarianship, 1937. California Institute, 1973-.
- Yoram Tambour, Ph.D., Research Fellow in Chemical Engineering B.Sc., Israel Institute of Technology (Haifa), 1972; Ph.D., 1977. California Institute, 1978-79.
- Steven Paul Tanis, Ph.D., Research Fellow in Chemistry B.A., Rutgers University, 1974; Ph.D., Columbia University, California Institute, 1978-79.
- Mark Allen Tanouye, Ph.D., Research Fellow in Biology A.B., Stanford University, 1972; A.M., 1973; Ph.D., Yale University, 1978. California Institute, 1978-79.
- Hugh Pettingill Taylor, Jr., Ph.D., Professor of Geology B.S., California Institute, 1954; A.M., Harvard University, 1955; Ph.D., California Institute, 1959. Assistant Professor, 1959-61; Research Fellow, 1961; Assistant Professor, 1962-64; Associate Professor, 1964-69; Professor, 1969-.
- Murray F. Teitell, Ph.D., Research Fellow in Biology B.A., Temple University, 1969; Ph.D., University of Texas, 1977. California Institute, 1977.
- Valentine L. Telegdi, Ph.D., Sherman Fairchild Distinguished Scholar M.Sc., Lausanne University, 1946; Ph.D., Swiss Federal Institute of Technology, 1950. Enrico Fermi Distinguished Service Professor, The University of Chicago, 1971-. California Institute, 1978-79.
- Matilde Pasqua Teleman, Laurea, Visiting Associate in Physics Laurea, Rome University, 1970. Italian Public Education Ministry Associate, 1975-. California Institute, 1977-78.
- Neculai Teleman, Ph.D., Bateman Research Instructor in Mathematics M.S., Bucharest University, 1967; Ph.D., Massachusetts Institute of Technology, 1977. California Institute, 1977.
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- Frederick Burtis Thompson, Ph.D., Professor of Applied Philosophy and Computer Science A.B., University of California (Los Angeles), 1946; M.A., 1947; Ph.D., University of California, 1952. Professor of Applied Science and Philosophy, California Institute, 1965-77; Professor of Applied Philosophy and Computer Science, 1977.
- Kip Stephen Thorne, Ph.D., Professor of Theoretical Physics B.S., California Institute, 1962; Ph.D., Princeton University, 1965. Research Fellow in Physics, California Institute, 1966-67; Associate Professor of Theoretical Physics, 1967-70; Professor, 1970-.
- John Todd, B.Sc., Professor of Mathematics B.Sc., Queen's University (Ireland), 1931. California Institute, 1957-.
- Olga Taussky Todd, Ph.D., Professor of Mathematics, Emeritus Ph.D., University of Vienna, 1930; M.A., University of Cambridge, 1937. Research Associate, California Institute, 1957-71; Professor, 1971-77; Professor Emeritus, 1977-.
- Thomas Anthony Tombrello, Jr., Ph.D., Professor of Physics B.A., Rice University, 1958; M.A., 1960; Ph.D., 1961. Research Fellow, California Institute, 1961-62; 1964-65; Assistant Professor, 1965-67; Associate Professor, 1967-71; Professor, 1971-.
- John T. Trauger, Ph.D., Senior Research Fellow in Planetary Science B.A., Oberlin College, 1965; M.S., The University of Wisconsin (Madison), 1967; Ph.D., 1972. California Institute, 1978-.
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- Ray Edward Untereiner, J.D., Ph.D., Professor of Economics, Emeritus A.B., University of Redlands, 1920; M.A., Harvard University, 1921; J.D., Mayo College of Law, 1925; Ph.D., Northwestern University, 1932. Professor, California Institute, 1925-68; Professor Emeritus, 1968-.
- David C. Van Essen, Ph.D., Assistant Professor of Biology B.S., California Institute, 1967; Ph.D., Harvard University, 1971. California Institute, 1976-.
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- Gerard Vauclair, Ph.D., Visiting Associate in Astronomy Dipl., University of Paris, 1966; Ph.D., 1972. Director of Research, National Center for Scientific Research (Paris), 1972-. California Institute, 1978.
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Jean-Luc Vuilleumier, Dr.sc.nat., Research Fellow in Physics Dipl., Swiss Institute of Technology, 1971; Dr.sc.nat., 1975. California Institute, 1976-

David Bertram Wales, Ph.D., Professor of Mathematics; Associate Dean of Students B.S., University of British Columbia, 1961; M.A., 1962; Ph.D., Harvard University, 1967. Bateman Research Fellow, California Institute, 1967-68; Assistant Professor, 1968-71; Associate Professor, 1971-77; Professor, 1977-; Associate Dean, 1976-.

- Billy J. Walker, Ph.D., Visiting Associate in Aeronautics and Applied Mathematics B.S., University of Oklahoma, 1963; M.S., 1964; Ph.D., 1967. Research Aerospace Engineer, U.S. Army Missile R & D Command, 1969-. California Institute, 1978-79.
- Robert Craig Walker, Ph.D., Research Fellow in Radio Astronomy B.A., University of California (San Diego), 1971; Ph.D., Massachusetts Institute of Technology, 1977. California Institute, 1977-78.
- Robert Lee Walker, Ph.D., Professor of Physics; Executive Officer for Physics B.S., University of Chicago, 1941; Ph.D., Cornell University, 1948. Assistant Professor, California Institute, 1949-53; Associate Professor, 1953-59; Professor, 1959-; Executive Officer, 1976-.

Robert Bruce Wallace, Ph.D., Research Fellow in Biology B.Sc., Simon Fraser University, 1972; Ph.D., McMaster University, 1975. California Institute, 1975-.

Peter Wannier, Ph.D., Assistant Professor of Radio Astronomy B.S., Stanford University, 1968; Ph.D., Princeton University, 1974. California Institute, 1976-; Staff Member, Owens Valley Radio Observatory, 1976-.

- Richard Arland Ward, Ph.D., Research Fellow in Physics B.A., Rice University, 1971; M.S., 1974; Ph.D., 1976. California Institute, 1976-.
- David Andrew Wark, B.Sc., Visiting Associate in Geochemistry B.Sc., University of Melbourne, 1960. Senior Technical Officer and Research Associate, 1969-. California Institute, 1977-78.
- Robert Rodger Wark, Ph.D., Lecturer in Art (PT)
   B.A., University of Alberta, 1944; M.A., 1946; M.A., Harvard University, 1949; Ph.D., 1952. Curator of Art, Huntington Library and Art Gallery, 1956-. California Institute, 1961-.
- Gerald J. Wasserburg, Ph.D., Professor of Geology and Geophysics S.B., University of Chicago, 1951; S.M., 1952; Ph.D., 1954. Assistant Professor of Geology, California Institute, 1955-59; Associate Professor, 1959-62; Professor, 1962-63; Professor of Geology and Geophysics, 1963-.
- Iwao Watanabe, M.E., Visiting Associate in Engineering Science M.E., University of Tokyo, 1971. Ship Dynamics Division, Ship Research Institute, Ministry of Transport (Japan), 1971-. California Institute, 1978-79.
- Deborah Kay Watson, Ph.D., Research Fellow in Chemistry B.S., Allegheny College, 1972; M.A., Harvard University, 1973; Ph.D., 1977. California Institute, 1977-78.
- Marion J. Watson, M.Sc., Visiting Associate in Astrophysics M.Sc., Queen's University, 1962. Lecturer, Carleton University, 1965-. California Institute, 1978.

- J. Harold Wayland, Ph.D., D.Sc., Professor of Engineering Science (PT) B.S., University of Idaho, 1931; M.S., California Institute, 1935; Ph.D., 1937. Research Fellow in Mathematics. 1939-41; Associate Professor of Applied Mechanics, 1949-57; Professor, 1957-63; Professor of Engineering Science, 1963.
- Stephen V. Weber, Ph.D., Weizmann Research Fellow in Astrophysics A.B., Princeton University, 1973; Ph.D., University of California, 1978. California Institute, 1978-79.
- William Henry Weinberg, Ph.D., Professor of Chemical Engineering and Chemical Physics B.S., University of South Carolina, 1966; Ph.D., University of California, 1970. Assistant Professor of Chemical Engineering, California Institute, 1972-74; Associate Professor, 1974-77; Professor, 1977-78; Professor of Chemical Engineering and Chemical Physics, 1978.
- David Franklin Welch, I.D., Associate Professor of Engineering Design A.B., Stanford University, 1941; I.D., California Institute, 1943. Instructor in Engineering Graphics, 1943-51; Assistant Professor, 1951-61; Associate Professor of Engineering Design, 1961-.
- Robert Allen Weller, Jr., Ph.D., Research Fellow in Physics B.S., University of Tennessee, 1971; Ph.D., 1978. California Institute, 1978-79.
- Jost O. L. Wendt, Ph.D., Visiting Professor of Chemical Engineering B.Sc., University of Glasgow, 1963; M.S., The Johns Hopkins University, 1966; Ph.D., 1968. Associate Professor, University of Arizona, 1974-. California Institute, 1978-79.
- Michael W. Werner, Ph.D., Assistant Professor of Physics B.A., Haverford College, 1963; Ph.D., Cornell University, 1968. California Institute, 1972-. Staff Associate, Hale Observatories, 1973-.
- Geoffrey W. West, B.Sc., Visiting Associate in Chemical Engineering B.Sc., University of Melbourne, 1948. Principal Research Scientist, CSIRO (Australia), 1946-. California Institute, 1978.
- James Adolph Westphal, B.S., Professor of Planetary Science B.S., University of Tulsa, 1954. Senior Research Fellow, California Institute, 1966-71; Associate Professor, 1971-76; Professor, 1976-; Staff Associate, Hale Observatories, 1966-74; Staff Member, 1974-.
- Ward Whaling, Ph.D., Professor of Physics B.S., Rice University, 1944; M.A., 1947; Ph.D., 1949. Research Fellow, California Institute, 1949-52; Assistant Professor, 1952-58; Associate Professor, 1958-62; Professor, 1962-.
- Patricia A Wheeler, Ph.D., Research Fellow in Environmental Engineering Science B.A., University of California (Irvine), 1971; M.S., 1974; Ph.D., 1976. California Institute, 1976-.
- Kenneth T. Whitby, Ph.D., Visiting Associate in Environmental Engineering Science B.S., University of Minnesota, 1946; B.M.E., 1948; Ph.D., 1954. Professor, University of Minnesota, 1966-. California Institute, 1978.
- James Hall Whitcomb, Ph.D., Senior Research Fellow in Geophysics B.S., Colorado School of Mines, 1962; M.S., Oregon State University, 1965; Ph.D., California Institute, 1973. Senior Research Fellow, 1973-.
- Gerald Beresford Whitham, Ph.D., Professor of Applied Mathematics; Executive Officer for Applied Mathematics

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

- Mark Edward Wiedenbeck, Ph.D., Research Fellow in Physics B.S., The University of Michigan, 1971; Ph.D., California Institute, 1978. Research Fellow, 1978-79.
- Bernhard Wielke, Ph.D., Max Kade Visiting Associate in Materials Science Ph.D., University of Vienna, 1970. Associate Professor, Institute of Solid State Physics, 1977-, California Institute, 1978-79.
- Cornelis A. G. Wiersma, Ph.D., Professor of Biology, Emeritus B.A., University of Leiden, 1926; M.A., University of Utrecht, 1929; Ph.D., 1933. Associate Professor, California Institute, 1933-47; Professor, 1947-76; Professor Emeritus, 1976-.
- Ralph Ambrose Wiggins, Ph.D., Visiting Associate in Geophysics Ph.D., Massachusetts Institute of Technology, 1965. Scientist, Del Mar Technical Associates, 1976-. California Institute, 1978.

- John Edward Wiktorowicz, Ph.D., Research Fellow in Biology B.S., Illinois Institute of Technology, 1974; Ph.D., The University of Texas (Galveston), 1977. California Institute, 1978-79.
- Louis L. Wilde, Ph.D., Assistant Professor of Economics B.A., University of Iowa, 1972; M.A., The University of Rochester, 1975; Ph.D., 1976. California Institute, 1976.
- Karl Armonde Wilks, Ph.D., Weizmann Research Fellow in Chemical Engineering B.S., Case Western Reserve University, 1971; M.S., 1974; Ph.D., 1976. California Institute, 1976-.
- Ian Stuart Williams, Ph.D., Research Fellow in Geology B.Sc., Australian National University, 1974; Ph.D., 1977. California Institute, 1977-.
- Norma Patricia Williams, Ph.D., Visiting Associate in Biology B.S., Howard University, 1966; M.S., 1968; Ph.D., 1974. Assistant Professor, 1976-. California Institute, 1978.
- Charles Harold Wilts, Ph.D., Professor of Electrical Engineering and Applied Physics B.S., California Institute, 1940; M.S., 1941; Ph.D., 1948. Assistant Professor of Electrical Engineering, 1947-52; Associate Professor, 1952-57; Professor, 1957-74; Professor of Electrical Engineering and Applied Physics, 1974. Executive Officer for Electrical Engineering, 1972-75.
- Howard Winet, Ph.D., Visiting Associate in Engineering Science (PT)
   B.S., University of Illinois, 1959; M.A., University of California (Los Angeles), 1962; Ph.D., 1969. Associate Professor, College of Science, Southern Illinois University, 1977-. California Institute, 1978-79.
- Lester Winsberg, Ph.D., Visiting Associate in Physics B.S., The University of Chicago, 1942; Ph.D., 1947. Professor, University of Illinois at Chicago Circle, 1961-. California Institute, 1978-79.
- Andrew Wiseman, Ph.D., Research Fellow in Biology B.S., Duke University, 1970; Ph.D., 1975. California Institute, 1975-.
- Veit Witzemann, Dr.rer.nat., Research Fellow in Chemistry Dipl., Freiburg University, 1971; Dr.rer.nat., Konstanz University, 1974. California Institute, 1975-.
- Stanley T. Wolfberg, M.B.A., Lecturer in Engineering (PT)
   B.S., California Institute, 1938; M.B.A., Graduate School of Business, Stanford University, 1940. California Institute, 1971-. Lecturer, 1977-.
- David Shotwell Wood, Ph.D., Professor of Materials Science 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., Visiting Assistant Professor of Systems Engineering (PT) B.S., Cornell University, 1968; M.S., Stanford University, 1969; Ph.D., 1972. Member, Technical Staff, Jet Propulsion Laboratory, 1977. Bechtel Instructor in Engineering, California Institute, 1972-74; Lecturer, 1975-76; Visiting Assistant Professor, 1976.
- James Alan Woodhead, Ph.D., Research Fellow in Geology B.S., California Institute, 1969; M.A., Princeton University, 1972; Ph.D., 1976. California Institute, 1976-.
- 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.- Lectrurer in Electrical Engineering, California Institute, 1947-49; Research Associate, 1950-52; 1962-73; Visiting Associate, 1973.
- Dorothy Scholl Woolum, Ph.D., Visiting Associate in Geochemistry B.A., Cornell University, 1964; Ph.D., Washington University, 1971. Research Fellow in Geology and Physics, California Institute, 1971-74; Visiting Associate in Geochemistry, 1974; 1977-.
- John Carl Woolum, Ph.D., Senior Research Fellow in Biology B.A., University of Colorado, 1960; Ph.D., Cornell University, 1965. California Institute, 1976-.
- Chun-Fang Wu, Ph.D., Research Fellow in Biology B.S., Tunghai University, 1969; Ph.D., Purdue University, 1976. California Institute, 1976.
- James H. T. Wu, Ph.D., Visiting Associate in Aeronautics B.Eng., Tsing-Hua University, 1943; M.A.Sc., University of Toronto, 1950; Ph.D., McGill University, 1961. Associate Professor, 1959-. California Institute, 1978-79.

- 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-.
- Peter G. M. Wuts, Ph.D., Research Fellow in Chemistry B.S., University of Washington, 1973; Ph.D., Northwestern University, 1977. California Institute, 1977-.
- 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; 1977.
- Amos Yahil, Ph.D., Visiting Associate Professor of Astrophysics
   B.Sc., Hebrew University (Jerusalem), 1966; Ph.D., California Institute, 1970. Senior Lecturer in Physics, Tel Aviv University, 1975-. Visiting Associate, California Institute, 1977; 1978.
- S. Barbara Yancey, Ph.D., Research Fellow in Biology
   B.A., Whittier College, 1950; M.S., 1972; Ph.D., University of Southern California, 1977. California Institute, 1977.
- Fleur Belle Yano, Ph.D., Visiting Associate in Physics B.S., Columbia University, 1954; M.A., University of Southern California, 1958; Ph.D., The University of Rochester, 1966. Professor, California State University (Los Angeles), 1973-. California Institute, 1977-78.
- James T. P. Yao, Ph.D., Visiting Associate in Earthquake Engineering B.S., University of Illinois, 1957; M.S., 1958; Ph.D., 1961. Professor, Purdue University, 1971-. California Institute, 1978.
- Lun-Shin Yao, Ph.D., Research Fellow in Engineering Science B.S.E., National Cheng-Kung University, 1966; M.S., The University of Texas (Austin), 1969; Ph.D., University of California, 1974. California Institute, 1978-79.
- Armon 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-.
- George Thomas Yates, Ph.D., Research Fellow in Engineering Science B.S., Purdue University, 1971; M.S., California Institute, 1972; Ph.D., 1977. Research Fellow, 1977-.
- Hsueh-Wen Yeh, Ph.D., Senior Research Fellow in Geochemistry B.S.E., National Cheng-Kung University (Taiwan), 1967; Ph.D., Case Western Reserve University, 1974. Research Fellow, California Institute, 1975-77; Senior Research Fellow, 1977.
- Huan-Chun Yen, Ph.D., Research Fellow in Physics B.Sc., National Taiwan University, 1968; M.Sc., California Institute, 1971; Ph.D., 1977. Research Fellow, 1977-78.
- Ajit Prithiviraj Yoganathan, Ph.D., Research Fellow in Chemical Engineering B.Sc., University College, University of London, 1973; Ph.D., California Institute, 1978. Research Fellow, 1977-.
- Kaori Yoshida, M.S., Visiting Associate in Biology M.S., University of Yamagata, 1976. California Institute, 1977.
- Yuk Ling Yung, Ph.D., Assistant Professor of Planetary Science B.S., University of California, 1969; Ph.D., Harvard University, 1974. Visiting Associate, California Institute, 1976; Assistant Professor, 1977.
- Sergey Yevgenyevich Yurchenko, Ph.D., Visiting Associate in Applied Physics Ph.D., Moscow State University, 1973. Junior Scientific Associate, Institute for Problems of Control, Academy of Sciences (USSR), 1973-. California Institute, 1978.
- Moshe Yust, M.Sc., Visiting Associate in Applied Physics B.Sc., Israel Institute of Technology, 1967; M.Sc., 1974. Group Leader, Ministry of Defense Research and Development Laboratories (Haifa), 1974-. California Institute, 1978-79.

- 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., Senior Research Fellow in Biology A.B., Columbia College, 1967; M.S., California Institute, 1968; Ph.D., 1973. Research Fellow, 1973-76; Senior Research Fellow, 1976.
- Valentina Zaydman, M.A., Lecturer in Russian M.A., Moscow State University, 1971. California Institute, 1974-.
- Ahmed H. Zewail, Ph.D., Associate Professor of Chemical Physics B.Sc., Alexandria University (Egypt), 1967; Ph.D., University of Pennsylvania, 1974. Assistant Professor, California Institute, 1976-78; Associate Professor, 1978-.
- 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.
- George Joseph Zimmer, Dipl., Visiting Associate in Applied Physics Dipl., Eotros University (Budapest), 1962. Group Leader, Central Research Institute for Physics, 1962.. California Institute, 1974; 1975; 1976; 1978.
- Thomas Zimmermann, Ph.D., Research Fellow in Applied Mechanics Ing. Dipl., Swiss Federal Institute of Technology, 1970; Ph.D., 1976. California Institute, 1977.
- Robert J. Zinn, Ph.D., Senior Research Fellow in Astronomy B.S., Case Institute of Technology, 1968; Ph.D., Yale University, 1974. Carnegie Fellow, Hale Observatories, 1974-. California Institute, 1975-.
- 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 and Mechanical Engineering B.S., Harvard College, 1950; M.S., California Institute, 1951; Ph.D., 1954. Research Engineer, Jet Propulsion Laboratory, 1950-57; Lecturer in Jet Propulsion, California Institute, 1956-57; Assistant Professor, 1957-60; Associate Professor, 1960-66; Professor, 1966-78; Professor of Jet Propulsion and Mechanical Engineering, 1978-.

George Zweig, Ph.D., Professor of Theoretical Physics 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-.



# 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 a national 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, history, independent studies program, literature, mathematics, physics, planetary science, 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 third and fourth year.

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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.

In short, every effort is made to provide undergraduate students with wellrounded, integrated programs that will not only give them sound training in their professional fields, but that 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 (about 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 students of exceptional ability. A high standard of scholarship is also maintained, as is appropriate for students of such competence.
# HISTORICAL SKETCH

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

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

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

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

It would have surprised Roosevelt to know that within a decade the little Institute, known from 1913 as Throop College of Technology, would have again raised its sights, leaving to others the training of more efficient technicians and concentrating its own efforts on Roosevelt's "hundredth man." On November 29, 1921, the trustees declared it to be the express policy of the Institute to pursue scientific researches of the greatest importance and at the same time "to continue to conduct thorough courses 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 850 undergraduates, 850 graduate students, and 720 faculty (including postdoctoral fellows).

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

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

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

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 held major responsibilities for 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 80 acres; the \$17 million endowment grew to over \$100 million; the faculty of 260 became 550; the number of campus buildings increased from 20 to 64; and the budget went from something under \$8 million to \$30 million. But enrollment remained relatively constant. In 1946 the total number of students, graduate and undergraduate, was 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. Six new campus buildings were dedicated under Brown's regime, and a major development campaign for \$130 million was under way when he resigned to become Secretary of Defense under President Carter in 1977. Dr. Marvin L. Goldberger, appointed president by the Board of Trustees in March 1978, assumed his new duties in July. He received his B.S. at Carnegie Institute of Technology (now Carnegie-Mellon University) and his Ph.D. at The University of Chicago. He came to Caltech from Princeton University where he was the Joseph Henry Professor of Physics.

As Caltech has developed in effectiveness and in prestige, it has attracted a steady flow of gifts for buildings, for endowment, and for current operations. The gifts invested in plant now total \$131,000,000 and those invested in endowment about \$190,000,000. 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. Nine of them and seven members of the faculty have received Nobel Prizes.

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

# BUILDINGS AND FACILITIES

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

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

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

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

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

William G. Kerckhoff Laboratories of the Biological Sciences: first unit, 1928; second unit, 1939; annex, 1948. The gift of Mr. and Mrs. William G. Kerckhoff of Los Angeles.

Athenaeum, 1930. A clubhouse for the teaching, research, and administrative staffs of the Institute, 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.

### 112 Buildings and Facilities

**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.

**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. Dr. Ramo is a member of the Board of Trustees.

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

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

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

# **Off-Campus Facilities**

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

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

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

**Palomar Observatory**, 1948, San Diego County. Site of the 200-inch Hale Telescope, built by the Institute with funds from Rockefeller sources. Operated by the Hale Observatories, which are sponsored jointly by the Institute and the Carnegie Institution of Washington.

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

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

The following facilities are owned by the Carnegie Institution of Washington and operated jointly with the Institute as parts of the Hale Observatories:

Mt. Wilson Observatory, 1904.

Las Campanas Observatory, 1971, Chile. Site of the 100-inch du Pont Telescope.

# LIBRARIES

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

Millikan Memorial, completed in 1967, is a nine-story building with 63,000 feet of floor space. It has a capacity of about 250,000 volumes and provides seats for about 200 students. Book collections have been distributed throughout the building in such a way that each major subject has its own area and retains its identity and its close relationship with its parent academic division. Library administrative services are concentrated on the second floor; here also are the catalog of campus libraries and general reference and information services. The first floor contains circulation services and the rare books room. The various divisional collections are on floors four through nine. The basement contains 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-energy research, astrophysics, chemical engineering, earthquake engineering, electrical engineering, Environmental Quality Laboratory, geology, environmental engineering, bioinformation systems and computer science, management, and public affairs. The libraries collectively subscribe to about 5,100 journals and serials and contain about 330,000 volumes.

# THE INDUSTRIAL RELATIONS CENTER

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

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

Representatives of many organizations in both the private and public sectors receive training in the field of management in general and in the specialized field of personnel administration. Special attention is given to programs for technical supervisors and managers who function in engineering and research laboratories. Other series are designed for the first- and second-line supervisors of non-exempt employees. The courses are presented on a number of bases: on-campus or off-campus; fulltime 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 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 brings some of the world's intellectual leaders to Caltech from industry, government, and the academic community. Through this program, Caltech's faculty and student body have an opportunity to be influenced in both teaching and research by the wisdom and experience of

eminent world leaders in various fields. The emphasis in the program is on giving faculty and students exposure to Fairchild Scholars in all academic Divisions — through teaching, seminars, lectures, and research, and establishing a forum for the exchange of ideas among Fairchild Scholars, Caltech faculty, students, and industry about new directions and ideas in science and engineering.

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

# STUDY AND RESEARCH

# Aeronautics

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

### Areas of Research

Aeronautics has evolved at Caltech from a field of basic research and engineering, 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 ef-

fects 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.

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

*Aero-Acoustics*. A number of topics in the broad field of aero-acoustics are actively under study at GALCIT. They include jet noise, combustion noise, sonic boom, nonlinear acoustics and 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, fuelefficient 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 138 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, heat transfer, and generation of energy.

Research studies in these areas which illustrate current interests include: linear and nonlinear vibrations, structural dynamics and design for earthquake and wind loads, linear and nonlinear problems in static and dynamic elasticity, plasticity and viscoelasticity, wave propagation in elastic and viscoelastic media, 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.

#### Physical 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 vibration tests of buildings, dams, and other structures, 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. In 1948, the California Institute of Technology and the Carnegie Institution of Washington recognized the advantages in the creation of a great astronomical center in which scientific programs could be pursued under favorable circumstances, with a variety of instruments, which would also draw young men and women of ability to graduate studies, where they might familiarize themselves with powerful tools of exploration. Consequently, for nearly 30 years, the two institutions together have conducted their research in optical astronomy through the combined scientific staff of the Hale Observatories and the various facilities at Palomar Mountain, Mount Wilson, Big Bear Lake, Cerro Las Campanas, and Pasadena. Research is thus a shared activity, within the Hale Observatories, wherein equipment and facilities are made available for the astronomical investigations of the combined staff, research fellows, and students. Academic activities, on the other hand, as well as the operation of the Owens Valley Radio Observatory, are the responsibility of the Institute's Division of Physics, Mathematics and Astronomy. The division also conducts work in theoretical aspects of astrophysics, and in laboratory astrophysics.

The radio a stronomy 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. Courses of study depend upon a broad and thorough preparation in physics, mathematics, and other relevant subjects; the faculty offers advanced instruction in astronomy, astrophysics, solar physics, planetary physics, radio astronomy, astronomical instrumentation, and observations with large telescop es.

### Areas of Research

Both observational and theoretical astrophysics are actively pursued. Topics of current interest in optical and infrared astronomy include observational cosmology, chemical abundances in normal and peculiar stars, spectroscopic and spectrophotometric studies of quasars, compact and Seyfert galaxies and related objects; studies of white dwarfs and other stars near the end-point of evolution; studies of the dynamics and composition of galaxies and clusters, nebulae and interstellar matter, statistical studies pertinent to the structure of the galaxy, and the physics of solar phenomena.

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

The research in radio astronomy covers the physical properties of galactic and extragalactic radio sources including quasars, radio galaxies, supernova remnants, pulsars, and the planets. The properties of the interstellar medium in our own and other nearby galaxies are investigated in spectroscopic studies of the 21-cm hydrogen line and 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. Joint operation of the Palomar Observatory with the Mount Wilson Observatory of the Carnegie Institution of Washington was initiated in 1948; the combined observatories, now including the Las Campanas Observatory and the Big Bear Solar Observatory, have been known since 1970 as the Hale Observatories. Graduate student thesis research may be conducted at any of these facilities. The great light-collecting power of the 200-inch Hale Telescope permits advanced studies of the size, structure, and motions of the stars of the galactic system; of the distance, motion, and nature of remote galaxies and quasi-stellar radio sources; and of many phenomena bearing directly on the constitution of matter. The 48-inch Schmidt has made possible a complete survey of the sky, as well as an attack upon such problems as the structure of clusters of galaxies, the luminosity function of galaxies, extended gaseous nebulae, and the stellar content of the Milky Way. These two unique instruments on Palomar Mountain supplement each other as well as the telescopes on Mount Wilson. The 200-inch Hale Telescope reaches as far as possible into space in a given direction, while the 48-inch Schmidt photographs upon a single plate an entire cluster of distant galaxies or a star cloud in our own Galaxy. At Palomar a 60-inch telescope was completed in 1969. It is utilized for photoelectric observations, image-tube spectroscopy, and photography.

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 observations made at Mount Wilson with the 60-foot and 150-foot towers. 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.

The Las Campanas Observatory in north central Chile, built by the Carnegie Institution of Washington, has recently been added to the group known as the Hale Observatories. Principal equipment consists of a 40-inch general purpose telescope, in use since 1971, and the new 100-inch Irénée du Pont Telescope which is now completed and equipped with auxiliary instruments. It is suited for wide-angle direct photography as well as for spectroscopy and photometry with instruments of the most modern type. The observatory provides access to southern skies with the most modern equipment at an excellent dark-sky site.

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

#### 122 Study and Research

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; 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 neurobiology, students at the Institute have an unusual opportunity to be introduced to modern biology.

### Areas of Research

Research (and graduate work leading to the Ph.D. degree) is chiefly in the following fields: biochemistry, biophysics, cell biology, developmental biology, genetics, immunology, molecular biology, neurobiology, neurophysiology, psychobiology, and virology. Biochemical methodology plays an important role in many of these fields, and there is extensive interaction with related programs in chemical biology within the Division of Chemistry and Chemical Engineering.

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

Neurobiology and behavioral biology are receiving increasing emphasis within the Division. A comprehensive program of research instruction has been formulated to span the disciplines from neuron physiology to the study of animal and human behavior. Related developments in the Divisions of Engineering and Applied Science and the Humanities and Social Sciences serve to fortify doctoral programs concerned with the study of brain and behavior.

#### Physical Facilities

The campus biological laboratories are housed in four buildings, the William G. Kerckhoff Laboratories of the Biological Sciences, the Gordon A. Alles Laboratory for

Molecular Biology, the Norman W. Church Laboratory for Chemical Biology, and the Mabel and Arnold Beckman Laboratories of Behavioral Biology. They contain classrooms and undergraduate laboratories, facilities to house experimental animals, and numerous laboratories equipped for biological, biochemical, biophysical, physiological, and psychological research at the graduate and doctoral levels. The constanttemperature equipment includes rooms for the culturing of the Institute's valuable collection of mutant types of Drosophila and Neurospora and complete facilities for tissue culture.

About 50 miles from Pasadena, at Corona del Mar, is the William G. Kerckhoff Marine Laboratory. The building houses several laboratories for research in marine physiology and developmental biology. It is equipped with its own shop, has boats and tackle for collecting marine animals, and running seawater aquaria for keeping them.

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



Roger the barn owl, who is 20 years old, came to Caltech from Princeton with Professor of Biology Mark Konishi, who hand-raised Roger and uses him in many behavioral experiments.

# **Chemical Engineering**

The research and teaching interests of the chemical engineering faculty are directed toward the study of the fundamentals of chemical and transport principles and their application to the analysis and synthesis of complex chemical systems. These interests lead the faculty and students into problems as diverse as the chemical processes occurring in various organs of the body, the chemistry of polluted atmospheres, the chemistry of coal conversion to synthetic fuels, the behavior of materials under conditions of unusual temperature and pressure, surface chemistry, and the fundamentals of heterogeneous catalysis and their 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, aerosol dynamics, fluid mechanics, liquid-state physics, polymers, plasma chemistry, coal conversion and combustion, desulfurization of fuels, heterogeneous catalysis and surface chemistry, solid-state chemistry, optimal control and estimation theory, and the physics and chemistry of two-phase systems.

- 1. Biomedical: Transport in tissues, artificial organs, and the cardiovascular system. Pulmonary bioengineering. Gas sterilization.
- Energy: Coal conversion to synthetic fuels by pyrolysis and gasification. Coal and fuel oil desulfurization by selective oxidation. Petroleum reservoir engineering and recovery methods.
- 3. 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.
- 4. Fluid mechanics: Rheology and transport properties of suspensions and polymer solutions. Mechanics of non-Newtonian fluids. Interfacial fluid mechanics and transport processes. Numerical simulation of fluid motion.
- 5. Heterogeneous catalysis and surface chemistry. Adsorption and catalytic reactions on well-characterized surfaces utilizing low-energy electron diffraction, Augerelectron spectroscopy, x-ray and uv-photoelectron spectroscopies, characteristic electron energy loss spectroscopy, inelastic electron-tunneling spectroscopy, and mass spectrometry. Theoretical modeling of solids, solid surfaces, and gas-surface interactions.
- 6. Optimal control and estimation theory with applications to chemical reactors and to petroleum reservoir engineering.
- 7. Plasma chemistry and engineering: Diffusion. Homogeneous and heterogeneous reactions.
- 8. Polymers: Mechanical properties of elastomers and block copolymers. Behavior of elastomers under pressure. Physics of elastomer networks.



Professor of Chemical Engineering and Chemical Physics Robert Vaughan and co-workers discuss application of NMR to solid materials.

- Solid-state and surface chemistry: Investigations using multiple-pulsed nuclear magnetic resonance techniques. Studies of effects of high pressure on chemical electronic properties.
- 10. Structure and dynamics of liquid systems: Macromolecular modeling and hydrodynamics. Rayleigh and Brillouin laser light scattering studies of super-cooled liquids, macromolecular solutions and particulate suspensions; critical phenomena, macromolecular dynamics and conformation in quiescent and flowing solutions; transport properties of liquids, molecular relaxation phenomena in liquids and amorphous solids. Structure of simple liquids by x-ray diffraction.

### Physical Facilities

Chemical engineering is 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 applied physics, biology, chemical engineering, and geology. There is strong interest on the part of the faculty in both teaching and research, and the undergraduate and graduate programs are designed to encourage the greatest possible amount of freedom, creativity, and flexibility.

#### Areas of Research

Caltech has long had a reputation for excellence in chemistry in the areas of molecular structure and the nature of chemical bonding. This tradition is continuing. Work in structural chemistry ranges from x-ray crystallographic structural determinations of covalent compounds, transition metal complexes, intermetallic compounds, 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 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 or her 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 finite element methods 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.

# **Computer Science**

Computer Science is not an option; if students wish to take advanced studies leading to the degree of Master of Science and Doctor of Philosophy in this field, they must elect the Engineering Science option.

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

### 128 Study and Research

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

### Areas of Research

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

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

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

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

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

## **Electrical Engineering**

Electrical engineering at the Institute comprises physical electronics, electronic circuits, and communication. Closely allied with the computer science program and the applied physics option, it offers students the opportunity for study in the more technological aspects of a wide variety of subjects including plasma dynamics, electromagnetic radiation, quantum electronics, modern optics, new solid-state materials and devices, computer systems and information theory. This broad spectrum of subjects complementing the program in electronic circuits and circuit function design provides exceptional and challenging opportunities for both experimental and theoretical work.

### Areas of Research and Physical Facilities

Laboratory facilities are available for a wide variety of research activities. At present electrical engineering activities are housed mainly in one building, the Harry G. Steele Laboratory of Electrical Sciences.

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

The Quantum Electronics Laboratory 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: generation and control of ultrashort pulses, integrated optical circuits, semiconductor injection lasers, and applications of nonlinear optics. Projects on laser isotope separation, sub-millimeter wave techniques, and relativistic electron lasers are anticipated.

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

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

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

## 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 solar power, automotive engines, nuclear and fusion power and their environmental consequences are addressed widely within the Division of Engineering and Applied Science, where the fundamentals of fluid dynamics, combustion, heat transfer, materials science, and electromagnetism are highly developed. Graduate programs in these areas are described further on page 242, and suggested undergraduate preparation on page 195. Investigations in conversion, control, and regulation of electric energy are conducted in the Power Electronics Laboratory (see page 129).

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 187, 188, 231, 233, while the fundamentals of earth resources and geothermal energy are pursued in the Division of Geological and Planetary Sciences, and are described on pages 134 and 252.

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.

## **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, essential new research strategies have been developed for the understanding of complex systems that cannot be described by conventional mathematics.

Therefore, this program, in addition to extensive research on 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 subjects 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 optic), a high-speed-cine-photomicrographic facility, and an automatic image processing unit for quantitative measurements of flows about moving microorganisms. It is also equipped with a versatile towing tank and flow measuring devices for investigating the swimming of fish and mechanical models.

### Free Surface Flows and Geophysical Fluid Mechanics

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

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

# **Environmental Engineering Science**

This interdisciplinary graduate program is concerned with protection and control of man's environment. Research and instruction stress basic studies 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 ensure the supply of water of adequate quality and quantity for population centers and industry? How can we safeguard our marine environment from pollution? What are the environmental consequences of alternative modes of energy production?

The academic disciplines of importance to the program in environmental science and technology include: chemistry of natural waters and atmospheres; physics and chemistry of disperse systems; marine biology and ecology; fluid mechanics of the natural environment; pollutant formation and control in combustion systems; 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; gasto-particle conversion processes in urban atmospheres; oceanic farming as a potential energy source; kinetics of sulfide oxidations in aqueous solutions; dilution in turbulent shear flows; buoyant discharges in coastal waters; and fine particle 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 are used for particulate characterization.

Meteorological variables including wind speed, relative humidity, and temperature can be measured with instruments on hand in the laboratory.

The Water Quality Laboratory is equipped for trace element analysis (atomic absorption, polarography, electrometry), 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: a 40-meterlong glass-walled flume with dual circulating water systems for turbulent density stratified shear flow studies. This flume is equipped with an advanced laser Doppler velocity measurement system that can be directly coupled to the laboratory computer for real-time analyses. The laboratory computer is a multi-task DEC 11T60 and can be used on several experiments simultaneously. The laboratory also has a wave flume with a computer-controlled wave generator system that can produce waves of specified profiles for special wave studies, and several other channels appropriate for sediment and diffusion studies.

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

# **Environmental Quality Laboratory**

The Environmental Quality Laboratory (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) *Energy policy, especially in relation to the environment* (geothermal energy; economics of taxes, incentives, and regulation; energy conservation).
- (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 (ocean sludge disposal).

Students who desire to work in EQL apply through an appropriate degree program, such as Environmental Engineering 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 are cultivated. Programs of study and research are pursued in geology, geobiology, geochemistry, geophysics, and planetary science.

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

#### Physical Facilites

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 occurs 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 literature, 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 with a normal undergraduate option. The student gathers a three-person faculty committee, representing at least two divisions of the Institute, and chooses his or her own scholastic requirements under this committee's supervision. Approval must also be obtained from the Independent Studies Committee, a standing committee of the faculty. The Independent Studies Program has no facilities of its own. Areas of study and research may be selected from any part of the Institute.

(For complete description see page 200)

# **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 115 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 nuclear- and fossil-fuel power plants, as well as all types of energy production and conversion installations, transportation systems, propulsion devices, 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

Opportunites 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 generally emphasizes basic subjects (such as combustion, two-phase flow, turbomachinery), which are applicable to a wide variety of engineering problems. The experimental facilities of the Jet Propulsion Center are located in the Karman Laboratory of Fluid Mechanics and Jet Propulsion. Some of the facilities of the Jet Propulsion Laboratory have also been 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*. Experiments in elementary particle physics are carried out at the major accelerator centers, principally at the Fermi National Accelerator Laboratory near Chicago and at the Stanford Linear Accelerator Center (SLAC). Current activities include a major program for the study of neutrino interactions at high energies at Fermilab, a study of the production of multiparticle states in hadron collisions at Fermilab, and the construction and use of a major new detector for the study of neutral particles emitted in e+e- colliding beams at SLAC.

A phenomenology group carries on an active program concentrating on the comparison of theories and experimental data. Current interests include parton models for lepton and high transverse momentum processes.

*Kellogg Radiation Laboratory.* Three conventional Van de Graaff accelerators and a 12-MeV tandem accelerator are used to study nuclear structure and reactions with particular emphasis on nuclear phenomena of importance in astrophysics. The ac-



Professors Ed Stone and Robbie Vogt, surrounded by data from previous space missions, are checking test data from cosmic ray apparatus presently flying on Voyagers 1 and II. (Prototype model under lucite cover.)

celerators 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. The nature and magnitude of symmetry-breaking in nuclei are investigated, with current studies of parity violation in <sup>18</sup>F caused by weak neutral currents.

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 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. A new program for the exploration of possible neutrino oscillations has recently begun.

*Cosmic Rays.* Measurements of energy and mass spectra of charged particles in space are carried out with sophisticated detectors carried on spacecraft and balloons. The data obtained are of interest for astrophysical phenomena such as element building in stars, astrophysical particle accelerators, and supernovae explosions. Measurements of isotopic composition of cosmic rays are carried out with high-resolution spectrometers on spacecraft.

Infrared Astronomy. Astrophysical observations at millimeter and submillimeter wavelengths are carried out with ground-based telescopes on Mt. Wilson, Palomar and Chile, and with the NASA airborne observatory.

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

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

*Radio Astronomy.* One 40-meter and two 27-meter antennas are used either individually or in interferometric combinations to investigate the properties of galactic and extragalactic radio sources, of the planets, and of gas clouds in the interstellar medium. Receiving equipment includes multiple narrow-band correlators for interferometric spectrometry, an autocorrelation spectrograph, and a recording terminal for very-long-baseline interferometry. A new correlator for very-long-baseline interferometry been put into operation. Three 10-meter antennas and receivers for millimeter wave observations, including interferometry, 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. The requirements for such thesis research vary from option to option, and the individual course descriptions should be consulted.

# STUDENT LIFE

Student Houses. The seven undergraduate student houses are situated on both sides of the Olive Walk near the eastern end of the campus. The original four — Blacker, Dabney, Fleming, and Ricketts — were built in 1931 from the plans of Mr. Gordon B. Kaufmann in the Mediterranean style to harmonize with the adjacent Athenaeum. The other three, designed by Smith, Powell and Morgridge, and generally consistent in appearance with the older group, were completed in 1960, and are named Lloyd, Page, and Ruddock. Each of the seven is a separate unit with its own dining room and lounge, providing accommodations for about seventy-five students.

Each house has its own 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 married graduate student or younger faculty member. All houses are under the general supervision and control of a member of the faculty known as the Master of Student Houses.

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

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

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

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

Freshman Advisers. Each member of the freshman class is assigned to a faculty adviser.



Freshman Camp includes a terpsichorean seminar.

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 courses, progress toward a degree, and, eventually, in assisting the student toward satisfactory placement in industry, or in graduate school. Normally, the association between student and adviser, which is primarily professional, is established before the beginning of the sophomore year and continues through graduation.

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

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

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

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

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

The student government is very active in campus affairs. The student members of each standing faculty committee insure that undergraduate opinion is considered seriously. Excellent informal relations between students and faculty and between students and administration promote mutual concern and goodwill. Recently the annual ASCIT Award for Excellence in Teaching was instituted to encourage faculty to increase their teaching efforts.

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

*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 a violation should occur, the appropriate board investigates and recommends disciplinary measures to the deans.

Student Body Publications. The publications of the student body include a weekly paper, the California Tech; an annual; a literary magazine; a student handbook, which gives a survey of student activities and organizations and serves as a campus directory; and an annual review of the quality of teaching in the various courses. These publications are staffed entirely by students. Through them ample opportunity is provided for any student who is interested in obtaining valuable experience not only in creative writing, photography, art work, and in the journalistic fields of reporting and editing, but in the fields of advertising and business management as well.

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

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. Established in 1916 when Caltech was still Throop College of Technology, the Caltech Y has been closely related to the Institute. As the oldest student organization on campus, it has involved people of diverse religious, ethnic, and political orientation in its leadership and activities; the Y has also pioneered through the years in providing numerous special services to the students.



Base runner's sprint versus the catcher's hustle.

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

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

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

*Public Events.* Beckman and Ramo Auditoriums serve as the home of the professional performing arts program on the Caltech campus. Each year, 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 and the Caltech Glee Club Christmas and Spring Concerts. 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 absent from the Institute for two years or more may also be required to submit this report.

Student Health Services. The Archibald Young Health Center, which includes a dispensary and an infirmary, provides for undergraduate and graduate students the following services: (1) office consultation and treatment by a staff physician at prescribed hours; (2) laboratory tests, consultations, and radiographs as prescribed or ordered by the staff physician; (3) inoculations and treatments administered by nurses; (4) routine medications, prescription drugs, and other supplies at cost; (5) infirmary care; and (6) psychological counseling through the services of staff psychologists. (Services are available for faculty and staff on a limited basis, covering 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.

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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 \$72, 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 services, facilities, programs, and activities are administered, in a nondiscriminatory manner without regard to race, religion, color, sex, national or ethnic origin, or nondisqualifying handicap, in accordance with the existing laws and regulations, including Title IX of the Education Amendments of 1972, Title VI of the Civil Rights Act of 1964, and Section 504 of the Rehabilitation Act of 1973 as amended.

# **Student Grievance Procedure**

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

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

The first step in this procedure is to submit the matter to the Vice President for Student Affairs, who is the ombudsman for student grievances. He will work with the grievant in attempting to resolve the matter. If the grievant is dissatisfied with the results, the grievant may appeal the case to the Grievance Committee. This committee consists of two members of each of the categories — undergraduate students, graduate students, faculty, and administration — appointed, respectively, by the ASCIT Board of Directors, the Graduate Student Council, the Chairman of the Faculty, and the President of the Institute. The Chairman of the Committee, non-voting except in 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.



An undergraduate plays chess to find the key that will unlock a room on Senior Ditch Day.

#### **Employment Experience of Recent Graduates**

A survey was made at the end of June 1977 of the future plans of those students who had graduated at the commencement ceremony June 10, 1977.

Of those receiving the B.S. degree, about whom we have definite information, 58% had been accepted for admission to graduate school for further education, 27% had accepted employment, and 14% were still seeking employment or graduate school admission. The median salary of those accepting employment was \$1,250 per month. At the M.S. level, 51% were continuing in graduate school, 32% were employed at a median salary of \$1,450 per month, 6% were in military service, and 10% were still seeking. Of those receiving the Ph.D. degree, 2% were continuing in school, 96% were employed at a median salary of \$1,850 per month, and 2% were still looking.

#### **Student Retention**

Most undergraduates enter the Institute at the freshman level. Of these, over the last several years, 67% have graduated from the Institute with Bachelor of Science degrees in the options of their choice. Of students registering at the Institute for the first time as sophomores or juniors 84% have graduated. At the graduate level 91% of the students entering graduate either with the degree of Master of Science or of Doctor of Philosophy or, occasionally, with both.

# **Patent Agreement**

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

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

arise from such inventions. The Institute will bear the expenses for such patent applications.

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

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

#### Access to Student Records

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

- 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 is responsible for maintaining all of these records, except for those involving Financial Aid. They are available to the Registrar, to the Vice President for Student Affairs, to the Dean of Graduate Studies, to the Director of Financial Aid, to the Faculty of the Institute, and to their respective staffs for the normal academic and business purposes of the Institute. Records involving Financial Aid are maintained by the Director of Financial Aid, and are available to the Director and staff, to the Dean of Graduate Studies and staff, to the Faculty Committee on Scholarships and Financial Aid, and to the Faculty Committee on Graduate Study for the purpose of granting and administering the Institute's Financial Aid program. All of these records are also available to such other organizations and persons as are entitled to them under Part 99 of the Code of Federal Regulations. None of these records nor any personally identifiable information contained therein, other than directory information (see below) will be made available to anyone else, other than the student, without written consent. Where consent is required and given, the student, upon request, will receive a copy of the records to be released. The Institute will keep a record, available to the student and kept with his or her file, of all persons and organizations, other than those authorized within the Institute, requesting or obtaining access to the files. This record will indicate specifically the legitimate interest 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 convenient time will be arranged within 10 working days after receipt of the request for the student to examine the records in his or her file. At that time the student may examine all records in the file with the exception of those specifically exempted by Part 99 of the Code of Federal Regulations. The student may obtain copies of any of the records available to him or her; the cost will be \$.44 for the first page copied and \$.12 for each additional page. All reasonable requests for explanations or interpretations of the records will be honored, and if inaccurate, misleading or otherwise inappropriate data are found

in the records, they will be promptly corrected or deleted. The student also has the right to insert into the records a written explanation respecting the contents of such records. If the student and the Registrar, or the Director of Financial Aid, or the Dean of Graduate Studies, or their deputies, do not agree on any item contained in the records, the student may submit a written request to the Vice Provost for a hearing to challenge the content of the records. The Vice Provost will schedule such a hearing within 30 days after receipt of the request and will notify the student reasonably in advance of the hearing of its date, time, and place. The hearing will be before a Board composed of the Vice Provost, the Vice President for Student Affairs, or their designated alternates, and at least one disinterested member of the Faculty who shall be appointed by the Chairman of the Faculty Board. None of those hearing the challenge may have a direct interest in the outcome. The student will be afforded a full and fair opportunity to present evidence relevant to the issues raised and may be assisted or represented by individuals of his or her choice at his or her own expense, including an attorney. The decision of the board on the correctness of the record, as determined by majority vote, will be in writing, will be rendered within 10 days after the conclusion of the hearing, and will be final. This decision will be based solely upon the evidence presented at the hearing and will include a summary of the evidence and of the reasons for the decision.

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

- 4. The Institute considers the following to be directory information: student's name, 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.

#### Academic Records of Veterans

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

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

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

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



# Section III

# INFORMATION AND REGULATIONS FOR THE GUIDANCE OF UNDERGRADUATE STUDENTS

## REQUIREMENTS FOR ADMISSION TO UNDERGRADUATE STANDING

The undergraduate school of the California Institute of Technology is coeducational; there is no set ratio of men to women. Undergraduates are admitted only once a year — in September. All undergraduates at the California Institute are expected to carry the regular program leading to the degree of Bachelor of Science in the option of their choice. Special students who wish to take only certain subjects and are not seeking a degree cannot be accepted.

# ADMISSION TO THE FRESHMAN CLASS

The freshman class of approximately 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 and personal qualifications. The specific requirements in each of these groups are described below. Personal interviews with applicants and two or three of their teachers are held at their schools whenever feasible. An application fee of \$10 is due at the time an application for admission is submitted. 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 154.)

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
-	Chemistry
	Mathematics
	Physics
	United States History and Government1
Group B:	Foreign Language, Shop, additional English, Geology, Biology or other
	Laboratory Science, additional History, Drawing, Commercial subjects,
	etc

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. A student seriously interested in the Institute would be well advised to take the Mathematics Level II Achievement Test by the December administration if possible. No exception can be made to the rule that all applicants must take these tests.

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

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

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

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

## Personal Interviews and Recommendation Forms

Enclosed with the Institute's application form are three recommendation forms which the applicant should distribute to three teachers at the applicant's high school who are best acquainted with the capabilities and preparation of the applicant with the request that they be filled out and returned directly to the California Institute. These recommendation forms provide valuable information on candidates. The College Board scores, the last of which will be received by about February 15, provide further important data. Since, however, there are many more applicants to the California Institute than our facilities can accommodate, as much information as possible is desired on each candidate for admission. Wherever preliminary information shows that an applicant has a chance of gaining admission, the Institute will attempt to hold a personal interview at the school he or she is attending. It is not possible to visit all of the schools involved. If a personal interview cannot be held, this in no way prejudices an applicant's chances of admission. The applicant has no responsibility with regard to the personal interview unless and until a notice is received giving the time and date when a representative will visit the school. These visits occur generally between March 1 and April 6.

#### Notification of Admission

Final selections will ordinarily be made and the applicants notified of their admission or rejection well before May 1. Most College Board member colleges have agreed that they will not require any candidate to give final notice of acceptance of admission or of a scholarship before this date. Upon receipt of a notice of admission an applicant should immediately send in the registration fee of \$10. In the event he or she subsequently cancels the acceptance, the registration fee is *not* refundable. Places in the entering class will not be held after May 1, if the applicant could reasonably be expected to have received notice at least ten days before that date. Otherwise, places will be held not more than ten days after notification. When the registration fee has been received, each accepted 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 financial aid, the application should be filed with the College Scholarship Service by the same date.) Early decision applicants will be notified by December 10 whether they have been accepted. An accepted applicant is then expected to withdraw all applications to other colleges. An applicant who is not accepted under the early decision plan will be considered without prejudice for admission at the regular time in April, unless final rejection is received in December.

#### **Advanced Placement Program**

A number of high schools and preparatory schools offer selected students the opportunity to accelerate and to take in the senior year one or more subjects 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 1, General and Quantitative Chemistry. It is assumed that such students have reasonable competence in the following areas: 1) *elementary* theories of atomic structure and electronic theories of valence, 2) chemical stoichiometry, and 3) computations based upon equilibrium relationships. For those students who qualify for Advanced Placement in Chemistry, the Institute requirement of 18 units of Ch 1 abc can be satisfied by completing with passing grades 2 *terms* of either (i) Ch 2 abc (9 units each term) or (ii) Ch 41 abc (9 units each term). The student's qualification for Advanced Placement in Chemistry will be determined in a personal interview with the Ch 2 instructor.

Humanities and Social Sciences. Students will not be admitted to upperclass humanities and social science courses until or unless they have successfully completed three terms of freshman humanities 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 di-

mensions; 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 170-173. In computing need the California Institute includes tuition, board and lodging, books and supplies, incidental fees and dues, and about \$550 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 \$1,500 less. Further information on tuition and other costs, and on loans and the deferred payment plan is given on pages 174-175.

## **New Student Orientation**

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

The orientation, usually off campus, takes place during three days immediately following freshman registration for the fall term. A large number of faculty members and upperclass student leaders participate to help introduce the new student to the Caltech community. The orientation period provides an opportunity for the new student to become acquainted with the campus, the Honor System governing personal conduct, and other aspects of life at Caltech. In addition, he or she can meet classmates and a number of the upperclass students and faculty. Thus the new student can begin to feel at home at Caltech and share in the common agreement on intellectual and moral standards before the pressure of academic work begins.

#### ADMISSION TO UPPER CLASSES BY TRANSFER FROM OTHER INSTITUTIONS

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

No application fee is charged in the case of transfer students, but 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 153-157. 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 either the preliminary letter or a postcard provided by the Admissions Office and transcripts have been received and evaluated. Transcripts are held in the files until such a letter or postcard is received.

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

All transfer applicants must arrange to have sent in their scores on the Scholastic Aptitude Test (SAT) of the College Entrance Examination Board. If they have taken the SAT in previous years, these scores will be acceptable; but applicants must instruct the College Board (see address on page 154) to send the scores to the Institute If the SAT has not been taken previously, it must be taken by the March series at the latest. College Board Achievement Tests are not required of transfer applicants. Before their admission to the upper classes of the Institute, all students are required to take entrance examinations in mathematics and physics covering the work for which they desire credit. In addition, an examination in chemistry is required for those desiring to major in chemistry or chemical engineering.

Two examinations of a comprehensive character are offered in mathematics and physics. One examination in each subject covers the work of the first year; the other examination, that of the first and second years. Representative examination papers will be sent to approved applicants upon request. The Institute courses for which those admitted will receive credit will be determined by the Committee on 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 Institute has a program with 12 relatively local public junior colleges, whereby a student at one of the junior colleges may follow a certain pattern of courses, maintain specified grades and grade-point averages, receive the recommendation of the junior college science faculty, and be considered for admission to the junior year without the necessity of taking tests. Decisions on such applicants will be made on a rolling basis and will be earlier than decisions under the standard program. Full details can be obtained from the junior college counselors. The colleges are: El Camino College, Fullerton Junior College, Glendale College, Long Beach City College, Los Angeles City College, Los Angeles Pierce College, Los Angeles Valley College, Pasadena City College, Riverside City College, Santa Ana College, Santa Monica College, Ventura College.

Physical examinations are required for transfer students as in the case of students entering the freshman class (see page 145). Admission is conditional upon a satisfac-

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

## EXCHANGE PROGRAMS

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

In addition, through the office of the Dean of Students, informal exchange programs are conducted with several colleges and universities throughout the country. The colleges currently in the program include Antioch, Pomona, Swarthmore, and Williams. Under these programs, a student can visit another campus for a period ranging from one term to a full academic year, without the formalities of transfer proceedings or written applications. Any student interested in the informal program should check with the Dean of Students for details.

#### ROTC

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

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

#### **REGISTRATION REGULATIONS**

#### Procedures

Students must register in person on the dates specified in the academic calendar. Registration material is to be picked up at a location designated by the Registrar and is returned to the registration area when completed. Students are not registered until they have both

- a. turned in a signed registration card with their approved study list, and
- b. made satisfactory arrangements with the Office of Student Accounts for the payment of all fees due the Institute.

Any student who has not completed both phases of registration within one week after registration day will be removed from the Institute rolls.

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

# **Changes of Registration**

All changes in registration must be reported to the Registrar's Office by the student prior to the published deadlines. A grade of F will be given in any course for which a student registers and which he or she does not either complete satisfactorily or drop. A course is considered dropped when a drop card is completed and returned to the Registrar's Office. A student may not at any time withdraw from a course 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.

#### Withdrawal from the Institute

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

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

#### Leave of Absence

Leave of Absence must be sought by written petition, and if granted must be filed with the Registrar together with a completed withdrawal card. Leave of up to one year can be granted by the appropriate dean for a student who is in good standing. A student in good standing is defined as a student who does not have to meet special academic requirements as a result of reinstatements. A petition for a *medical* leave of absence must carry the endorsement of the Director of Health Services or his representative and the appropriate dean. Other petitions should be addressed to the Undergraduate Academic Standards and Honors Committee, and the student must indicate the length of time and the reasons for which absence is requested. All leaves of absence will be reviewed by the Committee. In case of brief absences from any given class activity, arrangements must be made with the instructor in charge.

# 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. 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 164. 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 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 spe-

cial 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.

INO. OF												
Units	A+	Α	A-	<b>B</b> +	В	B-	C+	С	C	D+	D	F
1	4	4	4	3	3	3	2	2	2	1	1	0
2	9	8	7	7	6	5	5	4	3	3	2	0
3	13	12	11	10	9	8	7	6	5	4	3	0
4	17	16	15	13	12	11	9	8	7	5	4	0
5	22	20	18	17	15	13	12	10	8	7	5	0
6	26	24	22	20	18	16	14	12	10	8	6	0
7	30	28	26	23	21	19	16	14	12	9	7	0
8	35	32	29	27	24	21	19	16	13	11	8	0
9	39	36	33	30	27	24	21	18	15	12	9	0
10	43	40	37	33	30	27	23	20	17	13	10	0
11	48	44	40	37	33	29	26	22	18	15	11	0
12	52	48	44	40	36	32	28	24	20	16	12	0
13	56	52	48	43	39	35	30	26	22	17	13	0
14	61	56	51	47	42	37	33	28	23	19	14	0
15	65	60	55	50	45	40	35	30	25	20	15	0

*Grade-Point Average* is computed by dividing the total number of credits earned in a term or an academic year by the total number of units taken in the corresponding period. Units for which a grade of "F" has been received are counted, even though the course may have subsequently been repeated. Physical education units and credits, and grades of "P" are not included in computing grade-point average.

#### Pass-Fail Grading: The following regulations apply:

 Freshmen receive Pass-Fail grades in all courses by virtue of their classification as freshmen by an admissions committee or, for students whose status after the first year is uncertain, by the Undergraduate Academic Standards and Honors Committee.
All other students, undergraduate and graduate, in courses with numbers under 200 will receive letter grades unless the course is designated "Graded Pass-Fail" or unless, when it is allowed, the student files with the Office of the Registrar a completed Pass-Fail Course Selection Card not later than the last day for dropping courses.
In courses with numbers 200 or greater that are not designated either "Graded Pass-Fail" or "Letter grades only," the instructor may decide separately for each student which class of grades to use.

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

5) Any instructor may, at his or her discretion, specify prior to preregistration that his or her course, if not classified by the above regulations, is not available on a Pass-Fail

basis or that it is to be graded Pass-Fail only, subject to possible review by the responsible option. Such changes may be made only if the Registrar is notified two weeks before the beginning of preregistration.

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

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

#### Scholastic Requirements

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

*Ineligibility for Registration.* Undergraduates who register for programs 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.

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

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

(b) If they fail to obtain a grade-point average of at least 1.9 for the academic year. Students who have completed at least three full terms of residence at the Institute and have been registered for their senior year shall no longer be subject to the requirement that they make a grade-point average of at least 1.9 for the academic year. Seniors are subject to the requirement, however, that they must receive a grade-point average of at least 1.4 each term to be eligible for subsequent registration.

(c) Undergraduate students, including seniors, who have been *reinstated* and who fail to make a grade-point average of at least 1.9 on a full load of at least 36 units for the following term are ineligible to register.

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

Students ineligible for registration because of failure to meet the requirements stated in the preceding paragraphs may submit a petition to the Undergraduate Academic Standards and Honors Committee for reinstatement, giving any reasons that may exist for their previous unsatisfactory work and stating any new conditions that may lead to better results. Each such petition will be considered on its merits. *For the first such ineligibility,* the petition will be acted upon by the appropriate dean, after

consultation with the student and examination of the record. At the dean's discretion, such cases may be referred to the Undergraduate Academic Standards and Honors Committee for action. All subsequent reinstatements must be acted upon by the Committee. Reinstated students who again fail to fulfill the scholastic requirements for registration must petition the Undergraduate Academic Standards and Honors Committee, and action can only be taken by the Committee. In any case being considered by the Committee, the students may, if they wish, appear before the Committee or, on request by the Committee, they may be required to appear. A second reinstatement will be granted only under exceptional conditions.

Departmental and Option Regulations. 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. 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. A full year of residence is interpreted as meaning the equivalent of registration for three terms of not less than 36 units each.

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

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

Graduation with Honor. 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, includ-

ing 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. If denial of this petition may require that the student add courses, the student should petition at least one week before the last day for adding classes. A student may not drop a course or courses if this results in registration for fewer than 36 units, unless the prior approval of the Undergraduate Academic Standards and Honors Committee is obtained. Approval to register for fewer than 36 units will not be given to any 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

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

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 subsequent years. Upon the selection of an option, a freshman will be assigned an adviser in that option, whose approval must then be obtained for preregistration for the following year.

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

*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.

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 sailing. Standards for evaluation of student performance will be clearly defined at the beginning of each class. Participation in intramural sports will count toward the successful completion of an instructional activity.

Student-designed programs of physical fitness are submitted in writing to the Department of Physical Education during the pre-registration period. These programs must provide for regular participation in vigorous physical activity at least three days per week. The programs may consist of individual or group participation and may include intramural sports participation. At the end of the term the student files a brief written report with the Department of Physical Education reviewing his 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. This fee is not refundable, but it will be applied to tuition fees, upon registration.

For freshmen and transfer students, there is a \$10 Registration Fee payable upon notification of admission, and it is not refundable. Housing contracts, accompanied by a \$50 deposit, must be submitted to the Master's Office by the date specified in the instructions accompanying the contract. The deposit will be applied to the first term room charge.

#### **Expense Summary 1978-79**

General.	
General Deposit	\$ 25.00 <sup>1</sup>
Tuition	4,302.00
Student Body Dues, including The California Tech	24.00 <sup>2</sup>
Assessment for Big T	16.50 <sup>2</sup>
	\$4,367.50

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<sup>1</sup>This charge is made only once during residence at the Institute. <sup>2</sup>Fees subject to change by action of the Board of Directors of the Associated Students of the California Institute of Technology.

Other:	
Student House Living Expenses, including 10 meals	
per week while Institute is in session	
(Room and Board rates are subject to change)	
Room and Board	\$1,482.00
Dues	45.00
Meals not covered by board contract are available	
at Chandler Dining Hall (approx.)	630.00
Books and Supplies (approx.)	250.00
	\$2,407.00

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The following is a list of undergraduate student fees at the California Institute of Technology for the Academic Year 1978-79 together with the dates on which these charges are due. Fees are subject to change at the discretion of the Institute.

	First Term	Fee
September 20, 1978	General Deposit	\$ 25.00
(Freshmen)	Tuition	1,434.00
September 25, 1978	Associated Student Body Dues	8.00
(All Others)	Assessment for Big T	5.50
	Room and Board (for on-campus	
	residence)	554.00
	Student House Dues	15.00
	Second Term	
January 2, 1979	Tuition	\$1,434.00
-	Associated Student Body Dues	8.00
	Assessment for Big T	5.50
	Room and Board (for on-campus	
	residence)	472.00
	Student House Dues	15.00
	Third Term	
March 26, 1979	Tuition	61,434.00
,	Associated Student Body Dues	8.00
	Assessment for Big T	5.50
	Room and Board (for on-campus	
	residence)	456.00
	Student House Dues	15.00
Tuition Fees for fewer than	normal number of units:	
	Over 35 unitsFu	ll Tuition
	Per unit per term	\$ 40.00
	Minimum tuition per term	400.00
	Audit Fee \$40.00 per lecture hour, per term.	
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*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:

<sup>1</sup>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.

- 1. The date of approval of the request by the Dean of Students for Withdrawals.
- The date that registration for the reduced units is approved by the Undergraduate Academic Standards and Honors Committee or the date that drop cards are filed in the Registrar's Office, whichever is later, for *reduction in units*.

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

ASCIT Dues. As a service to the Associated Students of the California Institute of Technology, Inc., or ASCIT, dues of \$24 per year and an assessment of \$16.50 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 fee of fifty cents per year is charged to each member of the Associated Student Body (\$1 for 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 past due may be refused registration for the term following that in which the past due charges were incurred. Transcripts will not be released until all bills due have been paid or satisfactory arrangements for payment have been made with the Financial Affairs Office.

# FINANCIAL AID

# **Financial Aid for Entering Students**

Financial aid is awarded by the Freshman Admissions Committee to candidates who have been admitted to the Institute and have submitted a *Financial Aid Form* (FAF) and a copy of their parents' latest federal income tax return. Financial aid for transfer students is 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 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 and not to Caltech.

Financial Aid Forms must be sent to the appropriate College Board office not later than March 1 of the year in which admission is desired for freshman applicants, and by June 1 for transfer applicants. All applicants who have submitted this form by the above dates and who have submitted a copy of their parents' latest federal income tax return directly to the Caltech Financial Aid Office will be 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 intensive 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 financial aid if they do not apply for California State awards (Cal Grant A or B), provided their test scores indicate that they would have won a State award had they applied. Among the nationwide awards are the National Merit Scholarships and the Westinghouse Talent Search Awards. Applicants in need of financial assistance should enter any such contest for which they are eligible, in addition to applying for California Institute 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 or her 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 or her, 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.

## **Upperclass Financial Aid**

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 an application packet from the Financial Aid Office in February. The Financial Aid Form and the CIT Scholarship Application should be filled out by parents (or guardian) and the student and returned to the Financial Aid Office by April 15. No one will be considered for financial aid unless an FAF, 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.

## **Financial Aid Funds**

Applicants for admission who have a Financial Aid Form on file will be considered for the best award to which their relative need and academic standing entitle them. It is not necessary to apply for any particular financial aid award by name.

Funds for these awards are provided through gifts from the following donors and are awarded periodically.

Ethel Hazen Allen Scholarship Alumni Scholarships Agbabian Associates Converse Davis Dixon Associates Albert A. Erkel Hillman, Biddison & Loevenguth, Structural Engineers Johnson and Nielsen Associates, Structural Engineers James M. Montgomery, Consulting Engineers Moore and Taber Alumni Association Scholarships Earle C. Anthony Trust ARCS Foundation (Achievement Rewards for College Scientists) of Los Angeles R. C. Baker Foundation Scholarship Berry Holding Company Scholarships Bing Scholarship Robert Roe Blacker and Nellie Canfield Blacker Scholarship Bookstore Scholarships C F Braun & Co Scholarships California Foundation for Biomedical Research Class of 1927 Scholarship Cyprus Mines Corporation Scholarship Louise E. Dabney Scholarships Eastman Kodak Company Scholarship Educational Foundation of America The Henry Ford II Scholar Award Program General Motors Corporation Scholarships The Gnome Club Scholarship Goodyear Scholarship Robert E. Gross-Lockheed Aircraft Corporation Scholarship Harriet Harvey Scholarship Hollywood Canteen Scholarship Walter Humphry Scholarship Earle M. Jorgensen Scholarships JPL/Caltech Management Club Scholarship Clarence F. Kiech Scholarship Henry Kirshner Memorial Scholarship Mackenzie Foundation Premedical Scholarship George H. Mayr Foundation Scholarships Anna and James McDonnell Memorial Scholarship John Navas Scholarship La Verne Noyes Scholarships Charlotte Palmer Phillips Foundation Scholarship Elbert G. Richardson Scholarships

Evalyn Elizabeth Cook Richter Memorial Fund Paul K. Richter Memorial Fund Virginia Steele Scott Scholarships Lois F. Spalding Scholarship Standard Oil Company of California Scholarships John Stauffer Charitable Trust Scholarship Elizabeth Thomas Stone Scholarship Tomiyasu Scholarship Tomiyasu/General Electric Prize Scholarships Walter and Sylvia Treadway Scholarships Vernon O. Underwood Scholarship Waltmar Foundation Scholarships Alice Colby Wheeler Scholarship Brayton Wilbur-Thomas G. Franck Scholarship

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

Roland L. Andreau Scholarship Edward C. Barrett Scholarship Louis D. Beaumont Foundation Scholarships Meridan Hunt Bennett Scholarship and Fellowships Knowlton R. Birge Scholarship Mary Huntington Carr Scholarship William Duncan Chisholm Scholarship Dorothy Hixon Clark Scholarships Earl S. Condon Scholarship Matthew M. Corbett Scholarship Amy Crellin Scholarship Leo P. Delsasso Memorial Scholarship Alexander M. and Florence W. Drake Scholarship Robert S. and Nellie V. H. Dutton Scholarship L. L. Fentress Fund Robert C. Gillis Scholarship Florence A. Hampton Scholarship Robert Haufe Memorial Scholarship Gene B. Heywood Scholarship The Holly Scholarship Albert Hall Hughey Scholarships John C. Lewis Memorial Student Aid Fund Peter Madsen Undergraduate Scholarship Fund William C. McDuffie Scholarship Robert L. Minckler Scholarships David Lindley Murray Educational Fund Frances W. Noble Scholarship Pasadena Optimist Club Scholarship Edgar H. Pflager Scholarship Harry Leslie Remington Memorial Scholarship **Riley Scholarship** Frederick Roeser Loan, Scholarship and Research Fund William E. Ross Memorial Fund Frank Schaak Fund Harold O. Springer Scholarship William W. Stout Scholarship Claudia Wheat Scholarship

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## **Student Aid Loan Funds**

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

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

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

The Institute Loan Funds include the following: ARCS Foundation, Gustavus A. Axelson, W. H. Brown 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 until nine months after termination of formal education. Repayment of principal and interest commences twelve months after termination of formal education. During repayment, 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 223.

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.

*UCB Deferred Payment Plan.* In addition to the above loans a bank plan is available under which any student in good standing may borrow up to \$1,500 each year, not to exceed a maximum of \$6,000. Repayment may be made in installments after gradua-

tion. Interest on the amount borrowed is charged at 1 percent over the bank's commercial prime rate at the time of the inception of the loan and is payable quarterly. The interest is the only payment made under this plan during the undergraduate years. On November 1, following graduation, the student begins repayment at the rate of \$85 per month including interest. For those who go on to graduate school, repayment may be deferred until termination of formal education. If student status is discontinued, the repayment schedule of \$85 per month will begin after a grace period of 120 days.

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

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

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 a \$25 annual fee. These programs offer optional insurance coverage to protect the budget plan selected.

2. The Knight Tuition Payment Plan, offered by the Richard C. Knight Insurance Agency, Inc., 26 O'Farrell Street, San Francisco, California 94108, offers two payment programs. Both programs include insurance protection 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. The monthly payments earn interest at the rate of 5 percent per annum. 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, fees, and any related educational expenses of schooling over a period of one to four years. Life insurance is available to all insurable parents. Monthly repayment starts one month after the first check is received from the Tuition Plan. Cost of this program is for interest expense (which varies from 13 percent to 18 percent) and insurance premiums (if coverage is desired). The maximum number of months allowed for repayment is 96. A Prepayment Program is available which provides a prepaid program of monthly budgeted expenses in advance of each school term. Cost of this plan is a \$25 initial fee plus a \$.50 per month service charge. Insurance is available to insurable parents (if coverage is desired).

#### **Student Employment**

Students who desire part-time or summer employment may receive assistance from the Placement Office. If an undergraduate student is a financial aid recipient, any on-campus or JPL earnings must be considered part of the student's financial aid package. Because academic requirements are so demanding, undergraduate students must receive approval from the Undergraduate Dean to work more than 16 hours per week. Therefore any freshman seeking employment must receive permission from the Dean before he or she may work. We do not recommend that freshmen seek employment during the academic year, at least until after they have had an opportunity to assess their academic workload. *College Work Study Program.* This federally funded program is designed to pay part of the salaries of undergraduate and graduate students who are citizens or permanent residents of the United States. In addition to the above general employment constraints, College Work Study employment is limited to students who are employed by Caltech and JPL and who demonstrate financial need. Further information is available through the Office of Financial Aid; placement assistance can be obtained from the Placement Office.

## **Placement Service**

The Placement Office provides assistance to undergraduate students, graduate students, research fellows, and alumni for the procurement of employment. It arranges for interviews by prospective employers for candidates for degrees and 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 compiles an Annual Report giving information about employment of graduating students. Copies of this report are available from the Placement Service.

The Institute assumes no responsibility in obtaining employment for its graduates, although the Placement Office will make every effort to provide suggestions for employment for those who wish to make use of this service.

#### Merit Basis Scholarships

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

Caltech Prize Scholarships The Carnation Scholarships Jeremy V. Cassaday Award Fund

#### PRIZES

#### The Eric Temple Bell Undergraduate Mathematics Research Prize

In 1963 the Department of Mathematics established an Undergraduate Mathematics Research Prize honoring the memory of Professor Eric Temple Bell and his long and illustrious career as a research mathematician, teacher, author, and scholar. His writings on the lives and achievements of the great mathematicians continue to inspire many hundreds of students at the California Institute and elsewhere. A prize of \$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 Donald S. Clark Memorial Awards

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

## The Haren Lee Fisher Memorial Award in Junior Physics

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

#### The 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 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 Arie J. Haagen-Smit Memorial Fund

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

### 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. Earl McKinney Prize in English

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

The Morgan Ward Prize was established by the Department of Mathematics in 1963 to honor the memory of Professor Morgan Ward in recognition of his long service to mathematics and to the Institute. The competition is open only to freshmen or sophomores. An entry consists of a mathematical problem together with a solution or a significant contribution toward a solution. One or more winners are selected by a faculty committee acting on the advice of student judges. Each prize of \$25 is funded by the same source used to sponsor the Eric Temple Bell Prize.

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

#### The David Joseph Macpherson Prize in Engineering

The David Joseph Macpherson Prize in Engineering was established in 1957 by Margaret V. Macpherson in memory of her father, a graduate of Cornell University in civil engineering, class of 1878. A prize of \$400 is awarded annually to a graduating senior in engineering who exemplifies excellence in scholarship. The winning student is selected by a faculty committee of three, appointed annually by the chairman of the Division of Engineering and Applied Science.
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# UNDERGRADUATE OPTIONS AND COURSE SCHEDULES

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

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

The Institute unit system is described on page 265.

# Institute Requirements, All Options

	Course	Juits
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), CS/EE 11 (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 ter		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) <sup>1</sup>	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 <sup>2</sup>	x	x	х
	Additional Electives <sup>3</sup>	х	х	x
PE 1 abc	Physical Education <sup>4</sup>	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.

<sup>1</sup>This requirement can also be met by completing any two terms of Ch 2 abc or of Ch 41 abc. <sup>2</sup>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; CS/EE 11 - 6 units; Ge 1 - 3 units; Ph 3 - 6 units; Ph 4 - units. <sup>3</sup>A partial list of 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.

<sup>4</sup>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. Ma 108 abc may be accepted if not used to satisfy 1.
- 4. Passing grades must be obtained in a total of 483 units, including the courses listed above.

#### **Typical Course Schedule**

#### Second Year

		Un	Units per ter	
		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 <sup>1</sup>	9	9	9
	Electives	9	9	9
		45	45	45

#### Third Year

AMa 95 abc	Introductory Methods of Applied			
or	Mathematics (4-0-8)	12	12	12
Ma 108 abc	Advanced Calculus (4-0-8)			
	Humanities Electives <sup>1</sup>	9	9	9
	Electives	27	27	27
		48	48	48

#### Fourth Year

AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
	Humanities Electives <sup>1</sup>	9	9	9
	Electives <sup>2</sup>	27	<u>27</u>	27
		45	45	45

<sup>1</sup>See Institute Requirements for specific rules regarding humanities. <sup>2</sup>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 165.

# **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
- Either APh 78 abc, or two terms of APh 91, or one term of APh 91 plus one term of one of the following: APh 154, Ph 77, EE 91, Ch 26, Ae/APh 104 bc, ChE 126, MS 130, MS 131, MS 132
- 5. 54 additional units of APh courses numbered over 100. (Ph 106 abc may be used to satisfy this requirement.) None of these courses shall be elected by the student to be taken on a pass/fail basis. Note that APh 100 and APh 200 do not satisfy this requirement.
- Passing grades must be earned in a total of 516 units, including the courses listed above.

#### Typical Course Schedule

Second Year

		Uni	Units per tei	
		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 <sup>1</sup>	9	9	9
	Laboratory Electives <sup>2</sup>	6	6	6
APh 17 abc	Thermodynamics (3-0-6)	9	9	9
	Other Electives	9	_9	_9
		51	51	51
	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	Introductory Methods of Applied			
	Mathematics (4-0-8)	12	12	12
	Humanities Electives <sup>1</sup>	9	9	9
	Other Electives <sup>3</sup>	18	18	18
		50	50	50
	Fourth Year			
Aph 91 ab	Experimental Projects in Applied Physics <sup>4</sup>	6	6	
Ph 106 abc	Topics in Classical Physics	9	9	9
	APh Electives <sup>3</sup>	9	9	9
	Humanities Electives <sup>1</sup>	9	9	9
	Other Electives	<u>18</u>	<u>18</u>	<u>18</u>
		51	51	45

<sup>1</sup>See Institute Requirements for specific rules regarding humanities.

4See item 4, option requirements.

<sup>&</sup>lt;sup>2</sup>See item 1, option requirements.

<sup>&</sup>lt;sup>3</sup>See item 5, option requirements.

#### **Suggested Electives**

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

Sophomore Year	Junior Year	Senior Year
APh 23	Ph 77 ab	APh 91 c
Ge 1	EE 91 abc	APh 100
Ge 2	EE 114 abc	Ae/APh 101 abo
Bi 1	Ch 26 ab	APh 105 abc
Ay 1	Ge 154 abc	APh 114 abc
ME 1 ab	APh 100	AMa 101 abc
ME 19 abc		AMa 104
EE 13 abc		AMa 105 ab
EE 14 abc		Ch 125 abc
EE 90 abc		Ph 125 abc
Ma 5 abc		Ph 129 abc
MS 15 a		Ph 77 ab
More Specialized Courses <sup>1</sup>		
APh/MS 126 abc	APh 190 abc	
APh 140 abc	APh 195 ab	
APh 141	AM 135 abc	
APh 153 abc	ChE 103 abc	
APh 154	ChE 126 abc	
APh 156 abc	Ch 113 abc	
APh 161 abc	EE 91 abc	
APh 181 abc	EE 155 abc	
	Ge 104 abc	
	Ge 166	

<sup>1</sup>These courses are taught at irregular intervals depending upon demand: consult the preregistration 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 165.

# **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

. . . .

		Ur	uts per i	erm
		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 <sup>1</sup>	0-6	0-6	6
	Humanities Electives <sup>2</sup>	9	9	9
	Electives <sup>3</sup>	0-9	3-6	<u>12-15</u>
	Suggested total number of units	44-47	45-48	45-48
	Third Year			
Ph 92 abc	Modern Physics (3-0-6)	9	9	9
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ay 101	The Physics of Stars (3-2-6)		11	
Ay 102	Plasma Astrophysics and the			
	Interstellar Medium (3-0-6)			9
	Humanities Electives <sup>2</sup>	9	9	9
	Electives	18-24	9-12	9-15
	Suggested total number of units	45-51	47-50	45-51
	Fourth Year			
	Astronomy or Physics Electives	18	18	18
	Humanities Electives <sup>2</sup>	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<sup>4</sup>, AMa 105ab, 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<sup>4</sup>, Ph 125 abc<sup>4</sup>, Ay 22, Ay 100, Ay 110, Ay 131, Ay 132, Ay 133 ab, and Ay 141.

<sup>&</sup>lt;sup>1</sup>Students are required to take (a) Ph 3 if not already taken, (b) Ph 5 or Ph 6, and (c) Ph 7.

<sup>&</sup>lt;sup>2</sup>For rules governing humanities electives, see page 179. <sup>3</sup>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

<sup>&</sup>quot;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 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, and Ch 41 abc.
- 2. An additional 57 units of Bi courses.
- 3. Passing grades must be earned in a total of 516 units, including the courses listed above.

# **Typical Course Schedule**

Second Year

		Unit	s per	term
		1st	2nd	3rd
	Humanities Electives <sup>1</sup>	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
10 1	170	45-51	45-51	45-51

<sup>1</sup>For rules governing humanities electives, see page 179.

#### Third Year

Bi 7	Humanities Electives	9 9	9	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 <sup>1,2,3</sup>	15-21	14-20	24-30
		45-51	45-51	45-51
	Recommended Elective <sup>2</sup>			
Ch 21 abc	The Physical Description of			
	Chemical Systems	9	9	9
	Fourth Year			
	Humanities Electives	9	9	9
Bi 150	Neurobiology (4-0-6)	10		
	Electives <sup>3</sup>	26-32	36-42	36-42
		45-51	45-51	45-51

#### Suggested Electives

#### Second Year

Second Term: Ch 46a 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 22, Bi 23, Bi 27, Bi 119, Bi 137, Bi 156, Bi 157, Bi 158, 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 151, Bi 209, Bi 216, Bi 217, Bi 220 a, Bi 260, Ch 144 a, Ch 244 a
- Second Term: Bi/Ch 132 b, Bi/Ch 133, Bi 152, Bi 161, Bi 209, Bi 214, Bi 220 b, Bi 260, Ch 144 b, Ch 244 b, Env 145 a
- Third Term: Bi 115, Bi/Ch 132 c, Bi/Ch 133, Bi 141, Bi 209, Bi 218, Bi 220 c, Bi 241, Bi 260, Env 145 b, Ge 5

<sup>1</sup>Electives must include sufficient units of work in Biology to complete the graduation requirement for 140 units of work in Biology. <sup>2</sup>Ch 21 is strongly recommended for students interested in chemical biology, as many graduate

<sup>2</sup>Ch 21 is strongly recommended tor students interested in chemical biology, as many graduate programs expect entering students to have taken a course in physical chemistry. <sup>3</sup>The sequence of courses, Bi 150, Bi 156, Bi 157, Bi 151, and Bi 152 is designed to provide a

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

# **Chemical Engineering Option**

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

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

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

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

Juniors take courses in the physical description of chemical systems 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. Third-year students may also take the chemical engineering laboratory during the first term and may continue that laboratory or take the laboratory in physical chemistry. If the student wishes, electives may be taken in place of the laboratory courses during the junior year; in this case, the laboratory courses would be taken during the senior year.

Seniors take a course in applied chemical kinetics involving the basic study of chemical reactions combined with transport processes in systems of practical interest. This work in kinetics and other previous chemical engineering courses are applied to 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 165.

#### **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<sup>1</sup>
- 2. 4 units of laboratory other than AMa and CS, in addition to requirements in (1) above, and not including AMa, CS, or 18 units of chemistry electives
- 3. 18 units of chemistry electives<sup>2</sup>
- 27 units of science and engineering electives<sup>3</sup>
- Passing grades must be earned in a total of 516 units, including the courses listed below.

<sup>1</sup>These 9 units partially satisfy the Institute requirements in Humanities and Social Sciences. <sup>2</sup>In addition to chemistry courses taught within the Division of Chemistry and Chemical Engineering, other courses such as Bi 110 and Env 142 may be used to satisfy this requirement. <sup>3</sup>If research units (ChE 80) are to be used to fulfill elective requirements in the chemical en-

<sup>3</sup>If research units (ChE 80) are to be used to fulfill elective requirements in the chemical engineering option, a written research report approved by the research director must be submitted in duplicate before May 10 of the year of graduation.

#### **Typical Course Schedule**

#### Second Year

		Uni	ts 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			
ChE 126 ab AMa 95 abc	Chemical Engineering Laboratory (1-6-2) Introductory Methods of Applied	9	9	
Ch 21 abc	Mathematics (4-0-8) The Physical Description of Chemical	12	12	12
	Systems (3-0-6)	9	9	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
	Electives	9	9	18
		48	<b>48</b>	48
	Fourth Year			
ChE 101 ab	Applied Chemical Kinetics (3-0-6)	9	9	
ChE 110 ab	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 156. 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.

Beyond the freshman year, each student in the Chemistry option, in consultation with his or her adviser, selects a suitable course of study under the supervision of the division. Undergraduates in the Chemistry option are required to pass the following courses — Ch 14, Ch 21 abc, Ch 41 abc, and Ch 90, and a minimum of four quarters of laboratory work chosen from Ch 15, Ch 26 ab, Ch 46 ab, and Bi 111. Under-

graduates in the option must also take chemistry courses below the 100 level for a letter grade with the exception of Ch 1, Ch 2, Ch 3, and Ch 90, which are only graded pass/fail. A student wishing to deviate from these requirements should submit, with justification, an alternate curriculum for consideration by his or her adviser and the Undergraduate Study Committee. Within the total period of undergraduate study there are additional Institute requirements for Ma 1 abc, Ph 1 abc, Ma 2 abc, Ph 2 abc, and 108 units of humanities and/or social science as well as 9 units of PE.

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

Any student of the chemistry option whose grade-point average is less than 1.9 will be admitted to the option for the following year only with the special permission of the Division of Chemistry and Chemical Engineering.

#### **Option Requirements**

- 1. Ch 14, Ch 21 abc, Ch 41 abc, Ch 90, and a minimum of four quarters of laboratory work chosen from Ch 15, Ch 26 ab, Ch 46 ab, and Bi 111.
- 2. Passing grades must be earned in an approved program of study, including the courses listed above.

#### **Typical Course Schedule**

#### Second Year

		Unif	Units per te	
		1st	2nd	3rd
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electromagnetism and Quantum Mechanics			
	(4-0-5)	9	9	9
Ch 46 a	Experimental Methods of Covalent			
	Chemistry (1-6-2)		9	
	Electives	15-18	6-9	15-18
PE	Physical Education (0-3-0)	3	3	3
		45-48	45-48	45-48

#### Third Year

Ch 14	Chemical Equilibrium and Analysis (2-0-4)	6		
Ch 15	Chemical Equilibrium and Analysis			
	Laboratory (0-6-4)	10		
Ch 21 abc	The Physical Description of Chemical			
	Systems (3-0-6)	9	9	9
Ch 90	Oral Presentation (1-0-1)	2		
	Electives	18-22	38-42	36-40
		45-49	47-51	45-49

#### Fourth Year

Ch 26 a	Physical Chemistry Laboratory (0-6-4)	10	
	Electives	<u>37-41</u>	<u>47-51</u>
	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 <sup>1,2</sup>	Electives <sup>1,2</sup>	Electives <sup>1,3</sup>	Electives 1,3
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 ab
Electives <sup>1,2</sup>	Ch 90	Ch 90	Ch 90
	AM 95 ab	Electives <sup>1,3</sup>	Electives <sup>1</sup>
	Electives <sup>1,2</sup>		
Senior Year	Senior Year	Senior Year	Senior Year
Ch 26 ab	Ch 125 abc	Ch 26 ab	Ch 26 ab
Ch 112 abc or	Ph 106 abc or	L 391	Bi/Ch 132 ab
Ch 113 abc	Ch 135 ab	Ch 247 ab or	Bi/Ch 133
Ch 125 ab or	Ch 227 ab	Ch 242 ab	Ch 144 ab
Ch 120 abc or	Electives <sup>1.2</sup>	Electives <sup>3</sup>	Bi 111
Ch 135 ab or		4	Electives <sup>1</sup>
Ch 144 ab			
Electives <sup>1,2</sup>			

<sup>1</sup>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.

<sup>2</sup>Experience in computer programming and use is now important to all areas of chemistry. <sup>3</sup>Courses in biology and biochemistry are recommended as part of these electives.

#### **Suggested Elective Courses** for the Chemistry Option

1. Chemistry: ExperimentalChemicalScience(Ch3), ChemicalResearch(Ch80), 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), Introduction to Statistical Thermodynamics (ChE/Ch 164), Biophysical Chemistry of Macromolecules (Bi/Ch 132), Biophysical Chemistry of Macromolecules Laboratory (Bi/Ch 133), and Advanced Organic Chemistry (Ch 144).

- 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).
- Engineering: Introductory Methods of Applied Mathematics (AMa 95), Laboratory Research Methods in Engineering and Applied Science (E 5), Introduction to Solid-State Electronics (APh 3), Solid-State Electronics Laboratory (APh 9), Introduction to Linear Electronics (EE 5), Laboratory in Electronics (EE 90), Introduction to Computing (CS 10).
- 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 141).
- 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 142a
- 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 freshman laboratory courses or courses primarily for freshmen, graded on a pass/fail basis, and not serving as prerequisites for more advanced courses. The courses Ay 1, Bi 1, Env 1, and Ge 1 may be taken to satisfy this requirement only if taken after the freshman year. Note: AMa 181 abc may count toward either this requirement or the economics electives requirement, but not toward both.
- 5. Passing grades must be earned in a total of 516 units, including courses listed above.

#### **Typical Course Schedule**

#### Second Year

	Units per ter		term
	1st	2nd	3rd
Sophomore Mathematics (4-0-5)	9	9	9
Electromagnetism and Quantum			
Mechanics (4-0-5)	9	9	9
Introduction to Microeconomics (3-0-6)	9	9	9
Introduction to Macroeconomics:			
Principles and Problems (3-0-6)		9	
Electives <sup>1</sup>	18	9	18
	45	45	45
Third Year			
Intermediate Microeconomics (3-0-6)	9	9	
Econometrics (3-0-6)		9	
Money Income, and Growth (3-0-6)	. 9	9	•
Statistice (3-0-6)	9	-	•
Computer Modeling and Data			•
Analysis (3-0-6)	9		
Electives <sup>1</sup>	9	18	45
	45	45	45
Fourth Year			
	45	45	45
	Sophomore Mathematics (4-0-5)   Electromagnetism and Quantum   Mechanics (4-0-5)   Introduction to Microeconomics (3-0-6)   Introduction to Macroeconomics:   Principles and Problems (3-0-6)   Electives <sup>1</sup> Third Year   Intermediate Microeconomics (3-0-6)   Econometrics (3-0-6)   Statistics (3-0-6)   Computer Modeling and Data   Analysis (3-0-6)   Electives <sup>1</sup>	UnistSophomore Mathematics (4-0-5)Belectromagnetism and QuantumMechanics (4-0-5)Mechanics (4-0-5)Introduction to Microeconomics (3-0-6)Principles and Problems (3-0-6)Electives1Intermediate Microeconomics (3-0-6)Principles and Problems (3-0-6)Principles and Problems (3-0-6)Electives1Intermediate Microeconomics (3-0-6)Peconometrics (3-0-6)Peconometrics (3-0-6)Peconometrics (3-0-6)Peconometrics (3-0-6)Peconometrics (3-0-6)PeriodPeconometrics (3-0-6)Period <tr< td=""><td>Units per 1stSophomore Mathematics (4-0-5)9Electromagnetism and Quantum Mechanics (4-0-5)9Mechanics (4-0-5)9Introduction to Microeconomics (3-0-6)9Principles and Problems (3-0-6)9Electives118<math>\frac{18}{45}</math>9Electives19Intermediate Microeconomics (3-0-6)9<math>\frac{9}{45}</math>9Computer Modeling and Data Analysis (3-0-6)9<math>\frac{9}{45}</math>18<math>\frac{9}{45}</math>18<math>\frac{18}{45}</math>9<math>\frac{18}{45}</math>45</td></tr<>	Units per 1stSophomore Mathematics (4-0-5)9Electromagnetism and Quantum Mechanics (4-0-5)9Mechanics (4-0-5)9Introduction to Microeconomics (3-0-6)9Principles and Problems (3-0-6)9Electives118 $\frac{18}{45}$ 9Electives19Intermediate Microeconomics (3-0-6)9 $\frac{9}{45}$ 9Computer Modeling and Data Analysis (3-0-6)9 $\frac{9}{45}$ 18 $\frac{9}{45}$ 18 $\frac{18}{45}$ 9 $\frac{18}{45}$ 45

<sup>1</sup>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, bioinformation systems and computer science, solid mechanics, the science of materials, soil mechanics, bio-engineering science, elasticity and plasticity, plasma physics, and the theory of waves and vibrations. For those students who, in later life, hope to apply the science they learn to the useful and productive solution of the problems now confronting society, the option in engineering and applied science offers an unusually broad curriculum 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 165.

#### **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 the pass/fail option on any courses offered to meet this requirement.
- 4. 9 units1 of courses taken from the following list: APh 24, APh 154, APh 91 abc, Ae/APh 104 bc, AM 155, CE 105, CE 180, CS/EE 121, CS 140, E 99, EE 90 abc2, EE 91 abc, EE 194, Env 116, Env 143, Hy 111, Hy 121, JP 170, MS 90, MS 130, MS 131, MS 132, ME 126.
- 5. 9 units<sup>1</sup> of additional laboratory<sup>3</sup> 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.
- 8. Design (Synthesis). A total of 60 units must be taken from among the following courses: E 5, E 99, E 101, E 126, Ae 107, Ae/APh 104 bc, AM 155, CS/EE 11, CS 112, CS 114, CS 116, CS/EE 121, CS 140, CE 10, CE 17, CE 121, CE 150, EE 91, EE 114, Env 116, Env 146, ChE/Env 157, Hy 105, ME 1, ME 5, ME 101, ME 102

#### **Typical Course Schedule**

#### Second Year

	Units per term		
	1st	2nd	3rd
Ma 2 abc	9	9	9
Ph 2 abc	9	9	9
Humanities Electives	9	9	9
Electives	18	18	18
	45	45	45
Third Year			
AMa 95 abc or Ma 108 abc	12	12	12
Humanities Electives	9	9	9
Electives	24	24	24
	45	45	45

<sup>1</sup>These units will partially satisfy requirement 3 when in appropriate subjects. <sup>2</sup>Only 6 units of this course can be used to fulfill items 4 and 5. <sup>3</sup>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.

# Fourth Year

E 10		2	
Humanities Electives	9	9	9
Electives	33	33	33
	42	44	42

#### NOTES:

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

#### **Suggested Electives**

# **AERONAUTICS**

#### First Year

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

#### Second Year

APh/ME 17 abc; one course per term selected from: ME 1 ab, MS 15 abc, Ay 1, EE 5, APh 3, 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, ME 5 abc, MS 5 abc, E 101

#### Fourth Year

Ae/APh 101 abc, or Hy 101 abc, or Ae/AM 102 abc, and three courses per term selected from: Ae 103 abc, Ae/APh 104 abc, AMa 101 abc, AM 155, Hy 111, ME 126, JP 121 abc, APh 101, MS 120, MS 121, MS 122

#### APPLIED MECHANICS

#### First Year

One course per term selected from: E 5, Ge 1, CS/EE 4, CS 10, CS/EE 11

#### Second Year

One course per term selected from: APh/ME 17 abc, MS 15 abc, Ge 1, Bi 1, Ma 31, E 13

#### Third Year

AM 97 abc or AM 151 abc, ME 19 abc; one course per term selected from: Ge 2, Ma 112 ab, EE 90 abc, APh 50 abc, MS 5 abc

#### Fourth Year

AM 151 abc or AM 97 abc, AM 155, AM 125 abc or AMa 101 abc; one or two courses per term selected from: ME 126, AM 135 abc, AM 141 abc, Hy 101 abc, Ph 106 abc, AMa 104, AMa 105 ab

#### COMPUTER SCIENCE

#### First Year

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

#### Second Year

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

#### Third Year

CS 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

#### ELECTRICAL ENGINEERING

#### First Year

One or two courses per term selected from APh 3, APh 9, CS/EE 4, CS 10 ab, CS/EE 11, EE 5, Ph 3

#### Second Year

EE 14 abc, EE 90 abc, electives a (below)

#### Third Year

EE 13 ab, EE 115, EE 40, EE 60, electives b (below)

#### Fourth Year

Ee 91 ab, EE 151 abc, 2 electives c (below)

Suggested electives for various areas of EE specialization are:

Communications

- a. Selected from APh 23, APh 24, CS 112, CS 114, CS 116, CS/EE 121.
- b. EE 160 abc (substituted for EE 60), Ma 112 a
- c. AMa/EE 161 abc or EE 163 abc and selections from Ae/ChE/EE 172 abc, CS 137, EE 112 abc, EE 118, EE 119 ab, EE 194.

#### Control

- a. Selected from APh/ME 17 abc, E 13, E 101
- b. E 102 abc
- c. Ae/ChE/EE 172 abc, and selections from EE 112 abc, EE 113, EE 118, EE 120, EE 160 abc
- **Electronic Circuits**
- a. Selected from APh/ME 17 abc, E 13, E 101
- b. Selected from APh 50 abc, CS 112, CS 114, CS 116, CS/EE 121.
- c. EE 114 abc and selections from EE 112 abc, EE 113, EE 116, EE 117, EE 118, EE 119 ab, EE 120, EE 160 abc
- Quantum Electronics
- a. APh/ME 17 abc, APh 23, APh 24
- b. APh 50 abc
- c. Selected from APh 105 abc, APh 114 abc, APh 153 abc, APh 154, APh 190 abc, APh 195 ab, EE 155 abc, EE 194, Ph 125 abc
- Solid State Electronics
- a. APh/ME 17 abc
- b. APh 50 abc
- c. APh 181 abc, and selections from APh 105 abc, APh 114 abc

# ENERGY ENGINEERING First Year

One course per term selected from: APh 3, APh/MS 4, APh 9, ChE 10, E 5, CS/EE 4, CS/EE 11, Env 1, Gr 1, CS 10

#### Second Year

APh/ME 17 abc or ChE 63 abc; one course per term selected from: 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, Env/Ge 103 abc

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

#### ENVIRONMENTAL ENGINEERING SCIENCE

#### First Year

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

#### Second Year

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

#### Third Year

Env 20, ME 19 abc or ChE 103 abc, Ch 21, AMa 95 abc, Ec 118

#### Fourth Year

Those interested in air quality should take ChE/Env 157 ab, Env 116 and Env 170 ab. Those interested in water quality should choose from: Env 112 abc, Env/Ge 103 ab, Env 142 ab, Env 143, Env 145 ab, Env 146 abc

#### FLUIDS ENGINEERING AND JET PROPULSION

#### First Year

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

#### Second Year

APh/ME 17 abc, APh 3, Env 20, CS/EE 4, APh/MS 4, EE 5

#### Third Year

ME 19 abc, AM 97 abc; one course per term selected from: ME 1 ab; MS 5 abc; E 13, EE 13 bc

# Fourth Year

ME 118 abc, JP 121 abc; one course per term selected from: Hy 101 abc, AM 151 abc, ME 102 abc, Hy 111, ME 126, JP 170, E 101

# 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

APh/ME 17 abc; one course per term selected from: Ph 3, Ph 4, CS/EE 4, CS/EE 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 or ME 126, Hy 113 ab, Env 112 abc, or Env 117 or Env 146 abc

#### MATERIALS SCIENCE

## First Year

One course per term selected from: E 5, CS/EE 4, CS 10, ChE 10, APh 3, APh 9, APh/MS 4

#### Second Year

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

### Third Year

AM 97 abc, MS 5 abc, APh 50 abc, MS 15 abc

Fourth Year MS 90, MS 120, MS 121, MS 126 abc

#### MECHANICAL DESIGN

#### First Year

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

#### Second Year

ME 1 ab, APh/ME 17 abc, MS 15 abc

#### Third Year

ME 19 ab, AM 97 abc; one course per term selected from: ME 5 abc, ME 126, CS 10, EE 90

# Fourth Year

AM 151 abc, MS 5 ab; two courses per term selected from; Ae 107 abc, AM 155, E 13, E 101 or EE 13 a and EE 13 bc

# STRUCTURAL AND SOIL MECHANICS

#### First Year

One course per term selected from: Gr 1, CS 10, E 5, Ge 1, Ge 2

#### Second Year

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

#### Third Year

AM 97 abc, ME 19 abc

#### Fourth Year

CE 10 abc, CE 115 ab and CE 105, AM 151 abc, CE 180, CE 181, and CE 182 or Hy 113 ab and Hy 111, Env 112 abc or Env 146

# STRUCTURE AND PROPERTIES OF ALLOYS

### First Year

One course per term selected from: E 5, CS 10, Gr 1, ChE 10, CS/EE 4, APh 3, APh 9, APh/MS 4

#### Second Year

APh/ME 17 abc; one course per term selected from: ME 1 ab, MS 15 abc, EE 5

#### Third Year

AM 97 abc, MS 5 abc, APh 105 abc, Ch 21 abc, APh 50 abc

#### Fourth Year

APh 114 abc, MS 90, MS 120, MS 121, MS 125, MS 126 abc, Ph 125 abc, MS 130, MS 131, MS 132

# Geology, Geochemistry, Geophysics, and Planetary Science Options

The aim of the undergraduate program in the geological sciences is to provide thorough training in basic geological disciplines and, wherever possible, to integrate the geological studies with and build upon the courses in mathematics, physics, chemistry, and biology taken during the earlier years at the Institute. 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, 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 Requ	uirements					
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 <sup>1</sup>		27			
	Total required courses	126	108	27		27

<sup>1</sup>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.

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#### 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<sup>1</sup> ..... 30 Total required courses<sup>2</sup> ..... 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 The Physical Description of Chemical Systems<sup>3</sup> 27 Ch 14 Chemical Equilibrium and Analysis 6 Chemical Equilibrium and Analysis Ch 15 Laboratory 10 99 30 112 Geology Option Requirements Ge 107 Structural Geology ..... 9 Ge 114 Optical and X-Ray Mineralogy ..... 12 Petrology and Petrography Ge 115 ac 24 Ge 123 Summer Field Geology ..... 30 Ge 121 abc Advanced Field Geology ..... 36 Ch 21 abc The Physical Description of Chemical Systems<sup>3</sup> 27 27 Geology Electives<sup>4</sup> ..... 30 132 Geophysics and Planetary Science Option Requirements

Ph 106 abc	Topics in Classical Physics			27	
AMa 95 abc	Introductory Methods of Applied Mathematics			36	
	Option Electives <sup>5</sup>				54
	Total required courses	126	108	135	114

<sup>1</sup>The division requires 30 units of French, German, or Russian for graduation. Students with a <sup>2</sup>The division requires 30 times 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. <sup>2</sup>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. <sup>3</sup>Ch 41 abc or other chemistry courses may be substituted with prior consent of adviser and

<sup>4</sup>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. <sup>5</sup>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 con-

sent of the student's adviser.

# **History Option**

History majors must take not less than 99 units of H courses during their four years as undergraduates. Of these, not less than 45 *must* be in junior and senior tutorial (H 97 ab and H 99 abc), and another 18 *may* be in H 98 ab if a student wishes and his or her instructors agree.

The courses and tutorials in the history option cover four areas: medieval Europe to 1500, modern Europe, the United States, and Asia. Each history major will concentrate in one of these areas and write a research paper in it (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 freshman laboratory courses or courses primarily for freshmen, graded on a pass/fail basis, and not serving as prerequisites for more advanced courses. The courses Ay 1, Bi 1, Env 1, and Ge 1 may be taken to satisfy this requirement only if taken after the freshman year.
- 4. Passing grades must be earned in a total of 516 units, including the courses listed above.

#### **Typical Course Schedule**

A suggested program follows. Requirements are underlined; courses in parentheses are recommended.

	Second Year		
		Units per term	
	1st	2nd	3rd
Ma 2 abc (4-0-5)	9	9	9
Ph 2 abc (4-0-5)	9	9	9
Middle- or Upper-Level History,			
Literature, Philosophy, or			
Language	9	9	9
Introductory Social Science	9 (Ec/SS 11	a) 9 (Ec/SS 11 b	o) 9 (Ec/SS 11 c)
Electives	9	9	9
	45	45	45
	Third Year		
H 97 ab (2-0-7)		9	9
Science or Math	9	9	9 (Ma 112a)
History electives	9	9	9
Other electives	27	<u>18</u>	<u>18</u>
	45	45	45
	Fourth Year		
H 99 abc (1-0-8)	9	9	9
Science or Math	9	9	9
History electives	9 (H 98 a)	9 (H 98 b)	9
Other electives	18	<u>18</u>	<u>18</u>
	45	45	45

# Independent Studies Program

The Independent Studies Program (ISP) is an undergraduate option that allows the student to create his or her own scholastic requirements, under faculty supervision, and to pursue positive educational goals that cannot be achieved with a normal option. A student's program may consist of normal Caltech courses, research courses, courses at other schools, and independent study courses (item 5 below). In scope and depth the program must be comparable to a normal undergraduate program, but it need not include the specific courses or groups of courses listed in the formulated Institute requirements for undergraduates.

The ISP Committee, a standing committee of the faculty, has overall responsibility for the program. In addition, each student has his or her own committee of three advisers, two of whom must be professorial faculty. The Registrar keeps records and transcripts of all ISP students, and has application materials for admission into ISP.

#### Administrative Procedures and Guidelines

1. The student submits a written proposal describing his or her goals, reasons for applying and plan of study for at least the next year. The student must also recruit three faculty members, representing at least two divisions of the Institute, who approve of his or her plans and agree to act as an advisory "committee of three."

2. The committee of three forms the heart of the program and bears the chief responsibility for overseeing the student's progress. The chairman and one other member must be on the professorial staff. The third member may be any qualified individual such as a postdoctoral fellow, graduate student or faculty member of another institution. 3. The ISP committee considers each proposed program in consultation with the prospective members of the committee of three. If the program seems suitable, a three-party written contract is drawn up among the ISP committee, the committee of three, and the student. This contract includes the agreed-upon content of the student's program and the methods for ascertaining satisfactory progress for those parts of the student's program 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. 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 pretwentieth-century English literature: Lit 106 a, Lit 112 a or b, Lit 116, Lit 120, Lit 122 a or b, Lit 125 a and b, Lit 126
  - c. 27 units (three terms) selected from the following courses in American Literature: Lit 132, Lit 134, Lit 136, Lit 138, Lit 140, Lit 142 a or b or c, Lit 146 a
- 2. L 102 abc or L 130 abc or L 141 abc or the equivalent
- 3. 54 units of science, mathematics, and engineering courses. This requirement cannot be satisfied by freshman laboratory courses or courses primarily for freshmen, graded on a pass/fail basis, and not serving as prerequisites for more advanced courses. The courses Ay 1, Bi 1, Env 1, and Ge 1 may be taken to satisfy this requirement only if taken after the freshman year.
- 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 <sup>1</sup>	24	24	_24
		42	42	42
	Third Year			
	Electives	45	45	45
	Fourth Year			
	Electives	45	45	45

<sup>181</sup> 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

Units per term

continue the work of the mathematics option. A fuller statement of this regulation will be found on page 165.

# **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 123 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

		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, <sup>1</sup> minimum for first			
	two years: 45 units	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, <sup>1</sup> 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
	Equith Year			
	Tourin Icui			
	Selected course in Mathematics Humanities Electives, <sup>1</sup> minimum for	9	9	9
	graduation: 108 units Electives in Mathematics, Science,	9-18	9-18	9-18
	Engineering or Humanities minimum For each term the total number of units is	18	18	18
	required to fall within range	36-45	36-45	36-45

<sup>1</sup>For rules governing humanities electives, see page 179.

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.

# **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 in 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 165.

#### **Option Requirements**

- 1. Ph 3 or Ph 4
- 2. Ph 5 or Ph 61
- 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 103 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.

<sup>1</sup>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.

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# **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 <sup>1</sup>	9	9	9
Physics Laboratory <sup>2</sup>	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 <sup>1</sup>	9	9	9
Electives	18	18	18
	45	45	45

# Fourth Year

Ph 77 ab	6	6	
Physics Electives	18	18	18
Humanities Elective <sup>1</sup>	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 <sup>3</sup>	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

<sup>2</sup>See Institute Requirements for specific rules regarding humanities. <sup>2</sup>See Option Requirements 1, 2 and 3. <sup>3</sup>Several lower-division laboratory courses from other options (APh 24, EE 90, etc) have consid-erable physics content, and students wishing to substitute such a course for the requirement of Ph 5 or Ph 6 may petition the Physics Undergraduate Committee to do so.

#### Suggested Electives

	Sophomore Year	
Ma 5 abc	Ay 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 103 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, 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 freshman laboratory courses or courses primarily for freshmen, graded on a pass/fail basis, and not serving as prerequisites for more advanced courses. The courses Ay 1, Bi 1, Env 1, and Ge 1 may be taken to satisfy this requirement only if taken after the freshman year. Note: AMa 181 ab may count toward either this requirement or the economics electives requirement, but not toward both.
- 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

		Uni	ts per t	erm
		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			
Ma 112 a or	Statistics (3-0-6)	9		
CS/SS 142 a	Computing Modeling and Data Analysis			
00.00 112 0	(3-0-6)	9		
Ec 121 ab	Intermediate Microeconomics (3-0-6)	9	9	
Ec 122	Econometrics (3-0-6)		9	
PS/SS 122	Formal Theories in 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			
	Electives <sup>1</sup>	45	45	45
		45	45	45

 $^{1}\mbox{Students}$  may concentrate on research by taking 54 units of supervised research in their senior year.



# Section IV

# INFORMATION AND REGULATIONS FOR THE GUIDANCE OF GRADUATE STUDENTS

# THE GRADUATE PROGRAM

The Institute offers graduate work leading to the degrees of Master of Science and Doctor of Philosophy. In addition, it offers the following intermediate degrees: Aeronautical Engineer, Civil Engineer, Electrical Engineer, and Mechanical Engineer. The academic work of the Institute is organized in six divisions:

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

Graduate work at the Institute is further organized into graduate options. 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 1978-79 are as follows:

Aeronautics:	Prof. C. D.
Applied Mathematics:	Prof. H. B.
Applied Mechanics:	Prof. F. S.
Applied Physics:	Prof. D. L.
Astronomy:	Prof. P. Wa
Biology:	Prof. C. J.
Chemical Engineering:	Prof. L. G.
Chemistry:	Prof. W. A.
Civil Engineering:	Prof. F. S.
Electrical Engineering:	Prof. R. V.
Engineering Science:	Prof. F. S.
Environmental Engineering Science:	Prof. F. S.
Geological and Planetary Sciences:	Prof. A. L.
Materials Science:	Prof. F. S.
Mathematics:	Prof. R. P.
Mechanical Engineering:	Prof. F. S.
Physics:	Prof. W. W
Social Sciences:	Prof. L. E.

Babcock, Jr. Keller Buffington Smith nnier Brokaw Leal Goddard III Buffington Langmuir Buffington Buffington Albee Buffington Dilworth Buffington haling 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 at Pasadena City College for those students who need to improve their command of the language or who wish to perfect it. Information regarding these classes can be obtained from the Chairman of the Faculty Committee on Foreign Students and Scholars or from the International Desk. It is strongly recommended, however, that students who achieve a low TOEFL score make arrangements for remedial work during the summer preceding their registration.

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, and Mechanical Engineer, after a minimum of six 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. 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.

#### 212 Graduate Information

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 209) 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 217).

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 to accept it under more stringent conditions.

# Caltech Graduate Students Working at Special Laboratories

a. Any student who desires to take advantage of the unique opportunities available at the Special Laboratories, e.g., JPL or EQL, for Ph.D. thesis work, should be allowed to do so, provided he or she maintains good contact with academic life on campus, and the Laboratories commit support for the duration of the thesis research, and provided that all Caltech graduate thesis research carried out at the Special Laboratories be under the supervision of Caltech faculty members.

- b. A student's request to carry out thesis work at the Special Laboratories should be formally endorsed by the appropriate committee of his or her option and by an appropriate Special Laboratories group on a petition submitted through the option representative to the Dean of Graduate Studies. By such approval, the Special Laboratories would recognize their commitment of special equipment or any other resources required to the thesis work. Approval of the Special Laboratories should also indicate that the thesis topic is a sensible one from their point of view, but that the subject is not likely to be preempted from the student.
- c. Special Laboratories support of Caltech students doing thesis research at the Special Laboratories should be provided, if possible, in the form of a traineeship or otherwise through a campus graduate research assistantship (GRA) under a suitable work order. In this way a student can also receive a tuition 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 163), Pass-Fail grading may also be used, as described on page 164.

#### Exchange Program with Scripps Institution of Oceanography

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

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

# DEGREE REGULATIONS

#### Degree of Master of Science

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

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

A student who enters the Institute holding a master's degree from another institution will not normally be awarded a master's degree in the same field from the Institute unless the initial admission to Caltech graduate standing indicated that the student was to be a master's candidate. A student may not normally be awarded two master's degrees from the Institute.

Special regulations for the master's degree in each graduate option are on pages 224 through 263.

Residence and Units of Graduate Work Required. At least one academic year of residence at the Institute (as defined on page 211) and 135 units of graduate work subsequent to the baccalaureate degree are required for the master's degree. Included in these units are at least 27 units of free electives or of required studies in the humanities. Courses used to fulfill requirements for the bachelor's degree may not be counted as graduate residence.

To qualify for a master's degree, a student must complete the work indicated in the section on special regulations for his or her option with a grade-point average for the approved M.S. candidacy courses of at least 1.9, considering for this purpose only the grade of "P" as being equivalent to "C," and excluding grades for research.

In special cases, with the approval of the instructor and the Dean of Graduate Studies, courses taken elsewhere 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.

*Registration.* Continuity of registration must be maintained until all requirements for the master's degree have been completed, with the exception of summer terms and authorized leaves of absence.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree, he or she must file in the Office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. On the candidacy form, the student will submit a proposed plan of study, which must have the approval of his or her department. This plan of study, if approved, shall then constitute the requirements for the degree, and changes in the schedule will not be recognized unless initialed by the department representative.

All changes in registration must be reported on drop or add cards to the Registrar's Office.

#### Engineer's Degree

The work for an engineer's degree must consist of advanced studies and research in the field appropriate to the degree desired. It must conform to the special requirements established for the degree desired and should be planned in consultation with the members of the faculty concerned. Regulations governing registration will be found on page 211. 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 211) 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.

*Registration*. Continuity of registration must be maintained until all requirements for the engineer's degree have been completed, with the exception of summer terms and authorized leaves of absence.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree he or she must file in the office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. Upon receipt of this application, the Dean, in consultation with the chairman of the appropriate division, will appoint a committee of three members of the faculty to supervise the student's work and to certify to its satisfactory completion. One of the members of the committee must be in a field outside the student's major field of study. The student should then consult with this committee in planning the details of this work. The schedule of his or her work as approved by the committee shall be entered on the application form and shall then constitute a requirement for the degree. Changes in the schedule will not be recognized unless initialed by the proper authority. No course 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 same regulations as govern 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 the thesis by the chairman of the division and the members of the supervising committee, on a form obtained from the office of the Dean of Graduate Studies.

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

#### Degree of Doctor of Philosophy

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

Subject to the general supervision of the Committee on Graduate Study, the student's work for the degree of Doctor of Philosophy is specifically directed by the department in which he or she has chosen the major subject. Each student should consult his or her department concerning special divisional and departmental requirements. See pages 224-263.

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.

A student who holds a Ph.D. degree from another institution will not normally be admitted to graduate standing at Caltech to pursue a second Ph.D. degree. A student will not normally be awarded two Ph.D. degrees from the Institute.

*Minor Programs of Study.* The Institute has no required minor program for the degree of Doctor of Philosophy, but individual options may have minor requirements at their discretion and on the approval of the Graduate Study Committee. Those students enrolled in a doctoral program prior to October 1, 1974, will have the choice of completing their work under this new policy or under the minor policy in effect at the time they were first enrolled. For the earlier policy, reference may be made to copies of catalogs on file in the Graduate Office or in divisional offices.

A student who has satisfied the requirements for a minor program of study will be given recognition by explicit mention of the minor field on the Ph.D. diploma.

*Residence.* At least nine terms (three academic years) of residence subsequent to a baccalaureate degree equivalent to that given by the Institute are required for the doctor's degree. Of this at least one year must be in residence at the Institute. It should be understood that these are minimum requirements, and students must usually count on spending a somewhat longer time in residence. However, no student will be allowed to continue work toward the doctor's degree for more than 15 terms of graduate residence, nor more than 18 registrations for full- or part-time academic work except by special action of the Committee on Graduate Study. In either case graduate study taken elsewhere will be counted when residence credit at the Institute has been allowed. (See page 211 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.

Registration. Continuity of registration must be maintained until all requirements for

the doctor's degree have been completed, with the exception of summer terms and authorized leaves of absence.

Admission to Candidacy. On recommendation of the chairman of the division concerned, the Committee on Graduate Study will admit a student to candidacy for the degree of Doctor of Philosophy after the student has been admitted to work toward the doctor's degree and has been in residence at least one term thereafter; has initiated a program of study approved by the major department and, if needed, by the minor department; has satisfied the several departments concerned by written or oral examination or otherwise that he or she has a comprehensive grasp of the major and minor subjects as well as of subjects fundamental to them; has fulfilled any necessary language requirements; has shown ability in carrying on research with a research subject approved by the chairman of the division concerned. For special departmental regulations concerning admission to candidacy, see pages 224-263. 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.

#### 218 Graduate Information

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 224-263.

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.

# GRADUATE EXPENSES

The tuition charge for all students registering for graduate work is currently \$4,302 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 \$40 a unit for fewer than 36 units with a minimum of \$400 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 attendance at regular classes; (b) without reference to the number of terms in which the student has already been in residence; and (c) without reference to the status of the student as an appointee of the Institute, except that members of the academic staff of rank of Instructor or higher are not required to pay tuition.

Students who register for summer work, and who have not paid full tuition at the Institute during the preceding academic year may be subject to a summer health fee of \$33.

Each graduate student is required to make a general deposit of \$25 to cover loss of, or damage to, Institute property used in connection with work in regular courses of study. Upon completion of graduate work, or upon withdrawal from the Institute, any remaining balance of the deposit will be refunded.

Unpaid Bills. All bills owed the Institute must be paid when due. Any student whose bills are past due may be refused registration for the term following that in which the past due charges were incurred. Transcripts will not be released until all bills due have been paid or satisfactory arrangements for payment have been made with the Financial Affairs Office.

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 1978-79

General:	
General Deposit	\$ 25.00
Tuition	4,302.00
Graduate Student Council Dues	2.00
	\$4,329.00
Other:	
Books and Supplies (approx.)	\$375.00
Graduate House Living Expenses	
Room — \$747.00 to \$810.00 per academic year <sup>2</sup>	
(Room rates are subject to change.)	
Meals — Available at Chandler Dining Hall or the Athenaeum (member	rs only)

The following is a list of graduate fees at the California Institute of Technology for the Academic Year 1978-79, together with the dates on which these charges are due. Fees are subject to change at the discretion of the Institute.

	First Term	Fee
September 25, 1978	General Deposit	\$ 25.00
•	Tuition	1,434.00
	Graduate Student Council Dues	2.00
	Second Term	
January 2, 1979	Tuition	1,434.00
	Third Term	
March 26, 1979	Tuition	1,434.00
Tuition fees for f	ewer than normal number of units:	
	Over 35 units Fr	all Tuition

Over 35 units Full Tuition
Per unit per term 40.00
Minimum per term 400.00
Audit Fee, \$40.00 per lecture hour, per term.

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

<sup>&</sup>lt;sup>1</sup>This charge is made only once during residence at the Institute. <sup>2</sup>Room rent is billed one month in advance and is payable upon receipt of the monthly statement.

#### 220 Graduate Information

ASCIT Dues. Graduate students are eligible for membership in the Associated Students of the California Institute of Technology, Inc., or ASCIT, pursuant to by-laws thereof. Dues are \$24 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 Office of Student Accounts. The days in attendance are the number of days counted from the first day of the term to the date that the petition for *withdrawal*, *leave of absence*, or *reduction of units* (to fewer than 36) is approved by the Dean of Graduate Studies.

Housing Facilities. The Institute has four residence houses providing single rooms for 167 graduate students. These handsome and comfortable residences, located on campus, were donated by William M. Keck, Jr., Samuel B. Mosher and Earle M. Jorgensen, David X. Marks Foundation, and the family of Carl F Braun. The rates per academic year vary depending upon the accommodations and services provided. During the summer only, rooms may be rented on a month-to-month basis. Complete information may be obtained and reservations made by writing to the Office of Residence and Dining Halls, California Institute of Technology 91125.

The Institute owns a limited number of apartments and houses for rental to married Caltech students. Contact the Housing Office upon arrival for information.

The Off-Campus Housing Office maintains a current file of available rooms, apartments and houses in the Pasadena area. The listings are available for use upon arrival at Caltech. Please note: The Institute cannot make negotiations for individual housing off campus.

Dining Facilities. Graduate students are privileged to join the Athenaeum (faculty club), which affords the possibility of contact with fellow graduate students and with others using the Athenaeum, including The Associates of the Institute, distinguished visitors, and members of the professional staffs of the Hale Observatories, the Hunt-ington Library, and the California Institute.

The Chandler Dining Hall, located on the campus, is open Monday through Friday and most weekends when the Institute is in session. Breakfast, lunch, dinner, and snacks are served cafeteria style.

*Health Services.* Health services available to graduate students are explained in Section II.

The International Desk. The International Desk, 14 Dabney Hall, is maintained to help foreign students and visiting scholars with non-academic problems. They will find the services of the desk very helpful, particularly when they first arrive on campus. The International Desk operates under the advice of the Faculty Committee on Foreign Students and Scholars.

# FINANCIAL ASSISTANCE

The Institute offers in each of its divisions a number of fellowships, 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 endowed fellowships and scholarships for tuition and/or stipend to graduate students of exceptional ability who wish to pursue advanced study and research. Funds have been endowed by the following gifts.

Earle C. Anthony Fellowships Meridan Hunt Bennett Fellowships Robert Roe and Nellie Canfield Blacker Fellowships Norman Bridge Fellowship Edith Newell Brown Scholarships Theodore S. Brown Scholarships Elmer West Clark Fellowships Lucy Mason Clark Fellowship Samuel H. and Dorothy Breed Clinedinst Scholarship Ray G. Coates Scholarship Francis J. Cole Fellowships Continental Oil Company Fellowship Caroline W. Dobbins Scholarships and Fellowships Donald Wills Douglas Prize Fellowships Alexander M. and Florence W. Drake Fellowship Richard P. Feynman Fellowships J. S. Fluor Graduate Fellowship

Henry Ford II Scholar Award GALCIT Wind Tunnel Fellowships Daniel and Florence Guggenheim Foundation Fellowships Gulf Fellowship in Engineering and Applied Science Beno Gutenberg Fellowships Robert H. Halpenny Memorial Fund Clarence J. Hicks Memorial Fellowship Albert Hall Hughey Scholarship Saul Kaplun Fellowship William N. Lacey Fellowship in Chemical Engineering provided by the Union Oil Company Foundation Henry Laws Scholarships and Fellowships Smith and Louise Lee Memorial Fellowships Robert L. Leonard Scholarship Howard J. Lucas Fellowship Joseph F. Manildi Scholarship The Helen G. and Arthur McCallum Fund Clark B. Millikan Scholarships Robert A. Millikan Fellowships Li Ming Memorial Scholarship Blanche A. Mowrer Memorial Fund David Lindley Murray Educational Fund May McManus Oberholtz Scholarship Frederick Roeser Loan Scholarship and Research Fund William E. Ross Memorial Scholarships Eben G. Rutherford Fund Bruce H. Sage Fellowship in Chemical Engineering provided by the Union Oil Company Foundation Virginia Steele Scott Fellowship Evelyn Sharp Fellowship Roval W. Sorensen Fellowship Keith Spalding Memorial Scholarships Van Maanen Fellowship Laszlo Zechmeister Scholarship

# Special Fellowships and Research Funds

In addition to the National Science Foundation, the Department of Health, Education, and Welfare, the Energy Research and Development Administration, and the California State Graduate Fellowship program, gifts are received annually from the following donors to support graduate study.

American Vacuum Society
Los Angeles Chapter of ARCS (Achievement Rewards for College Scientists) Foundation
R. C. Baker Foundation
C F Braun & Co
California Foundation for Biochemical Research
California Institute Research Foundation
Corning Glass Works Foundation
Dean's Student Aid Fund Josephine de Karman Trust Eastman Kodak Company Lawrence A. Hanson Foundation The John Randolph Haynes and Dora Haynes Foundation Fannie and John Hertz Foundation Hughes Aircraft Company International Business Machines Corporation William F. Marlar Memorial Foundation Northrop Corporation Jessie Smith Noyes Foundation, Inc. Pickering-Link Foundation Rockwell International Gordon Ross Medical Foundation Schlumberger Foundation Jack J. Schoustra The Spencer Foundation Standard Oil Company of California Stauffer Chemical Company John and Beverly Stauffer Foundation Thomas J. Watson Foundation Weyerhaeuser Company Foundation Xerox Corporation

A number of governmental units, industrial organizations, educational foundations, and private individuals have contributed funds for the support of fundamental research related to their interests and activities. These funds offer financial assistance to selected graduate students in the form of graduate research assistantships.

#### Bohnenblust Travel Grants in Mathematics

Special grants may be awarded to outstanding graduate students in mathematics to enable them to travel here or abroad to further their mathematical education. The Mathematics Department established these awards in 1978 to honor H. F. Bohnenblust, who served Caltech as Professor of Mathematics, Executive Officer for Mathematics, and Dean of Graduate Studies. Application forms and further details are available in the Mathematics Office, 253 Sloan.

# Work-Study Programs

Limited opportunities are available for work-study programs in certain areas of interest. At the present time the sponsors of such programs are the Hughes Aircraft Company, Scientific Education Office, World Way, P.O. Box 90515, Los Angeles, California 90009, and the Jet Propulsion Laboratory of the California Institute of Technology. Potential students wishing to consider participation in the Hughes program may make inquiry to the address above as well as making application for graduate study at the Institute. Those wishing to be considered for the JPL program should 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

There are four sources of loans available to graduate students: Federal loans under the National Direct Student Loan (NDSL) program, loans under the Federal Insured Student Loan (FISL) program, loans from special funds of the California Institute of Technology, and UCB Tuition Loans. The amount of loans available from the programs of the federal government is limited by the appropriate government regulations. NDSL borrowers are subject to the same repayment terms and qualification requirements as outlined for undergraduate students on page 174. Loans from Institute funds normally may not exceed \$2,500 per year. These loan funds are listed on page 174. Repayment terms, including interest rates, may be obtained from the Office of Student Accounts.

The terms and conditions of UCB Tuition Loans are outlined on page 174.

# 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, AMà 152, AMa 153, AMa/EE 161, AMa 181, AMa 220, AMa 251, AMa 260.

*Group C*. Courses dealing with special topics in the sciences. A complete list cannot be given here but examples are courses in elasticity, fluid mechanics, dynamics, quantum mechanics, electromagnetism, communication theory, etc.

#### Master's Degree in Applied Mathematics

Entering graduate students are 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 Applied Physics Electives<sup>1</sup>..... Minimum 54 units

Suggested Electives<sup>2</sup>: APh 105, APh 114, Ae/APh 101, APh/MS 126, APh 140, APh 141, APh 153, APh 154, APh 156, APh 161, APh 181, APh 190, APh 200, Ph 125, Ph 129, AMa 101, AMa 104, AMa 105, AM 135, ChE 103, ChE 165, Ch 113, Ch 120, Ch 125, Ge 104, Ge 154, Ge 166.

## 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. Ouantum Mechanics course level: Ph 125 or Ch 125
  - 3. Mathematical Methods course level: AMa 101, AM 125, or Ph 129
  - 4. Statistical Physics and Thermodynamics course level: APh 105
  - 5. Solid-State Physics or Fluid Dynamics course level: APh 114, Ae/APh 101, or APh 156

Competence in *each* of these subjects must be demonstrated by either successfully completing an appropriate Caltech course with a grade no lower than C or, with the exception of number 3, by taking an oral examination over the subject matter. Separate examinations will be given on each area.

b. Oral candidacy examination. The student will prepare a brief presentation on a topic agreed upon by the student and the student's proposed thesis research adviser, normally the projected research topic.

The candidacy examination will be based upon the student's background in applied physics and its relation to this presentation.

The oral examination will be given only after the student has demonstrated competence in the five areas and must be completed before the close of the student's second year of residency.

c. Competence in research must be demonstrated as follows: The student must have a doctoral thesis adviser and must have completed 18 units of research with this adviser no later than the beginning of the student's third year of residence.

The Minor. By its nature, Applied Physics spans a variety of disciplines and the major requirement reflects this. A minor is not required of students majoring in Applied Physics. They are, however, encouraged to take advanced courses appropriate to their particular interests.

Thesis and Final Examination. The candidate is required to take a final oral examination covering his or her doctoral thesis, its significance and relation to his or her major

<sup>&</sup>lt;sup>1</sup>Must be selected from APh 114, Ch 125 or Ph 125, APh 105, Ae/APh 101 or APh 156. <sup>2</sup>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.

field. This final examination will be given not less than two weeks after the doctoral thesis has been presented in final form, and prior to its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted.

Subject Minor in Applied Physics. Graduate students electing a subject minor in Applied Physics must complete 54 units of graduate courses in Applied Physics. The courses may be selected from any of the Applied Physics courses with numbers greater than 100, excluding APh 110 and APh 200.

The student's proposed program must be approved by the Applied Physics Graduate Studies Committee. The Committee will examine the course program to determine which of the following areas of interest in Applied Physics it includes:

Group A: Ae/APh 101, APh 156, APh 161.

Group B: APh 105, APh 114, APh 140, APh 141, APh 181, 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 Examination in physics (see Placement Examinations, page 260) covering material equivalent to Ph 92, Ph 106, and Ph 125. An oral examination by the staff covering material equivalent to Ay 20, Ay 21, Ay 101, and Ay 102 is given on the Friday preceding the beginning of instruction for the first term. These examinations will test whether the student's background of atomic and nuclear physics, mathematics, physics, and astronomy is sufficiently strong to permit advanced study in these subjects. If it is not, students will be required to pass the appropriate courses.

#### Master's Degree in Astronomy

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

#### Degree of Doctor of Philosophy in Astronomy

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

*Physics Program*: The student's program during the first two years of graduate study should include at least 36 units of physics courses, exclusive of Ph 92, Ph 106, and Ph 125. This requirement may be reduced on written approval of the department for students who take substantial numbers of units in Ph 92, Ph 106, and Ph 125. Students in radio astronomy should include Ph 209 in the required 36 units of physics; they may take the remaining units in an advanced course in electrical engineering or applied mechanics. Theoretical astrophysics students 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 subject of biology, supplemented with advanced course work and independent study in this subject; (b) an optional minor program, usually designed to provide the student with professional insight into a subject outside the major one and consisting of specialized course work, or course work and a special research program; and as a rule (c) a program of course work designed to provide a well-rounded and integrated training in biology and the appropriate basic sciences, and adjusted to special interests and needs. (b) and (c) may include supervised, independent study. An individual program will be recommended to each student in a meeting with the student's advisory committee (see below). A student majoring in psychobiology may arrange to do one or more terms on another campus to obtain relevant course work in psychology and medicine not offered at the Institute. The Division of Biology does not encourage applications from students who have pursued undergraduate study in biology at the Institute, because the broader perspective to be gained from graduate study in a different setting is considered to be essential for the full development of each student's potential. Exceptions to this policy may be considered by the faculty of the division if there are circumstances, such as completion of an advanced degree at another institution, which indicate that it would be in the best interests of a student to pursue graduate study at the Institute.

## Admission

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

When feasible, visits to the campus for personal interviews will be arranged before a final decision for admission is made. Graduate Record Examinations (verbal, quantitative, and an advanced test in *any* science) are required of applicants for graduate admission intending to major in biology. Applicants are encouraged to take these examinations and request that the scores be transmitted to Caltech, in November or earlier, to ensure unhurried consideration of their applications.

#### Advisory Committees

An advisory committee will be constituted for each student, to provide consultation

and advice throughout the period of study until admission to candidacy. Each advisory committee will consist of three or four faculty members, including a student's current research supervisor and at least one member of the Graduate Admissions Committee who will serve as chairman of the advisory committee. The composition of the committee will be adjusted as necessary if the student changes research supervisors or areas of interest. Each student meets with his or her advisory committee at the time of beginning work in the division to formulate a plan of study, again in the third term of the first year of study to discuss progress and subsequent plans, and at other times when problems arise or advice is needed.

Teaching Requirements for Graduate Students

All students must acquire teaching experience.

#### Master's Degree in Biology

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

## Degree of Doctor of Philosophy in Biology

*Major Subjects of Specialization.* A student may pursue major work leading to the doctoral degree in any of the following subjects:

Biophysics	Immunology
Cell Biology	Molecular Biology
Developmental Biology	Neurobiology
Genetics	Psychobiology

At graduation, a student may choose if the degree is to be awarded in biology or in the selected subject. If the award is to be in biology, a minor will be designated only if it is from another division of the Institute.

*Minor Subjects.* The Division of Biology does not have a requirement for a minor, but encourages students to undertake work outside of their major subject. Recognition of such work on a student's diploma requires completion of a formal minor program, which usually consists of 45 units of advanced course work or research, either in another division of the Institute in accordance with the regulations of that division, or in one of the major subjects of specialization in biology that is not closely related to a student's major field. Students should consult with their advisory committee in planning such a program.

Admission to Candidacy. To be recommended by the Division of Biology for admission to candidacy for the doctor's degree, the student must have demonstrated an ability to carry out original research and have passed, with a grade of B or better, the candidacy examination in the major.

Thesis Committee. After admission to candidacy, a thesis committee is appointed for each student by the chairman of the division upon consultation with the student and the major professor. This committee will consist of the student's major professor as chairman and four other appropriate members of the faculty including a member of the faculty of the minor (if any). The thesis committee will meet with the student soon after admission to candidacy and at intervals thereafter to review the progress of the thesis program. This committee will, with the approval of the Dean of Graduate Studies, also serve as the thesis examination committee (see below).

Thesis and Final Examination. Two weeks after copies of the thesis are provided to the examination committee, the candidate collects the copies and comments for correction. At this time, the date for the final examination is set at the discretion of the major professor and the division chairman, to allow as necessary for such matters as publication of the examination in the Institute calendar, thesis correction, preparation of publications, and checking out and ordering of the student's laboratory space. The final oral examination covers principally the work of the thesis, and according to Institute regulation must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate 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 subjects listed above under major subjects of specialization. Requirements for such a minor are determined by the faculty committee designated for each subject. A minor program in biology is also available to students of other divisions. Such a program shall consist of 45 units of upper division course work in the Biology Division, each course passed with a grade of "C" or better. Approval of each program must be obtained from the Biology Graduate Advisory Committee. A student majoring in another division who elects a subject minor in biology may if desired arrange to have the minor designated as biology, rather than with the name of the specific minor subject.

# **Chemical Engineering**

## Aims and Scope of Graduate Study in Chemical Engineering

The Institute was one of the earliest schools to emphasize instruction on basic subjects rather than on specialized material relating primarily to particular industries or processes. The general objective of the graduate work in chemical engineering is to produce individuals who are exceptionally well trained to apply the principles of mathematics, the physical sciences, and engineering to new situations involving chemical reactions and the transport of momentum, energy, and material.

#### Admission

It is expected that each applicant for graduate study in the Division of Chemistry and Chemical Engineering will have studied mathematics and physics substantially to the extent that these subjects are covered in the required undergraduate courses at Caltech. In case the applicant's training is not equivalent 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. A student who has taken ChE 126 a or its equivalent as an undergraduate may substitute an equal amount of research, ChE 280. A research report must be submitted on the work performed under ChE 280. A student originally admitted to the Ph.D. program may use his or her ChE 280 research report. The M.S. ChE 280 requirement, also submitting the necessary research report.

mathematics, AM 113 abc, if an equivalent course has not been taken previously. In addition to the required courses, 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 include up to 30 units of freely elected graduate courses, which may be in humanities as well as in engineering and science subjects.

## 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 could be completed in three calendar years.

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

*Course Requirements.* Although there are no formal chemical engineering course requirements, 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 the graduate level in chemical engineering. This will be done by way of chemical engineering courses, an oral subject examination which is to be taken at the end of the third term of the student's first year of graduate residence at the Institute, and a written progress report on his or her research, to be submitted before the end of the 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 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 217 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 not uncommon, and interdisciplinary programs with biology, physics, and geology are open and encouraged.

An extensive program of seminars will enable you to hear of and discuss notable work in your own and other areas. In the Divisional Research Conferences, members of the staff and distinguished visitors present accounts of research of broad interest. More specialized seminars are devoted to such subjects as chemical physics, organic chemistry, inorganic and electrochemistry, organometallic chemistry, and chemical biology. Graduate students are encouraged also to attend seminars in other divisions.

#### Placement Examination

During the week preceding 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 complete satisfactorily a prescribed course, or courses, in order to correct the deficiency.

#### Course Program

For an advanced degree, no graduate courses in your principal area of research are required. You should plan a program of advanced courses in consultation, at first with a representative of the divisional Committee on Graduate Study and later with your research adviser.

#### Master's Degree in Chemistry

Students are not ordinarily admitted to graduate work leading to an M.S. degree, but the master's program is available. All master's programs for the degree in chemistry must include at least 40 units of chemical research and at least 30 units of advanced courses in science. The remaining electives may be satisfied by advanced work in any area of mathematics, science, engineering, or humanities, or by chemical research. Two copies of a satisfactory thesis describing this research, including a one-page digest or summary of the main results obtained, must be submitted to the divisional graduate secretary at least ten days before the degree is to be conferred. The copies of the thesis should be prepared according to the directions formulated by the Dean of Graduate Studies and should be accompanied by a statement approving the thesis, signed by the staff member directing the research and by the chairman of the Committee on Graduate Study of the division.

#### Degree of Doctor of Philosophy in Chemistry

*Candidacy.* There is no formal course work required in your *major* field of interest (for minor requirements, see below). However, to be recommended for candidacy for the doctor's degree in chemistry, in addition to demonstrating an understanding and knowledge of the fundamentals of chemistry, you must give satisfactory evidence of proficiency at a high level in your primary field of interest, as approved by the division. This is accomplished by an oral candidacy examination which must be held during or before your fifth term of graduate residence (excluding summer terms). At this examination you will be asked to demonstrate scientific and professional competence and promise by discussing a research report and propositions as described below.

The research report should describe your progress and accomplishments to date and plans for future research. Three propositions, or brief scientific theses, must accompany the report. These should reflect your breadth of reading, originality, and ability to see valid scientific problems. They should *not* all be in your own field of research. The research report and propositions must be in the hands of your examining committee one week 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 course work outside your principal area of research. This program consists of at least 36 units of course work (the equivalent of approximately four standard one-term courses) outside the scientific area in which your dissertation research is performed (exclusive of courses taken in fulfillment of the chemistry language requirement). These courses may be either inside or outside the chemistry option. Courses for the minor shall be taken on a letter grade basis unless the course is offered with only a pass/fail option. A grade of C or better is required for credit toward the minor. Your adviser has the responsibility of determining which courses fulfill the requirement in your particular case, subject to final approval by the chemistry graduate studies committee.

Thesis and Final Examination. The final examination will consist in part of oral presentation and defense of a brief resume of your research and in part of the defense of a set of propositions prepared by you. Five propositions are required. In order to obtain diversity with respect to subject matter, not more than two shall be related to the immediate area of your thesis research. Each proposition shall be stated explicitly and the argument presented in writing with adequate documentation. Propositions of exceptional quality presented at the time of the candidacy examination may be included among the five submitted at the time of final examination.

The propositions should display originality, breadth of interest, and soundness of training; you will be judged on your selection and formulation of the propositions as well as on your defense of them. You should begin formulating a set of propositions early in the course of graduate study.

You must submit a copy of the thesis and propositions in final form to the chairman and to each member of the examining committee, and a copy of the propositions and an abstract of the propositions to the divisional graduate secretary, *not less than* two weeks 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

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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 (page 116):

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

While research and course work in aeronautics at the Institute cover a very broad range of subjects, a choice of one of the above fields allows students to specialize in their own interests while still taking advantage of the flexibility offered by the breadth of interests of the aeronautics group. A student with an interest in energy-related subjects will find many courses and research projects of particular use. Subjects of major importance in the efficient use of energy in transportation and power production such as turbulent mixing, drag reduction, and 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 224)

# 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 225)

# Chemical Engineering

(See page 231)

# 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.

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 substi-
- tute 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; the examining committee will consist of such individuals as may be recommended by the chairman of the division and approved by the Dean of Graduate Studies.

Subject Minor in Civil Engineering. A student majoring in another branch of engineering, or in another division of the Institute, may, with the approval of the faculty in civil engineering, elect civil engineering as a subject minor. At least 54 units of approved courses must be taken, and an oral examination must be passed.

## Computer Science

(See page 244)

# Electrical Engineering

#### Aims and Scope of Graduate Study in Electrical Engineering

The Bachelor of Science degree may be followed by graduate study leading either to the Master of Science degree in Electrical Engineering, usually completed in one year, or the more advanced degrees of Electrical Engineer or Doctor of Philosophy, usually completed in three to five years. The doctoral candidate may first obtain the Master of Science degree or may enter directly into studies for the degree of Doctor of Philosophy. In judging admission for the Ph.D. degree, the EE faculty places particular emphasis on any evidence of future research potential. The graduate curriculum is flexible. Students participate in graduate seminars and in research projects.

## Placement Examination

Students admitted to work toward any advanced degree in electrical engineering are required to take a placement examination in mathematics. This examination is given on the Friday of the week preceding registration, and will be concerned primarily with subject matter of the undergraduate course AMa 95 abc. The result of this examination has no bearing on a student's admission to graduate study, but in the event that preparation in this subject area is judged to be inadequate, the student will be required to enroll in AM 113 abc, for which graduate credit will be received. Notices of the placement examination are sent well in advance of the examination date.

#### Master's Degree in Electrical Engineering

Of the 135 units required for this degree, a minimum of 99 units are required from the following list of courses: CS/EE 121, EE 112, EE 113, EE 114, EE 115, EE 116, EE 117, EE 118, EE 119, EE 151, EE 155, EE 160, AMa/EE 161, EE 163, EE 194, CS/EE 281, EE 291<sup>1</sup>, APh 105, APh 114, APh 140, APh 153, APh 154, APh 156, APh 181, APh 185, APh 190, APh 214, Ph 125, Ph 209, AM 125, CS 112, CS 114, CS 116, CS 137, CS 138, CS 139, BIS 240, AMa 101, AMa 104, AMa 105, AMa 153, AMa 181, Ch 125.

Other electives may be substituted upon approval of the electrical engineering faculty. E 150 abc, Engineering Seminar, is required. Students are urged to consider including a humanities course in the remaining free electives.

<sup>1</sup>Not more than 21 units may be used toward the total of 99 units.

The attention of students interested in energy-related studies is drawn to EE 114 abc, Electronic Circuit Design; EE 117, Power Electronics; EE 291, Advanced Work in Electrical Engineering (in the Power Electronics Laboratory); ME 102 abc, Principles of Energy Conversion and Distribution; and to 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. New Ph.D. students, and M.S. students who wish to transfer to Ph.D. studies, are required to make an oral presentation to a faculty committee at the beginning of the second term.

*Candidacy.* To be recommended for candidacy for the doctor's degree the applicant must satisfy the following requirements:

- a. Complete 18 units of research in his or her field of interest.
- b. Obtain approval of a course of study consisting of at least 189 units of advanced courses in electrical engineering or related subjects listed on page 241, except that units in research (e.g., EE 191 and 291) may not be counted in this total. The course taken to satisfy requirement (c) may be included in this total. Courses taken to fulfill the requirements for the Master of Science degree may be included also.
- c. Pass one of the following subjects with no grade lower than C: AMa 101 abc, AM 125 abc, Ma 108 abc, Ph 129 abc. An applicant may also satisfy any of the above course requirements by taking an examination in the subject with the instructor in charge. This examination will cover the whole of the course specified, and the student may not take it either in parts or more than twice.
- d. Pass a qualifying oral examination covering broadly his or her major field and minor program of study. This examination is normally taken near the end of the second year of graduate study.

Thesis and Final Examination. The candidate is required to take a final oral examination covering the doctoral thesis and its significance in and its relation to his or her major field. This final examination will be given not less than two weeks after the doctoral thesis has been presented in final form, and 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 129), 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 250-252. The central area of fundamental combustion research is focused here. In Aeronautics (p. 235) 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 and two-phase fluid flow is crucial for all thermal power generation. A world center of research in this field is found in the Aeronautics and Mechanical Engineering laboratories at Caltech.

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 became predominant and relate to research in Materials Science (p. 248), Electrical Engineering (p. 241), and Applied Physics (p. 225), where both the foundation for advanced solar cells and the principles 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. 241). Investigations in conversion, control, and regulation of electric energy are conducted in the Power Electronics Laboratory.

In Environmental Engineering Science (p. 245) 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 biomass source of energy. Some of this and other energy/environment research is carried out in Caltech's interdisciplinary Environmental Quality Laboratory (see page 133).

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 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 abc, Methods of Applied Mathematics I; AM 125 abc, Engineering Mathematical Principles; or Ph 129 abc, Methods of Mathematical Physics. Students emphasizing Bioinformation Sys-

tems or Computer Science should refer to different requirements given below.

A minimum of 54 units of courses must have the approval of the student's adviser and the faculty in engineering science.

## Degree of Doctor of Philosophy in Engineering Science

*Course Requirements.* To be recommended for candidacy for the Ph.D. degree in engineering science, the student must, in addition to the general Institute requirements: a. complete 12 units of research;

- b. complete at least 50 units of advanced courses arranged by the student in conference with his or her adviser and approved by the faculty in engineering science;
- c. pass with a grade of at least C an advanced course in mathematics or applied mathematics such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the faculty in engineering science. The requirements in mathematics shall be in addition to requirement (b) above, and shall not be counted toward any minor requirements. Students emphasizing Bioinformation Systems or Computer Science should refer to different requirements given below.

Language Requirements. Students are encouraged to discuss with their advisers the desirability of taking foreign languages. Foreign languages are not required.

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

A subject minor is not required for the Ph.D. degree in engineering science; however, students majoring in other fields may take a subject minor in engineering science provided the program consists of 45 units sufficiently far removed from their major program of study and is approved by the appropriate faculty group and by the option representative.

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

See description on page 130. M.S. degrees are given in this area under the option of Engineering Science. A minimum of 54 units must be selected from applied mathematics, computer science, and biology courses, as approved by the faculty in bioinformation systems.

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

See description on page 130. Ph.D. degrees are given in this area under the option of Engineering Science.

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

- a. complete 12 units of research;
- b. complete at least 50 units of advanced courses arranged by the student in conference with his or her adviser and approved by the faculty in bioinformation systems;
- c. students in bioinformation systems are required to take at least an additional 27 units of advanced mathematics as approved by the faculty in bioinformation systems.

Other requirements are the same as listed under Engineering Science above.

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

See description on page 127. M.S. degrees are given in this area under the option of Engineering Science. The following requirements apply:

- 1. The course sequence CS 137, 138, 139 (or equivalent credit) is required.
- 2. Of the general 135 units of advanced courses beyond the baccalaureate degree:
  - a. 9 units must be from CS 112, CS 114, CS 116, CS/EE 281, CS 286 or advanced EE courses;
  - b. 27 units must be from advanced CS courses not including courses satisfying requirements 1 or 2a and not including research units.
  - c. 27 units must be advanced units outside the area of specialization, and not a CS course;
  - d. At most, 36 research units, i.e., CS 140, CS 280, and CS 282, will be counted toward the overall 135 unit requirement.

Degree of Doctor of Philosophy in Engineering Science, with Emphasis on Computer Science See description on page 127. Ph.D. degrees are given in this area under the option of Engineering Science.

*Course Requirements.* To be recommended for candidacy for the Ph.D. degree in engineering science with emphasis on computer 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 computer science;
- c. students in computer science may be required to take additional units of advanced mathematics as approved by the faculty in computer science.

Other requirements are the same as listed under Engineering Science above.

# Environmental Engineering Science

## Aims and Scope of Graduate Study in Environmental Engineering Science

Environmental problems cut across many disciplines. Graduate study in environmental engineering science emphasizes environmental problem areas and the application of information from several 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, 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/Ch 164, ChE 165 ab, Ae/ChE/EE 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, wastewater reclamation and reutilization, 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.

I Inite non term

#### 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		enn
		1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
MS 120	Kinetics of Crystal Imperfections (3-0-6)	9		
MS 121	Solid-State Diffusion (3-0-6)		9	
APh/MS	The Electronic Structure of			
126 abc	Metals and Alloys (3-0-6)	9	9	9
MS 130	Metallography and Pyrometry (0-6-3)	9		
MS 131	Crystal Defects (1-6-2)		9	
MS 132	X-ray Crystallography Laboratory (0-6-3)			9
	Electives (see below)	Minimu	ım 60 f	or year
	Total	Minimur	n 135 f	or 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 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. The program is intended to be completed within the nine months of the academic year, even by students who hold assistantships. Each student is assigned to a member of the faculty, who will serve as the student's adviser and who will assist the student in planning a course of study. The program of study must be approved by the adviser, and any subsequent changes must also have the adviser's approval.

The schedules of courses are given below:

## **Mechanical Engineering**

		Units per term		
		1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
	Approved electives <sup>1</sup>	Minimum	81	per year
	Free electives <sup>2</sup>	Minimum	51	per year
	Total	Minimum	135	per year

Approved electives: Courses from AM, AMa, ME, JP, MS, and Hy with numbers of 100 and above will generally meet the conditions for the approved electives.

Program Suggested for Propulsion

E 150 abc	Seminar (1-0-0)	1	1	1
JP 121 abc	Jet Propulsion Systems and Trajectories (3-0-6)	9	9	9
	Approved electives <sup>1</sup>	Minimum	98	for year
	Free electives <sup>2</sup>	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.

<sup>1</sup>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 133 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.

<sup>2</sup>Students are urged to consider including a humanities course in the free electives.
#### Program Suggested for Energy

E 150 abc	Seminar (1-0-0)	1	1	1
ME 102 abc	Principles of Energy Conversion and			
	Distribution (3-0-6)	9	9	9
	Approved electives <sup>1</sup>	Minimum	98	for year
	Free electives <sup>2</sup>	Minimum	27	for 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

## 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;

<sup>1</sup>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.

<sup>2</sup>Students are urged to consider including a humanities course in the free electives.

- 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 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 deficiences 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 197-198). Particular attention is called to requirements in petrology, field geology, chemistry, physics, and mathematics; competence in these subjects will be evaluated during the placement examination. Students in geophysics or planetary science may petition the Academic Officer for permission to satisfy the basic division requirement for the Ph.D. program (p. 254) in place of the undergraduate petrology and field geology requirement. The Institute requires a year of residence and a total of 135 graduate units for a Master's degree. These 135 units of courses numbered over 100 may include as many as 27 units of courses required in the 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. For students in their 6th year of graduate residence (or 5th year beyond the M.S.) such a presentation and review is specifically required before the faculty may vote to continue to award financial aid, for at most one additional year. The option representatives have the responsibility to organize these reviews and to make recommendations to the full division faculty, which may deny permission to continue in the Ph.D. program for any student showing inadequate progress. For a student who has passed the Ph.D. preliminary qualifying examination, permission to continue toward the Ph.D. degree may be withdrawn only upon action of the division as a whole.

Qualifying Examination. This examination will consist of the oral defense of three propositions, each supported by a succinct one-paragraph statement of the problem and of the candidate's specific approach to it. The propositions offered must represent a knowledge and breadth of interest judged acceptable by the division in terms of the student's maturity. Students have the privilege of consultation and discussion with various staff members concerning their ideas on propositions, but the material submitted must represent the work of the student and not a distillation of comments and suggestions from the staff. Candidates should realize that propositions based on field investigations are just as acceptable as those arising from laboratory or theoretical work. In general, the examination is designed to evaluate the student's background in the earth sciences and allied fields and capabilities in applying scientific principles to the solution of specific problems. The ideal candidate will display originality and imagination as well as scholarship.

All first-year students must submit to the Core Committee by May 15 a preliminary status report of their choice of proposition topics. The statement should be as specific as possible, and should preferably give the specific 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 should be taken during the first year. Ge 104 abc, Ge 105 ab, and Ge 160 are especially recommended as part of these courses. Students may be exempted from one or more quarters of Ge 101 by the instructor and the Academic Officer on the basis of previous work taken. Where appropriate these 45 units may be counted as part of a subject minor within the division. Students who take a subject minor in another division or who show evidence of similar course work elsewhere may, by petition to the Academic Officer, be excused from up to 27 units of such courses. Throughout their graduate work students are expected to participate in departmental seminars and in seminar courses led by distinguished visitors.

Geology and Geobiology: In addition to the general Institute and basic division requirements candidates for the Ph.D. in geology or geobiology must successfully complete a minimum of 90 units of 100-200 level courses, including the 200-level courses most pertinent to their major field, but excluding languages, research and reading courses, and certain courses constituting basic preparation in their field as follows: Ma 1, Ma 2, Ph 1, Ph 2, Ch 1, Ge 104, Ge 105, Ge 107, Ge 114, Ge 115, Ge 123. At least 36 of the 90 units must be taken outside the geology division (with a grade of C or better) and may be used as part of the minor; Ch 21 abc may be included as part of these units. For good work in most modern earth science fields a proficiency in mathematics equivalent to that represented by AM 113 (Engineering Mathematics) is essential. Summer study and research at a marine biology laboratory are required of most candidates in geobiology.

*Geochemistry:* In addition to the general Institute and basic division requirements, the Ph.D. candidate in geochemistry must demonstrate a knowledge of both geology and chemistry equivalent to the average attained in the Caltech undergraduate curriculum in geochemistry. Beyond this, the candidate will be expected to take a minimum of 90 units of 100- and 200-level courses, at least 54 units of which should be outside the division; Ch 21 abc may be included as part of these units. The same courses can be presented to satisfy the requirements for a minor. A proficiency in mathematics equivalent to AM 113 (Engineering Mathematics) is desirable.

*Geophysics*: In addition to the general Institute and basic division requirements, the Ph.D. candidate in geophysics must successfully complete a minimum of 90 units of 100-200 level courses chosen from the three categories listed below. At least 18 units must be completed in each group.

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

Group B. Courses in physics, applied physics, and chemical physics: Ph 106, Ph 125, AM 131, AM 141, APh 114, APh 214, Ph 127, Ph 205, Ph 236, MS 205, Ch 21, Ch 125. Geophysics courses cannot be substituted for courses in this group.

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

The recommended courses in these three categories are only representative of the required level, and substitutions may be made upon consultation with the student's adviser. Students with an exceptionally strong background in one or more of the areas represented by these groups may, upon petition to the option representative, be excused from up to 18 units of the overall 90 unit requirement. Research and reading courses cannot be used to satisfy these requirements but are highly recommended as preparation for the oral qualifying examination.

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

These requirements may be met by successful completion of at least 45 units of suitable course work at the 100 or higher level in each category. The requirements in the first category 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 the 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 mixor 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 a thesis in their option and submit it in final form by May 10 of the year in which the degree is to be conferred. A first draft of the thesis *must* be submitted to the division chairman by March 1 of the year in which it is proposed to take the degree.

Candidates are expected to publish the major results of their thesis work. The manuscript should be reviewed by the member of the staff supervising the major research before being submitted for publication. The published paper should have a California Institute of Technology address and a Division of Geological and Planetary Sciences Contribution Number, and at least five reprints should be sent to the division.

*Final Examination.* The final oral examination for the doctorate will be scheduled following submission of the thesis and, in conformity with an Institute regulation, it must be scheduled at least two weeks before the degree is to be conferred.

## Minor in Geological and Planetary Sciences

A student majoring in another division of the Institute may, with the approval of the Division of Geological and Planetary Sciences, elect a minor in any one of the major subjects listed above. Such a subject minor will include at least 45 units normally, including one or more 200-level courses as well as the 100-level supporting courses. 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 137. 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 have been part of the undergraduate curriculum of the entering graduate student. The basic course in algebra, Ma 120, presupposes an undergraduate introductory course in modern algebra similar to Ma 5 abc. 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.

## Bohnenblust Travel Grants in Mathematics

Special grants may be awarded to outstanding graduate students in mathematics to enable them to travel here or abroad to further their mathematical education. The Mathematics Department established these awards in 1978 to honor H. F. Bohnenblust, who served Caltech as Professor of Mathematics, Executive Officer for Mathematics, and Dean of Graduate Studies. Application forms and further details are available in the Mathematics Office, 253 Sloan.

### Master's Degree in Mathematics

Entering graduate students are normally admitted directly to the Ph.D. program, since the Institute does not offer a regular program in mathematics leading to the master's degree. This degree may be awarded in exceptional circumstances either as a terminal degree or as a degree preliminary to the Ph.D. degree. Sufficiently advanced undergraduates may be admitted to graduate standing to pursue a master's degree simultaneously with the bachelor's program.

The recipient of a master's degree will be expected to have acquired, in the course of studies as an undergraduate or graduate student, a comprehensive knowledge of the main fields of mathematics comparable to 180 units of work in mathematics at the Institute with course numbers greater than 90.

The general Institute requirements specify that the recipient of a master's degree must have taken at least 135 units of graduate work as a graduate student at the Institute, including at least 81 units of advanced graduate work in mathematics. This advanced work is interpreted as work with a course number greater than 115 and may include a master's thesis.

#### Degree of Doctor of Philosophy in Mathematics

*Candidacy Examination.* Before being admitted to candidacy for the Ph.D. in mathematics the student is expected to 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 will 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, 1979. Special inquiries will be welcomed by the chairman of the Physics Graduate Admissions Committee. It is required 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 339-344.

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:

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 these requirements. In addition to these course requirements, the student will normally take other advanced courses, particularly in the field of specialization. In general a student will find it desirable to continue graduate study and research for two years after admission to candidacy.

The student is expected to obtain a grade of C or better in each course. If he or she obtains grades below C in courses, or an unsatisfactory grade on the written or oral candidacy examination, the Physics Graduate Committee will review the student's entire record, and if it is unsatisfactory will refuse permission to continue work for the Ph.D.

*Candidacy Examinations.* A written candidacy examination, in several 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 217. *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

Students desiring a subject minor in physics should discuss their proposed program with the chairman of the Physics Graduate Committee. 45 units are required for approval of a subject minor in physics. Physics courses with numbers over 100 will be allowed for the subject minor, but those which count at reduced credit for physics graduate students will count at the same reduced credit toward the minor. At least 18 of the 45 units must be chosen from the Physics Electives list, excluding Ph 129 and any specific courses in physics required for the student's major program. The required oral examination in the subject minor will normally be a separate examination but may be part of one of the oral examinations in the major subject if sufficient time is made available. It is the responsibility of the candidate to make arrangements for this examination with the chairman of the Physics Graduate Committee.

# Social Science

# Aims and Scope of Graduate Study in Social Science

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 policymaking 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 Ma 112 a. The completion of courses in advanced calculus or applied mathematics is also recommended. Under certain circumstances, students may be permitted to complete some of the mathematical requirements after entering the program. Students will find that courses in abstract algebra, functional analysis, topology, and probability theory will be of significant help in their graduate

work, and they will be expected to take whatever courses in mathematics are directly relevant to their research after entering the program.

#### Placement Examinations

Entering students will take placement examinations in social science and mathematics to determine their level of attainment. Required remedial work, if any, will be determined by the option committee in consultation with the student and will be based primarily on the results of the placement examinations and review of the student's undergraduate program. In cases where there is a clear basis for ascertaining the status of entering students, the placement examinations may be waived.

#### Course Program

No graduate courses in social science are specifically required for an advanced degree in social science. However, students will, in consultation with the option committee and their research adviser, develop a program 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 last 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.

#### 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.



# 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 101 abc. Selected Topics in Anthropology. 9 units (3-0-6).

An 123 ab. The Anthropology of Development. 9 units (3-0-6); first, second terms. Social change in contemporary tribal and peasant societies. Emphasis will be placed on the impact of modernization, especially through urbanization, industrialization and the intensification of agriculture, and of revitalization of the social organization of selected societies in Latin America, Europe, Africa and elsewhere over the past half century. Instructor: Scudder.

**An 124.** The Evolution and Current Status of Small-Scale Human Societies. 9 units (3-0-6); third term. Prerequisite An 123 a. Lectures deal with human and cultural evolution prior to the rise of the pre-industrial city; reading and student projects deal with the implications of the contemporary world for small-scale human societies, and for the Navajo in particular. Instructor: Scudder.

## APPLIED MATHEMATICS

# **Undergraduate** Courses

**AMa 95 abc.** Introductory Methods of Applied Mathematics. 12 units (4-0-8); first, second, third terms. Prerequisites: Ma 1 abc, Ma 2 abc, or equivalent. The topics studied include introductions to the following: functions of complex variables; linear ordinary differential equations; special functions; eigenfunction expansions; integral transforms; linear partial differential equations and boundary value problems. Instructor: Keller.

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: Bountis.
- c. Applications of Differential Geometry. *Prerequisites: Ma 2, Ph 2.* Basic concepts of differential geometry such as frame fields, Frenet formulas, connection forms, differential manifolds, tangent vectors, differential forms and their integrals, geodesics, curvature, Riemannian geometry, and covariant derivatives are explained mainly with the aid of curves and surfaces in three-dimensional Euclidean space. The concepts are applied to particle dynamics, fluid dynamics, and electromagnetic theory. Text: Barrett O'Neill, *Elementary Differential Geometry*. Instructor: Lagerstrom.

# **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: Saffman.

**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: Kreiss.

**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; eigenvalueeigenvector 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: Kreiss.

AMa 106 ab. Numerical Linear Algebra. 9 units (3-0-6); second, third terms. Prerequisite: some familiarity with elementary matrix theory. Computational methods for problems in linear algebra such as linear transformations, eigenvectors-eigenvalues, direct and iterative methods for simultaneous equations, overdetermined systems, linear programming, etc. Coding principles, computational efficiency, stability and error analysis are stressed. 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. Not offered in 1978-79.

AMa 151 abc. Perturbation Methods. 9 units (3-0-6); first, second, third terms. Prerequisite: AMa 101 or equivalent; may be taken concurrently with instructor's permission. The course discusses uniformly valid approximations in various physical problems. Generalized boundary layer technique. Coordinate straining techniques; Poincaré's method. Problems with several time scales; averaging techniques; method of Krylov-Bogoliubov. Eigenvalue problems. Examples taken from various fields of science. Instructor: Cohen.

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 gas-dynamics, water waves, plasma physics, electromagnetism. Not offered in 1978-79.

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: Whitham.

AMa/EE 161 abc. Mathematical Theory of Information, Communication, and Coding. 9 units (3-0-6); three terms. Prerequisite: 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 and rate distortion theory. Error-control systems, especially algebraic and convolutionary codes. Decoding algorithms and their implementation complexity. Practical applications to informational systems. Not offered in 1978-79.

AMa 181 ab. Mathematical Programming and Game Theory. 9 units (3-0-6); second, third terms. Prerequisite: some knowledge of linear algebra. Theory of linear and nonlinear programming. Simplex algorithm. Integer programming and network flows. Zerosum, two-person games. Linear models of exchange and production. Kakutani fixed-point theorem. Theory of n-person games. Applications to engineering and economics. Not offered in 1978-79.

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 1978-79.

**AMa 204 abc.** Numerical Solution of Differential and Integral Equations. 9 units (3-0-6). Prerequisite: some familiarity with elementary numerical methods. Theoretical and practical study of methods for approximate solution of various linear and nonlinear ordinary and partial differential and integral equations with the use of digital computers. Not offered in 1978-79.

**AMa 220 abc. Bifurcation Theory and Nonlinear Boundary Value Problems.** 9 units (3-0-6). Prerequisite: some knowledge of differential equations. Theory and applications of bifurcation and nonlinear boundary value problems in mechanics, fluid dynamics and nonlinear diffusion processes. Lyapounov-Schmidt theory. Multiple bifurcations and

Newton's polygons. Extension of bifurcated branches, secondary bifurcation, perturbed bifurcation and imperfection sensitivity. Hopf bifurcation of periodic solutions. Catastrophe theory. Nonlinear boundary value and eigenvalue problems. Monotonicity methods. Stability theory. Degree theory. Not offered in 1978-79.

**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 1978-79.

**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 1978-79.

**AMa 260 abc. Special Topics in Continuum Mechanics.** 9 units (3-0-6). Prerequisites: AMa 101 and instructor's permission. A course designed to reflect recent and current research interests of the staff and students working on mathematical problems in the areas of elasticity, fluid mechanics, and related fields. Not offered in 1978-79.

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: Mayer.

**APh/MS 4. Introduction to Materials Science.** 6 units (2-0-4); third term. Selected engineering systems, such as jet engines, superconducting transmission lines and nuclear reactors, are discussed in terms of the critical role played by materials in their construction and performance. Those material properties of greatest significance are explored to show how they are governed by the structure and basic physics and chemistry of the material. Graded pass/fail. Instructor: Wood.

**APh 9. Solid-State Electronics Laboratory.** 6 units (1-3-2); second term. Prerequisite: APh 3. Six units credit allowed toward freshman laboratory requirement. An introductory nonstructured project laboratory designed to provide an opportunity for projects related to the course APh 3. 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 the laws of thermodynamics and their underlying physical significance, thermodynamic energy functions, Maxwell relations, and the applications of equilibrium thermodynamics; nonequilibrium thermodynamics such as the analysis of heat engine cycles, and an introduction to statistical mechanics and kinetic theory. Instructor: Goodstein.

**APh 23. Demonstration Lectures in Optics.** 6 units (2-0-4); first term. Prerequisites: Ma 1 abc, Ph 1 abc. Nine demonstration lectures covering the fundamentals of optics with emphasis on modern optical applications. These demonstrations are intended to exhibit basic optical phenomena including refraction, dispersion, birefringence, diffraction, and laser oscillation, and the applications of these phenomena in optical systems: two-beam and multiple-beam interferometry, Fourier-transform spectroscopy, Fourier-transform image processing, holography, electro-optic and acousto-optic modulation, optical detection and heterodyning, optical fibers and integrated optical systems, optical communications and radar, adaptive optical systems. Instructor: Bridges.

**APh 24. Introductory Modern Optics Laboratory.** 6 units; second term. Prerequisite; APh 23. Laboratory experiments to acquaint students with the contemporary aspects of modern optical research and technology. Experiments encompass many of the topics and concepts covered in APh 23. Instructor: Bridges.

**APh 50 abc. Applied Physics.** *9 units* (3-0-6); *first, second, third terms. Prerequisites: Ph 2 abc, Ma 2 abc, or equivalents.* 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: Dimotakis.

**APh 78 abc. Senior Thesis, Experimental.** 9 units; first, second, third terms. Prerequisite: instructor's permission. This course is intended to provide supervised experimental research experience, and is open only to senior applied physics majors. Requirements will be set by individual faculty members, but will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Applied Physics Undergraduate Committee. Not offered on a pass/ fail basis. Instructors: Applied Physics Staff.

**APh 79 abc. Senior Thesis, Theoretical.** 9 units; first, second, third terms. Prerequisite: instructor's permission. This course is intended to provide supervised theoretical research experience, and is open only to senior applied physics majors. Requirements will be set by individual faculty members, but will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Applied Physics Undergraduate Committee. Not offered on pass/fail basis. This course cannot be used to satisfy the laboratory requirement in APh. Instructors: Applied Physics Staff.

**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. The course begins with the study of one-dimensional flows and then moves to consideration of flows with progressively more complex dimensionality. During the third term viscous flows will be treated. Topics to be discussed include: thermodynamics of fluid flow, equations of motion; one-dimensional compressible flow, shock waves, nonsteady flow; acoustics, thin airfoil theory; potential flow; kinematics of fluid flow, stress, vorticity; vortex flows; dynamics of real fluids, viscous flow, boundary layer theory. Instructor: Sturtevant.

Ae/APh 104 abc. Experimental Methods. 9 units (3-0-6 first term; 1-3-5 second and third terms). Prerequisites: ME 19 abc, AM 97 abc or equivalent, AMa 95 abc or equivalent (may be taken concurrently), Ae/APh 101 abc (may be taken concurrently). Lectures on experiment design and implementation. Measurement methods, transducer fundamentals, instrumentation, signal processing, noise theory, analog and digital electronic fundamentals, data acquisition and processing systems. Experiments (second and third terms) in solid and fluid mechanics, with emphasis on current research methods, on low-speed and high-speed aerodynamics, laser Doppler velocimetry, signal noise. Text: Class notes. Instructor: Coles.

**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: McGill.

**APh 110. Topics in Applied Physics.** 2 units (2-0-0); first, second, third terms. A seminar course designed to acquaint juniors and first-year graduate students with the various research areas represented in the option. Lecture each week given by a different faculty member of the option, reviewing, in general terms, his or her field of research. Graded pass/fail. Instructors: Humphrey and Applied Physics faculty.

**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: Smith.

APh/MS 126 abc. The Electronic Structure of Metals and Alloys. 9 units (3-0-6); first, second, third terms. Prerequisite: an introductory course in quantum mechanics. The basic principles of quantum mechanics and thermodynamics applied to understanding electronic band structure, metallic cohesion, structural stability, phase equilibrium and the kinetics of phase transitions, metastable states, lattice dynamics and elastic behavior, transport properties, superconductivity, magnetism, and the physics of metallic surfaces and thin metals films. Comparison of theory with experimental data and phenomenological concepts will form an integral part of the course with some discussion of current technological areas of application including superconducting devices and high field magnets, magnetic memory devices, radiation damage to metals, and corrosion resistance. Instructor: Johnson.

**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<sup>3</sup>, ultralow temperature experiment, cryogenic techniques, and macroscopic quantum devices. Offered in alternate years; not offered in 1978-79.

**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 1978-79.

**APh 153 abc.** Modern Optics. 9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc. The emphasis is on fundamental principles of modern optics and on understanding of contemporary optical systems. Geometrical optics, ray matrices, and the Hamiltonian analogy will be discussed as an introduction to the wave equation and its solutions. Topics to be covered include: Fresnel and Fraunhofer diffraction, Fermat's principle, the analysis of systems based on e.m. theory, Gaussian beam propagation, interferometry, holography, speckle, van der Lugt filters, pattern recognition, fiber optics, light modulation, diffraction by sound, radiometry, detectors, sources. Text: Class notes and selected references. Instructor: Hesselink.

**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: Bellan.

APh 161 abc. Nuclear Energy. 0 units (3-0-6); first, second, third terms. Prerequisites: AMa 95 abc and Ph 106 abc or equivalent. Fission and fusion reactors, underlying nuclear physics, particle diffusion, static and dynamic phenomena, effects of radiation on matter, reactor types, economics of nuclear energy. Not offered in 1978-79.

**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.

## 272 Subjects of Instruction

**APh 190 abc. Quantum Electronics.** 9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125, or equivalent. This course is concerned with generation, manipulations, propagation, and applications of coherent radiation. Starting with the basic theory of the interaction of electromagnetic radiation with resonant atomic transitions, the course takes up the subjects of laser oscillation, important laser media, Gaussian beam modes, the electro-optic effect, nonlinear-optics theory, second harmonic generation, parametric oscillation, stimulated Brillouin and Raman scattering. Other topics include: Light modulation, diffraction of light by sound and quantum noise theory. Text: *Quantum Electronics* by Yariv, class references and research literature. Instructor: Yariv.

**APh 195 abc.** Molecular Gas Lasers. 9 units (3-0-6); first, second terms. An introduction to gas lasers based on transitions involving molecular degrees of freedom. Some acquaintance with fluid mechanics, and knowledge of electromagnetic theory and quantum mechanics at the advanced undergraduate level will be assumed. Background material on the interaction of radiation and matter, and optical resonators will be included, but the emphasis will be on processes particular to molecular lasers. Examples of electrical discharge, gas dynamic, and chemical lasers will be discussed. Offered in alternate years; not offered in 1978-79. Instructor: Culick.

**APh 200.** Applied Physics Research. Units in accordance with work accomplished. Offered to graduate students in applied physics for research or reading. Students should consult their advisers before registering for the course. Graded pass/fail.

**APh 214 abc.** Advanced Solid-State Physics. 9 units (3-0-6); first, second, third terms. Prerequisites: APh 114 abc and Ch 125 abc or Ph 125 abc. A course in experimental and theoretical solid-state physics. Topics include: phonons; electronic excitation in solids; electron-phonon interactions; optical transport, and magnetic properties; superconductivity; ferroelectricity. The emphasis will be mainly theoretical with frequent comparison between theoretical predictions and experimental results. Not offered in 1978-79.

**APh 250.** Advanced Topics in Applied Physics. Units and term to be arranged. The content of this course will vary from year to year. Topics of current interest will be chosen according to the interests of students and staff. Visiting faculty may present portions of this course from time to time. Instructors: Staff.

**APh 281 abc.** 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. Not offered in 1978-79.

**APh 300.** Thesis Research in Applied Physics. Units in accordance with work accomplished. APh 300 is elected in place of APh 200 when the student has progressed to the point where his or her research leads directly toward the thesis of the degree of Doctor of Philosophy. Approval of the student's research supervisor and of his or her department adviser or registration representative must be obtained before registering. Graded pass/fail.

# ART

Art 101. Topics in Art. 9 units (3-0-6). Instructors: Staff.

**Art 102. British Art of the Georgian Period.** *9 units (3-0-6); third term.* An introduction to the visual arts and the vocabularies of analysis for the study of painting through an in-depth study of the British art of the Georgian period in the collection of the Huntington Art Gallery. Instructor: Wark.

**Art 103. Ancient Art.** *9 units (3-0-6); 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. Not offered in 1978-79. 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.

**Art 110. History of Western Architecture: An Introduction.** 9 units (3-0-6); first term. A survey of the history of Western architecture from ancient times to the present, focusing on great monuments. Analyses of masterworks of architecture will consider building types, forms, technology, and the fulfillment of specific cultural functions from the Egyptian tomb to the "skyscraper" office building in the USA. Town planning, the landscaped environment, architect and architect/engineer will also be topics of discussion. Instructor: Price.

# ASTRONOMY

# Undergraduate Courses<sup>1</sup>

**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. Instructors: M. Cohen, J. 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: Oke.

**Ay 21. Galaxies and Radio Sources.** 9 units (3-0-6); second term. Prerequisite; Ay 20. The extragalactic distance scale. Clusters of galaxies. Introduction to cosmology. Galactic and extragalactic radio sources. Instructor: 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: Sargent and staff.

Ay 42. Research in Astronomy, Radio Astronomy, and Astrophysics. Units in accordance with work accomplished. Properly qualified undergraduates may, in their senior year, undertake independent or guided research with the goal of preparing a senior thesis. Graded pass/fail. Instructors: Staff.

<sup>1</sup>See also Ge 101 a.

Ay 43. Reading in Astronomy, Radio Astronomy, and Astrophysics. Units in accordance with work accomplished. Student must have a definite reading plan and obtain permission of instructor before registering. Graded pass/fail. Instructors: Staff.

# **Advanced Courses**

**Ay 100.** Astronomical Measurements and Instruments. 12 units (3-3-6); second term. The theory of optical instruments; spectrographs; the Schmidt and other wide-field telescopes. Laboratory instruments. Radio telescopes, radiometers and interferometers. Techniques and dectectors in infrared and x-ray astronomy. Laboratory exercises. Instructors: Oke, M. Cohen.

Ay 101. The Physics of Stars. 11 units (3-2-6); first term. Prerequisite: Ay 20. The physics of stellar atmospheres and interiors. Instructor: Goldreich.

**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: Blandford.

**Ay 110. Senior Seminar in Astrophysics.** *6 units (2-0-4); second term.* Designed for Ay seniors. Seminar on astrophysical topics of current interest. The lectures will be given by the students. The emphasis will be on topics which require a synthesis of previous formal course work. Instructor : Sargent.

**Ay 131. Stellar Atmospheres.** 9 units (3-0-6); second term. Prerequisites; Ay 20 (undergraduates), Ay 120 (graduates) and Ph 92 abc or equivalents. General survey of the methods for studying the structure and composition of stellar atmospheres. Instructor: J. Cohen.

**Ay 132. Stellar Interiors.** 9 units (3-0-6); 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: Moffet, 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; offered in 1978-79. Instructor: Zirin.

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 1978-79. Instructor: Wannier.

**Ay 139. Stellar Dynamics and Galactic Structure.** 9 units (3-0-6); second 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 1978-79.

**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. Not offered in 1978-79.

**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 1978-79. Instructors: Sargent, Gunn.

**Ay 208.** Modern Observational Astronomy. 6 units (1-0-5); third term. Prerequisite: instructor's permission. An observational course for graduate students in astronomy in which modern astronomical techniques are used in conjunction with the various telescopes on Mount Wilson and Palomar Mountain. Students will be permitted to register for only one term. Given in alternate years; not offered in 1978-79.

**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 1978-79. Instructor: Goldreich.

**Ay 218 ab. High-Energy Astrophysics.** 9 units (3-0-6); second, third terms. Prerequisites: Ph 106 and Ph 92 or Ph 112 or equivalent, including a solid understanding of electromagnetic theory, special relativity, and quantum mechanics. Equation of state and physical processes at high densities and at high temperatures. Hydrodynamics; shock waves, magnetohydrodynamics. Radiation processes (thermal, synchroton, bremsstrahlung, inverse Compton, and coherent). Relativistic gravity. Not offered in 1978-79.

**Ay 234.** Seminar in Radio Astronomy. 6 units (2-0-4); second term. Prerequisite: Ay 133 ab. Recent developments in radio astronomy for the advanced student. Current pubblications and research in progress will be discussed by students and staff. Given in alternate years; offered in 1978-79. Instructors: M. Cohen plus visitors.

The following courses will be offered from time to time by members of the Institute and Observatories staffs:

Ay 135. Topics in Modern Astronomy.

- Ay 136. Solar System Astrophysics.
- Ay 137. Topics in Space Astronomy and Physics.
- Ay 151. Seminar in Stellar Atmosphere Theory.
- Ay 152. Advanced Stellar Interiors.

- Ay 203. Cosmical Electrodynamics.
- Ay 204. Advanced Spectroscopy.
- Ay 206. Variable Stars.
- Ay 213. Selected Topics in Observational Cosmology.
- Ay 214. Theoretical Cosmology.
- Ay 216. Dynamics and Formation of Galaxies and Clusters.
- Ay 217. Theoretical Astrophysical Spectroscopy.

BIOINFORMATION SYSTEMS (See Engineering and Applied Science)

# 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 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: Lazarides, 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: Konopka and staff.

**Bi 27. Biology Scholars Program.** Units to be arranged. A program providing, by arrangement, a flexible combination of course work and independent study in biology for selected students in the junior and senior years. Pass/fail grading may be permitted. Instructors: Konopka and staff.

# **Advanced Courses**

(A) Subjects intended for graduate and undergraduate students.

**Bi 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. Not offered in 1978-79.

**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 course emphasizes macromolecular structure and the metabolic processes involved in energy store and utilization and considers the storage, transmission and expression of generic information in prokaryotes and eukaryotes. It also includes other topics in biochemistry of higher organisms, such as molecular regulatory mechanisms and the biochemistry of cell membranes. Instructors: Campbell, Maniatis, Raftery, Richards.

**Bi 111. Biochemistry Laboratory.** 10 units (0-8-2); second term. Open to students enrolled in Bi/Ch 110; others require consent of instructor. An introduction to current methods in biochemical research, through laboratory projects suggested by the lecture and seminar material of Bi/Ch 110. Instructors: Mitchell and staff.

**Bi 114. Immunology.** *12 units (4-0-8); first term. Prerequisite: Bi 122 or equivalent.* A course on the principles and methods of immunology and their application to various biological problems. Instructor: Hood.

**Bi 115.** Virology. 10 units (3-4-3); third term. Prerequisite: Bi/Ch 110 or instructor's permission. An introduction to the chemistry and biology of bacterial, plant, and animal viruses. The subject matter will include viral structure, the biochemistry and regulation of virus replication, viral genetics, and virus-induced changes in the host cell. Instructor: Strauss.

**Bi 116. Immunology Laboratory.** 5 units (0-5-0); first term. Open to students enrolled in Bi 114; others require instructor's permission. Laboratory research projects to serve primarily as a means of acquiring experience with some of the methods and problems of immunology. Instructor: Owen.

**Bi 119.** Advanced Cell Biology. 9 units (3-0-6); third term. Prerequisites: Bi 9, Bi/Ch 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 150 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/Ch 132 ab. Biophysical Chemistry of Macromolecules.** 9 units (3-0-6); first, second terms. Prerequisite: Ch 21 or equivalent. The biophysical chemistry of nucleic acids, proteins, and membranes. Topics are chosen because of their relevance to molecular biology. Given in alternate years; not offered in 1978-79. Instructors: Campbell, Chan, Davidson.

**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. Not offered in 1978-79. 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 in alternate years; offered in 1978-79.

**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 1978-79. 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 1978-79. 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 1978-79. 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. Not offered in 1978-79. Instructors: Horowitz, Dickerson and staff.

**Bi 150.** Neurobiology. 10 units (4-0-6); 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. Instructors: Hudspeth, Van Essen.

**Bi 151.** Integrative Physiology of the Central Nervous System. 9 units (3-0-6); first term. A trip through the vertebrate visual system, from retinal image to visuomotor behavior, to illustrate the principles of integrative neurophysiology. Instructor: Pettigrew.

**Bi 152. Behavioral Biology.** 6 units (2-0-4); second term. Introduction to ethology and behavioral genetics. Topics include causation, development, evolution, and genetic analysis of animal behavior, with examples from both invertebrates and vertebrates. Instructors: Konishi and Benzer.

**Bi 155.** Psychobiology. 6 units (2-0-4); second term. An introduction to the field with lectures, reading, and discussion in selected topics dealing with neural constraints in human behavior, functional plasticity, hemispheric specialization, and the mind-brain relation. Instructor: Sperry.

**Bi 156.** Neurochemistry. 9 units (3-0-6); third term. Prerequisite: Bi 150 or instructor's permission. A lecture and discussion course covering chemical aspects of synaptic transmission, impulse conduction, axonal transport, neuroendocrine control mechanisms, and control of nerve cell differentiation, growth, and systemic organization. Instructor: Brockes.

**Bi 157. Comparative Nervous Systems.** 9 units (2-3-4); third term. An introduction to the comparative study of the gross and microscopic structure of nervous systems. The main emphasis will be on the vertebrate nervous system; the highly developed central nervous systems found in arthropods and cephalopods will also be examined. Variation in nervous system structure with function and with behavioral and ecological specializations and the evolution of the vertebrate brain will be discussed. Offered in alternate years; offered in 1978-79. Instructor: Allman.

**Bi 158.** Primatology. 9 units (3-1-5); third term. Evolutionary and behavioral biology of primates. Topics will include fossil primates, comparative anatomy, physiology and ethology of primates, and tool invention and symbolic communication in primates. Offered in alternate years; not offered in 1978-79. Instructor: Allman.

**Bi 161.** Neurophysiology Laboratory. 6 units (0-4-2); second term. Prerequisite: Bi 150, 151, or instructor's permission. The principles of cellular neurophysiology are illustrated using the frog nerve-muscle preparation. Students conduct all aspects of the experiments, including dissections, fabrication of microelectrodes, and intracellular stimulation and recording. Instructor: Lester.

(B) Subjects primarily for graduate students.

**Bi 202.** Biochemistry Seminar. 1 unit; all terms. A seminar on selected topics and on recent advances in the field. In charge: Mitchell.

**Bi 204. Genetics Seminar.** 2 *units; all terms.* Reports and discussion on special topics. In charge: Lewis and staff.

**Bi 209.** Psychobiology Seminar. Units to be arranged; all terms. Prerequisite: instructor's permission. An advanced seminar course in brain mechanisms and behavior. In charge: Sperry.

**Bi 211. Topics in Membrane and Synaptic Physiology.** 6 units (3-0-3); first term. Graduate seminar discussing the original literature on the biophysics and biochemistry of processes mediated by the neuronal cell membrane. Particular emphasis on current aspects of synaptic transmission. Offered in alternate years; not offered in 1978-79. Instructor: Lester.

**Bi 212. Topics in Ethology and Behavioral Genetics.** 6 units (2-0-4); second term. Reading and discussions of original papers related to animal behavior and its analysis by ethological and genetic methods. Offered in alternate years; not offered in 1978-79. Instructors: Benzer and Konishi.

**Bi 213. Selected Topics in Integrative Neurophysiology.** 6 units (2-0-4); third term. *Prerequisite: Bi 151 or instructor's permission.* A reading and discussion course on current problems in the vertebrate central nervous system. The emphasis will be upon those areas which shed light on the mechanisms of neural plasticity. Offered in alternate years; not offered in 1978-79. Instructor: Pettigrew.

**Bi 214.** Topics in Sensory Transduction. 6 units (2-0-4); second term. Prerequisite; Bi 150 or 151 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 1978-79. 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 1978-79. 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 1978-79. Instructor: Allman.

**Bi 218. Cellular Basis of Behavior.** 6 units (2-0-4); third term. Lectures and seminars will emphasize one of the following topics during each quarter that the course is offered: Neural and humoral factors in the temporal organization of behavior; hormones and the nervous system; mechanisms of plasticity. Students will give seminars dealing with current research, drawn from the literature, in the selected topic area. Instructor: Strumwasser.

**Bi 219. Topics in Developmental Neurobiology.** 6 units (2-0-4); third term. This course will be concerned with the development of the vertebrate nervous system. Particular emphasis will be placed on understanding the factors that underlie the formation of specific neural connections. The format will involve reading and discussing original papers in a few selected areas. Among the topics covered will be: 1) the influence of genetic and environmental factors in development; 2) the specificity of connections formed during re-innervation; and 3) patterns of abnormal neurogenesis in mammalian mutants. Offered in alternate years; offered in 1978-79. Instructor: Van Essen.

**Bi 220.** Advanced Seminar in the Molecular Biology of Development. 4 units (1-0-3); all terms. Discussion of current papers on various pertinent topics including: nucleic acid renaturation and hybridization studies; transcription level regulation of gene function; evolutionary change in developmental processes; molecular aspects of differentiation in certain more intensively studied systems, etc. Primarily for graduate students. In charge: Davidson.

**Bi 241.** Advanced Topics in Molecular Biology. 6 units (2-0-4); third term. Prerequisite: instructor's permission. Reading and discussion of new areas in molecular biology. Instructor: Dreyer.

**Bi 260.** Advanced Physiology. Units to be arranged; second, third terms. A project laboratory using advanced techniques of physiology. Instructor: Lester.

**Bi 270. Special Topics in Biology.** Units to be arranged; first, second, third terms. Students may register with permission of the responsible faculty member.

**Bi 280-291. Biological Research.** Units to be arranged; first, second, third terms. Students may register for research in the following fields after consultation with those in charge: neurophysiology (280), biochemistry (281), neurochemistry (282), developmental biology (283), genetics (284), immunology (285), molecular biology (286), virology (287), biophysics (288), psychobiology (289), cell biology (290), neurobiology (291).

# BUSINESS ECONOMICS AND MANAGEMENT

# **Advanced Courses**

**BEM 100 abc. Business Economics and Management.** 9 units (3-0-6); first, second, third terms. Open to graduate students. This course endeavors to bridge the gap between engineering and business. The principal divisions are: 1) managerial accounting and information flows; 2) business finance; 3) quantitative technique and business decisions; 4) economic applications to business; and 5) systems analysis. Instructors: Morrisroe, Forsythe, Ramo.

**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. Instructors: Staff.

**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. Instructors: Staff.

# 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: Staff (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. Instructors: Seinfeld (a), Gavalas (b).

**ChE 103 abc. Transport Phenomena.** 9 units (3-0-6); first, second, third terms. Prerequisites: AMa 95 or AM 113 ab, or concurrent registration in either. A rigorous development of the basic differential equations of conservation of momentum, energy, and mass in fluid systems. Solution of problems involving fluid flow, heat transfer, convective diffusion, and staged and continuous unit operations. Instructors: Shair (a), Stephanopoulos (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 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: Flagan, Seinfeld.

**ChE 162.** Catalysis and Surface Chemistry. 9 units (3-0-6); third term. Prerequisite: Ch 21 abc or the equivalent. Thermodynamics of two-dimensional systems. Physical adsorption and the BET theory. Chemical adsorption and the Langmuir isotherm. 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 statistical mechanical formulation of the second and third laws of thermodynamics. Classical statistical mechanics and an introduction to quantum statistics. The ideal monatomic, diatomic and polyatomic gas. Translational, rotational, vibrational and electronic partition functions. Chemical equilibria. Real gases and distribution functions. The ideal crystal lattice. Instructor: Weinberg.

**ChE 165.** Applied Chemical Thermodynamics. 9 units (3-0-6); second, 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. Instructor: Shair.

**ChE 166 ab. Engineering Properties of Polymeric Materials.** 9 units (3-0-6); first, second terms. Prerequisite: AMa 95 or equivalent. Basic engineering properties of polymeric materials for the materials scientist and the chemical, mechanical, aeronautical, electrical, and civil engineer. Instructor: Tschoegl. **ChE 167 ab. Advanced Polymer Science.** 9 units (3-0-6); second, third terms. Prerequisite: ChE 166 ab or equivalent. A course in the science of synthetic macromolecules: their characterization and properties. The emphasis is on an understanding of polymer properties in terms of molecular structure. Not offered in 1978-79. Instructor: Tschoegl.

**ChE 168.** Polymer Science Laboratory. 9 units (0-7-2); third term. Prerequisite: ChE 166 ab or equivalent. An introduction to some of the basic techniques employed in the synthesis and characterization of synthetic polymers. Not offered in 1978-79. 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. Prerequisite: AM 113 or AMa 95, or concurrent registration in either, or instructor's permission. Foundations of heat, mass and momentum transfer. Governing differential equations; unidirectional flows; laminar flow of incompressible fluids at high and low Reynolds number; bubbles, drops and other small particles; forced and free convection heat and mass transfer. Selected topics from: transport processes in suspensions, packed beds or porous media; and mixing processes, such as Taylor diffusion. Instructor: Leal.

**ChE 174. Special Topics in Transport Phenomena.** 9 units (3-0-6); third term. Prerequisite: AM 113 or AMa 95, or concurrent registration in either, or instructor's permission. Advanced problems in heat, mass and momentum. 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 207 abc. Mechanical Behavior of Polymers.** 9 units (3-0-6); first, second, third terms. Prerequisite: AM 113, AMa 95, 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 1978-79. Instructor: Tschoegl.

ChE 280. Chemical Engineering Research. Offered to Ph.D. candidates in Chemical Engineering. Main lines of research now in progress are covered in detail on page 124.

# 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: Bercaw, Chan.

**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, organo-transition metal chemistry, and biochemistry. Graded pass/fail. Instructor: Bercaw.

**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, solubility, complexions 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 modern instrumental techniques that are currently employed in industrial and academic research. Emphasis will center on determinations of chemical composition, measurement of equilibrium constants, and trace-metal analysis. Instructors: Anson, Raftery, Schaefer.

**Ch 21 abc. The Physical Description of Chemical Systems.** 9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 abc, Ph 2 abc, Ma 2 abc. The main emphasis is on atomic and molecular theory, quantum mechanics, statistical mechanics, thermodynamics, and chemical kinetics. Instructors: Beauchamp, Goddard, Davidson.

**Ch 26 ab. Physical Chemistry Laboratory.** 10 units (0-6-4); second, third terms. Prerequisites: Ch 1 abc and Ch 21 a or equivalent. Laboratory exercises which provide illustrations of the principles of physical chemistry, an introduction to problems of current interest, and techniques of contemporary research. Instructors: Kuppermann, Zewail.

**Ch 41 abc. Chemistry of Covalent Compounds.** 9 units (3-0-6); first, second, third terms. Prerequisite: Ch 1 abc or instructor's permission. This course will cover the synthesis, structure, and mechanisms of reactions of covalent compounds. Emphasis will be on the study of molecules formed from carbon and other first- and second-row elements. Instructors: Dervan, Ireland.

**Ch 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); *second term.* Training in the techniques of oral presentation of chemical topics. Practice in the effective organization and delivery of reports before groups. Instructors: Anson, Marsh.

# **Advanced Courses**

**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 course emphasizes macromolecular structure and the metabolic processes involved in energy storage and utilization and considers the storage, transmission and expression of genetic information in prokaryotes and eukaryotes. It also includes other topics in biochemistry of higher organisms, such as molecular regulatory mechanisms and the biochemistry of cell membranes. Instructors: Campbell, Maniatis, Raftery, Richards.

**Ch 112 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. (c) not offered in 1978-79. Instructors: Gagné, Gray.

**Ch 113 abc. Advanced Ligand Field Theory.** *12 units (1-0-11); first, second, third terms. Prerequisite: Ch 21 abc or concurrent registration.* A tutorial course which involves problem solving in the more advanced aspects of ligand field theory. This course is recommended only for students interested in detailed theoretical work in the inorganic field. Instructor: Gray.

**Ch 117. Introduction to Electrochemistry.** *6 units (2-0-4); second term.* A discussion of the structure of the electrode-electrolyte interface, the mechanism by which charge is transferred across it, and of the experimental techniques used to study electrode reactions. The topics covered change from year to year but usually include diffusion currents, polarography, coulometry, irreversible electrode reactions, the electrical double layer, and the kinetics of electrode processes. Given in alternate years. Offered in 1978-79. Instructor: Anson.

**Ch 118 ab. Experimental Electrochemistry.** *Units by arrangement; second, third terms.* Laboratory practice in the use of selected electrochemical instruments and techniques. The student may pursue a set of expository experiments or elect to carry out a research project in electrochemistry. Instructor: Anson.

**Ch 120 abc. The Nature of the Chemical Bond.** 6 units (2-0-4); first, 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. Offered as a tutorial in 1978-79. 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: Janda, Marsh, Vaughan.

**Ch 125 abc. The Elements of Quantum Chemistry.** 9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or an equivalent brief introduction to quantum mechanics. A first course in molecular quantum mechanics consisting of a quantitative treatment of quantum mechanics with applications to systems of interest to chemists. The course includes the basic elements of quantum mechanics, electronic structure of atoms and molecules, some discussion of scattering theory, and the interactions of radiation fields with matter. Instructors: McKoy, Zewail.

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**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 1978-79. 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. Not offered in 1978-79.

**Bi/Ch 132 ab. Biophysical Chemistry of Macromolecules.** 9 units (3-0-6); first, second terms. Prerequisite: Ch 21 abc or the equivalent. The biophysical chemistry of nucleic acids, proteins, and membranes. Topics are chosen because of their relevance to molecular biology. Given in alternate years; not offered in 1978-79. Instructors: Campbell, Chan, Davidson.

**Bi/Ch 133. Biophysical Chemistry of Macromolecules Laboratory.** 14 units (0-10-4). A laboratory course designed to provide an intensive training in the techniques for the characterization of biological macromolecules. Open to selected students. Not offered in 1978-79. 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, or with consent of instructor. Rate energetics and mechanisms of chemical reactions. Theory of elementary processes. Application to simple and complex organic, inorganic, and enzymatic systems. Instructors: Beauchamp, Marcus.

**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 1978-79.

**Ch 144 ab. Advanced Organic Chemistry.** 9 units (3-0-6); first, second terms. Prerequisite: Ch 41 abc or equivalent. Lectures will focus on the design and execution of experiments in the study of organic reaction mechanisms. A critical analysis of current problems in physical organic chemistry will be presented such that research papers can be read with a real application of their chemical context and relevance. Topics such as thermochemical estimates, carbonium ions, carbanions, carbenes, nitrenes, free radicals, biradicals, orbital symmetry, photochemistry, thermal reactions, and electrophilic and nucleophilic substitution will be covered. Instructors: Dervan, Roberts.

**Ch 154 ab. Organometallic Chemistry.** 6 units (2-0-4); second, third terms. 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 1978-79. Instructor: Bercaw.

**ChE/Ch 164.** Introduction to Statistical Thermodynamics. 9 units (3-0-6); first term. Prerequisite: Ch 21 abc or the equivalent. Ensembles and a statistical mechanical formulation of the second and third laws of thermodynamics. Classical statistical mechanics and an introduction to quantum statistics. The ideal monatomic, diatomic and polyatomic gas. Translational, rotational, vibrational and electronic partition functions. Chemical equilibria. Real gases and distribution functions. The ideal crystal lattice. Instructor: Weinberg.

Ch 180. Chemical Research. 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 1978-79.

**Ch 224 a. Magnetic Resonance.** 9 units (3-0-6); third term. 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 1978-79. Instructor: Chan.

**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. 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. 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. Not offered in 1978-79.

**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. Not offered in 1978-79. Instructors: Raftery, Richards.

**Ch 247 a. Organic Reaction Mechanisms.** 6 units (2-0-4); third term. A detailed analysis of selected current problems in physical organic chemistry, the relationship of theory and experiment, and new research areas such as the reactions of metal carbon bonds, organic photochemistry, and catalysis by transition metals will be presented. Given in alternate years; offered in 1978-79. Instructor: Grubbs.

**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 1978-79. 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 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. Instructor: Davis.

**Ec/SS 11 b. Social Science Principles and Problems—Non-Market Decisions.** 9 units (3-0-6); second, third terms. Prerequisite: Ec/SS 11 a or equivalent. This course concentrates on non-market decisions. It focuses on committee and legislative decisionmaking as well as providing an introduction to recent work in the theory of voting and the political process. Instructors: Fiorina, Miller.

Ec/SS 11 c. Social Science Principles and Problems—Applications to Public Policy. 9 *units* (3-0-6); *third term. Prerequisite: Ec/SS 11 b or equivalent.* This course is devoted to current social problems and is designed to show the student that the theoretical tools developed in the first two terms can be used as the basis for rational solutions to pressing social problems. Instructor: Noll.

**Ec 13. Reading in Economics.** Units to be determined for the individual by the department. Not available for credit toward humanities-social science requirement. Graded pass/fail.

**Ec 15. Introduction to Macroeconomics: Principles and Problems.** 9 units (3-0-6); second, third terms. Prerequisite; Ec/SS 11 a or equivalent. Problems of inflation and depression and the tools of monetary and fiscal policy. Instructors: Klein, Oliver.

**Ec 98 abc. Senior Research and Thesis.** *Prerequisite: instructor's permission*. Senior economics majors wishing to undertake research may elect a variable number of units, not to exceed 12 in any one term, for such work under the direction of some member of the economics faculty.

HSS 99. See page 326 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 or equivalent. An examination of the traditions, schools of thought, and controversies which have helped shape modern economic analysis. Not offered in 1978-79. Instructors: Staff.

**Ec 115.** Population and Environment. 9 units (3-0-6); third term. This course will be concerned with: 1) the causes and consequences of rapid population growth; and 2) the problem of reducing the rate of growth through control of fertility. Instructor: Scudder.

**Ec 116.** Contemporary Socioeconomic Problems. 9 units (3-0-6); first term. Prerequisites: Ec/SS 11 a and Ec/SS 11 b or equivalent. An analytical investigation of the economic aspects of certain current social issues. Topics to be discussed include the economics of education, medical care systems, urban affairs, and the welfare system. Instructor: Klein.

**Ec 118. Environmental Economics.** 9 units (3-0-6); third term. Prerequisite: Ec/SS 11 a or equivalent. The methods of price and welfare theory are used to analyze the causes of air, water, and other environmental pollution, to examine their impact on economic welfare, and to evaluate selected policy alternatives for managing our environment. Instructors: Staff.

**Ec 120.** International Economic Theory. 9 units (3-0-6); third term. Prerequisites: Ec/SS 11 a and Ec/SS 11 b or equivalent. An investigation of the factors affecting the exchange of goods and services and the flow of capital between markets. Theory is stressed in this course. Instructor: Oliver.

**Ec 121 ab. Intermediate Microeconomics.** 9 units (3-0-6); first, second terms. Prerequisites: Ec/SS 11 a and Ec/SS 11 b or equivalent. The course includes a study of consumer preference, the structure and conduct of markets, factor pricing, measures of economic efficiency, and the interdependence of markets in reaching a general equilibrium. Instructor: Wilde.

**Ec 122. Econometrics.** 9 units (3-0-6); second term. Prerequisite: Ma 112 a. The application of statistical techniques to the analysis of economic data. Instructor: Grether.

**Ec 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); second, third terms. Prerequisites: Ec/SS 11 a and Ec/SS 11 b or equivalent or instructor's permission. This course includes an intensive study of Keynes's *General Theory of Employment* and post-Keynesian developments in the theory of income, consumption, investment, and growth. Instructor: Nelson.

**Ec 127.** Problems in Economic Theory (Seminar). Units by arrangement; first, second, third terms. Prerequisite: Ec 126 or its equivalent. Consideration of selected topics in economic theory. Instructors: Staff and guest lecturers.

**Ec 128.** The Elements of Dynamic Economics. 9 units (3-0-6); second term. Prerequisite: *Ec/SS 11 a or equivalent*. This course is concerned with explaining: 1) the role of competition as a determinant of the rate of progress; and 2) the relationship between microbehavior and macroperformance. Instructor: Klein.

**Ec 129.** Economic History of the United States. 9 units (3-0-6); first term. Prerequisite: Ec/SS 11 a or equivalent. An examination of certain analytical and quantitative tools and their application to American economic development. Instructor: Davis.

**Ec 130 ab. Political Foundations of Economic Policy.** *9 units (3-0-6); first, second terms.* Mathematical theories of individual and social choice are introduced as an approach to the class problems of welfare economics and economic policy. Not offered in 1978-79. Instructor: Plott.

**Ec 131. Labor Economics.** 9 units (3-0-6). Prerequisite: Ec/S5 11 a or equivalent. This course will focus on the modern theory of labor markets. Empirical evidence will be used to supplement theoretical results. Not offered in 1978-79. Instructor: Wilde.

**Ec/PS 134. The Political Economy of Urban Areas.** 9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent. This course will focus on development of a theory of urban government using analytic concepts from microeconomics and political science. Not offered in 1978-79. Instructor: Miller.

**Ec 135.** Marxist Economics. 9 units (3-0-6); second term. Prerequisite: Ec/SS 11 a or equivalent. A critical survey of the economic theory of capitalism as developed in the writings of Marx, Engels, and Lenin. Not offered in 1978-79. Instructor: Quirk.

**Ec 150. Independent Study on Population Problems.** Units to be arranged. Prerequisite: *Ec 115 or equivalent.* This course covers a broad range of problems including the technological, economic, demographic, sociological, political, and biological aspects of population growth, movement, and density. Graded pass/fail. Instructors: Scudder, Bonner, Munger.

# ELECTRICAL ENGINEERING (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 Seminar Presentations.** 2 units (1-0-1); second term (the first 36 persons to register will be accommodated this term. Any additional students registered will be scheduled for the third term). This course in seminar presentations is designed to meet the needs of engineers and engineering managers. The student receives guidance and practice in organizing and preparing the topic for presentation and in speaking with the help of visual aids, including the blackboard, overhead projector, and the slide projector. Instructors: Iwan, Wolfberg, and staff.

**E 13. System Dynamics.** 12 units (3-0-9); first term. Prerequisites: Ma 1 abc, Ph 1 abc, or instructor's permission. This course may be substituted for EE 13 a and serves or may serve as a prerequisite to EE 13 b. Predicting the behavior of systems of physical members from their mathematical models/mechanical, electrical, fluid, thermal, and others. Natural dynamic characteristics and stability: s-plane analysis and Routh's method. Dynamic coupling and natural modes. Forced response using Fourier, impulse, and Laplace techniques. Instructor: Cannon.

**E 99. Energy Research Laboratory—Combustion and Emissions.** 9 units (2-3-4); second term. The work in this course is divided into three parts. In the first, the students each design and build a burner or other combustion device and measure the quantities going in and the emissions coming out. In the second, they repeat the same type of measurements for an operating power plant. In the third, they undertake whatever experiments they deem necessary to establish consistencies and discrepancies between parts one and two. Not offered in 1978-79.

**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 103 abc. Data Analysis and Estimation Procedures.** 9 units (3-0-6); first, second, third terms. Prerequisite; instructor's permission. The basic statistical and mathematical concepts and tools needed for the effective analysis and interpretation of experimental data are presented. The emphasis is placed on the analysis of random data and on procedures leading to the optimal estimation of quantities of interest. Topics include: fundamentals of random variables and processes; vector, function and functional spaces and expansions; generalized harmonic analysis; approximation theory; sampling theory; estimation theory; filtering and prediction; data acquisition and processing; measurement and estimation procedures; interpolation; differentiation; integration; optimal filtering prediction. Examples will be drawn from various fields. Instructor: Marmarelis.

**E 126 abc.** Analysis and Synthesis of Engineering Systems. 9 units (3-0-6); first, second, third terms. A variety of systems drawn from civil, mechanical, electrical, and aerospace engineering will be studied in detail. Students will analyze and synthesize a number of engineering systems using interactive computer facilities. 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. The course begins with the study of one-dimensional flows and then moves to consideration of flows with progressively more complex dimensionality. During the third term viscous flows are treated. Topics to be discussed include: thermodynamics of fluid flow, equations of motion; one-dimensional compressible flow, shock waves, nonsteady flow; acoustics, thin airfoil theory; potential flow; kinematics of fluid flow, stress, vorticity; vortex flows; dynamics of real fluids, viscous flow, boundary layer theory. Instructor: 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. Twoand 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. Instructors: Babcock, Knauss.

**Ae 103 abc. Vehicle Performance and Dynamics.** 9 units (3-0-6); first, second, third terms. Prerequisite; AMa 95. Performance and dynamic behavior (stability and control) of vehicles moving in a continuum (air or water) will be discussed in a unified way. Examples to be discussed will include the dynamics and performance of vehicles such as submarines, VTOL and STOL aircraft, subsonic and supersonic aircraft and rockets. Topics include speed performance, climb and descent, range, take-off and landing distances, static longitudinal and lateral stability, equations of unsteady motion, dynamic stability, responses to controls and disturbances. Instructor: Kubota.

Ae/APh 104 abc. Experimental Methods. 9 units (3-0-6 first term; 1-3-5 second and third terms). Prerequisites: Me 19 abc, AM 97 abc or equivalent, AMa 95 abc or equivalent (may be taken concurrently), Ae/APh 101 abc (may be taken concurrently). Lectures on experiment design and implementation. Measurement methods, transducer fundamentals, instrumentation, signal processing, noise theory, analog and digital electronic fundamentals, data acquisition and processing systems. Experiments (second and third terms) in solid and fluid mechanics, with emphasis on, current research methods, on low-speed and high-speed aerodynamics, laser Doppler velocimetry, signal noise. Text: class notes. Instructor: Coles.

**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/AM 108 abc. Finite Element Methods. 9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission. A course on finite elements covering fundamental concepts, computer implementation, and mathematical analysis of the method. Techniques for general classes of linear and nonlinear elliptic, parabolic, hyperbolic, and eigenvalue problems. Survey and evaluation of important finite elements. Error estimates and computer code architecture for typical problem classes. Implicit and explicit algorithms in transient analysis. Emphasis on problems from structural and solid mechanics, and special topics of interest to the class, e.g., algorithms for viscoelasticity, viscoplasticity, nonlinear heat conduction, Navier-Stokes equations, contactimpact problems, etc. Instructor: Hughes.

Ae 109 ab. Energy and Environmental Problems in Aeronautics. 9 units (3-0-6); first and second terms. Historical and projected energy requirements of commercial, private, and military aviation, and relation to the total energy problem. Examination of major factors affecting aircraft energy consumption in taxiing, takeoff and climb, cruise, and landing modes. Problems and prospects for new fuels and advances in aerodynamic and power plant design. Environmental problems of noise and air pollution, including effects of power plant exhaust emissions on the troposphere (subsonic aircraft) and the stratosphere (supersonic aircraft). Methods of reducing pollutant emissions by analysis and experiments on combustion and mixing processes in aircraft power plants. Instructor: Lees.

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. Not offered in 1978-79.

**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 1978-79.

**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: Roshko, Brown.

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); second term. Prerequisite: instructor's permission. General mathematical formulation of the theory of thin elastic shells. Membrane and bending stresses in shells. Elastic stability. Surveys of recent advances in the non-linear theories of stressing and buckling of shells. Instructor: Babcock.

**Ae 213. The Mechanics of Fracture.** 9 units (3-0-6); third term. Prerequisites: 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. Instructor: Knauss.

**Ae 217.** Aero- and Hydroelasticity. 9 units (3-0-6). Prerequisite: instructor's permission. General formulation of aeroelastic and hydroelastic problems. Aeroelastic oscillations of cylinders, transmission lines and suspension bridges. Steady state problems; divergence, loss of control. Flutter of airfoils with nonlinear stiffness and damping characteristics. Instability of hydrofoils. Not offered in 1978-79.

Ae 221. Theory of Viscoelasticity. 9 units (3-0-6); second term. Prerequisites: Ae 202 or equivalent and instructor's permission. Material characterization and thermodynamic foundation of the stress-strain laws. Correspondence rule for viscoelastic and associated elastic solutions and integral formulation for quasi-static boundary value problems. Treatment of time-varying boundary conditions such as moving boundaries and moving loads. Stress waves. Approximate methods of viscoelastic stress analysis. Not offered in 1978-79.

**Ae 225. Special Topics in Solid Mechanics.** *9 units (3-0-6); first, second, third terms.* Subject matter will change from term to term depending upon staff and student interest but may include such topics as structural dynamics; aeroelasticity; thermal stress; mechanics of inelastic materials; and nonlinear problems. Not offered in 1978-79.

Ae 231. Wing Theory. 9 units (3-0-6); second term. Prerequisites: AeiAPh 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: Stewart.

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, shockwave structure, one-dimensional flow with chemical reactions, nonsteady one-dimensional flow, two-dimensional inviscid and viscous flows. Not offered in 1978-79.

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 1978-79.

**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 1978-79.

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: Mani.

Ae 237. Non-Steady Gasdynamics. 9 units (3-0-6); first term. 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 1978-79.

Ae 239. Turbulent Shear Flows. 9 units (3-0-6); third term. Similarity arguments for classical shear flows; jet, wake, plume, mixing layer, boundary layer. Survey of current research on large coherent structures. Role of such structures in mixing, entrainment, and transport. Not offered in 1978-79.

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. Not offered in 1978-79.

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 and student interest. Not offered in 1978-79.

# APPLIED MATHEMATICS (See page 265)

### 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: Hudson.

### **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. Twoand 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. Instructors: Babcock, Knauss.

Ae/AM 108 abc. Finite Element Methods. 9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission. A course on finite elements covering fundamental concepts, computer implementation, and mathematical analysis of the method. Techniques for general classes of linear and nonlinear elliptic, parabolic, hyperbolic, and eigenvalue problems. Survey and evaluation of important finite elements. Error estimates and computer code architecture for typical problem classes. Implicit and explicit algorithms in transient analysis. Emphasis on problems from structural and solid mechanics, and special topics of interest to the class, e.g., algorithms for viscoelasticity, viscoplasticity, nonlinear heat conduction, Navier-Stokes equations, contactimpact problems, etc. Instructor: Hughes.

**AM 113 abc. Engineering Mathematics.** 12 units (4-0-8); first, second, third terms. A course for graduate students who have not had the equivalent of AMa 95 abc. Prerequisite: Ma 1 abc, Ma 2 abc, or equivalent. Linear differential equations, including power series solutions and special functions. Introduction to complex variable theory with applications. Linear differential equations and special functions in the complex domain. Fourier series and orthogonal functions. Solution of boundary value problems for partial-differential equations by conformal mapping, separation of variables, and integral transforms. Instructors: Sternberg, Jennings.

**AM 125 abc. Engineering Mathematical Principles.** 9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or AM 113 abc. Topics include: linear spaces, operators and matrices, integral equations, variational principles, differential equations, stability, perturbation theory. Applications to problems in engineering and science will be stressed. Instructor: Corngold.

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

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related theorems of linearized elastostatics and elastodynamics. Integration theory and applications to specific problems of engineering interest. Instructor: Knowles.

AM 136 abc. Advanced Mathematical Elasticity Theory. 9 units (3-0-6); first, second, third terms. Prerequisite: AM 135 abc or equivalent. Topics drawn from the more advanced linear theory and the nonlinear theory. Specific content varies according to interest of students and instructor. Not offered in 1978-79.

**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 268)

#### BIOINFORMATION SYSTEMS

### Undergraduate Course

**BIS 80 abc. Undergraduate Research.** Units in accordance with work accomplished. Consent of both research adviser and course supervisor required before registering. This course is intended to provide supervised research by undergraduates. The topic of research must be approved by the supervisor and a formal final report must be presented at the completion of the research. Graded pass/fail. Bioinformation systems staff. Course Supervisor: McCann.

### Advanced Courses

**Bi/BIS 121 abc. Biosystems Analysis.** 6 units (2-0-4); three terms. Prerequisite: Bi 150 or instructor's permission. 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. Instructor: 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.

**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 281)

### 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: AelAM 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 transducers suitable for the measurement of strong earthquake ground motion, and of structural response to such motion. Study of principal methods of dynamic tests of structures including generation of forces and measurement of structural response. Instructor: Housner.

**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: Housner.

**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<sup>1</sup>

# **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 Computing. 6 units (2-0-4); third term. State machines, stored program machines, control structures, modular program design, symbolic control and data manipulation, assemblers, compilers and high-level programming language. Instructor: Mead.

**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: Bacon.

**CS 80 abc. Undergraduate Research in Computer Science.** Units in accordance with work accomplished. Consent of both research adviser and course supervisor required before registering. This course 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.

<sup>1</sup>For linguistics see page 328.

# Advanced Courses

**CS 112. Principles of Digital Information Processing**. 9 units (3-3-3); first term. Prerequisites: CS/EE 4 and CS 10 or their equivalents. CS 112 presents the principles and concepts of information processing systems with emphasis on the design of stored program, synchronous computers, minimization of Boolean functions, switching theory, arithmetic algorithms, machine models, and assembler language programming. Instructor: Ray.

**CS 114. Microprocessor Systems.** 9 units (3-3-3); second term. Prerequisite: CS 112 or equivalent. This course presents the issues peculiar to microprocessors and microprocessor systems. Emphasis is on student solutions to real problems using development aids and interactive computing. Instructor: Ray.

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**CS 116.** Technology, Architecture, and Applications of Computers. 6 units (3-0-3); *third term. Prerequisite: CS 112 or equivalent.* CS 116 offers a series of seminars on the technology, architecture, and applications of computers. About half of the lectures will be given by guests from industry and from the academic departments at Caltech. Instructor: Ray.

**CS/EE 121.** Microprocessor Laboratory. 9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor; third term. Prerequisite: CS 114 or equivalent. A project laboratory to permit the student to design and build a microprocessor system. Instructor: Ray.

**CS 137. Systematic Computer Programming.** 12 units (3-3-6); first term. Prerequisite: CS/EE 10 or equivalent. An informal introduction to computer programming in a well-structured, efficient programming language. The main goal is to enable the student to write small programs with a clearly defined purpose and structure and to test and document them systematically. The influence of computer properties on program efficiency is discussed and an overview of a simple compiler is given. Instructors: Staff.

**CS 138.** Data Structures and Algorithms. 12 units (3-3-6); second term. Prerequisite; CS 137 or equivalent. An introduction to the abstract properties and implementation techniques of computer programming languages. The main topic is the axioms and representation of data structures and algorithms. Exercises in language implementation are solved by small student teams. Instructors: Staff.

**CS 139. Multiprogramming and Resource Sharing.** *12 units (3-3-6); third term. Prerequisites: CS 137, CS 138 or equivalent.* An introduction to the common principles of computer operating systems. The main topics are the abstract properties of concurrent processes and their implementation in terms of processor and store management, scheduling algorithms and resource protection techniques. The students will solve exercises in multiprogramming and study selected advanced topics. Instructors: Staff.

**CS 140 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 1978-79. Instructor: Thompson.

**CS 145. Programming with Associons.** *9 units (3-0-6); first term. Prerequisites: CS 137, 138 and 139, or equivalent.* A programming language will be designed for associative machines with distributed processing. The semantics of this language will be formally defined. The correctness of associon programs will be proved. Problem areas from which programming exercises are selected include graph theory, data base management, and artificial intelligence. Instructor: Rem.

**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 1978-79.

**CS 185. Self-Timed Logic Systems.** 9 units (3-3-3) first term. Prerequisite: CS 110 or equivalent and permission of instructor. Systems in which the inevitable logic delays are modeled in timing networks. Sequencing mechanisms, sub-routing mechanism, arbitration between contenders, and three-level implementations of self-timed logic will be discussed. Applications to fully segmented and partly synchronous systems will be considered. Instructors: Staff.

**CS 198.** Special Topics. 9 units (3-0-6). Prerequisite: CS 137, 138, 139, or CS 110 or equivalent and permission of instructor. Topics of interest in computer science are offered on an informal basis. Topics offered in the past or planned include: design of highly parallel computers, automatic circuit layout, and special purpose programming languages. Topics vary from quarter to quarter. May not be offered in any particular quarter. Instructors: Staff.

**CS 238. Design and Analysis of Computer Algorithms.** 12 units (3-0-9); second term. *Prerequisite: CS 137, 138, 139 or instructor's permission.* A two-quarter sequence concerning the design of computer algorithms and the analysis of their complexity. The first quarter includes random access machines as a model of computation and covers data structures used in the design of efficient algorithms. Problem areas from which algorithms are selected include sorting, searching, and graph theory. Instructor: Rem.

**CS 239. Design and Analysis of Computer Algorithms.** *12 units* (3-0-9); *third term. Prerequisite*: CS 238. A continuation of CS 238. Problem areas from which algorithms are selected include matrix operations, the fast Fourier transform, and pattern matching. An introduction to NP-complete problems will be discussed. Instructor: Rem.

**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. Not offered in 1978-79. 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.** *12 units* (3-6-6); 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: Sutherland.

**CS 286.** Computer Architecture. 12 units (3-6-3); first term. Prerequisites CS 137 or CS/EE 281. Instructor's permission to register also required. Relative merits of hardware and software implementations of different computer functions. Examples will be taken from available and proposed systems. Intensive student participation leading to continuing student hardware and software projects is expected. Instructor: Minter.

**CS 288 abc. Philosophy of Computing.** 9 units (3-3-3). Prerequisite: instructor's permission. Topics in the design and use of computers for advanced applications will be considered. What is the distinction between data and program? How are data elements identified? accessed? recognized? How do different computer architectures and computer languages reflect the way their designers answered these questions? Student participation in projects, reporting on selections from the literature, and class discussion expected. Since the content of this course may change from year to year, it may be repeated for credit. Instructor: Kay.

# 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 amplifer. 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: Bacon.

**EE 13 ab.** Circuit Theory. 9 units (3-0-6); first, second terms. Prerequisites: Ma 1 abc and Ph 1 abc. Analysis of linear systems in the time and frequency domains. Loop and node equations, two terminal pair networks, Fourier and Laplace transforms, convolution, autocorrelation, feedback systems, flow graphs, and distributed linear systems. Introductory synthesis and filter theory. Computer solution of problems. Instructor: Langmuir.

**EE 14 abc. Introduction to Electronic Engineering.** 9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc. Linear circuit analysis, Kirchoff's laws and the circuit elements, transient and steady-state network solutions, phasor notation and manipulation, Thevenin and Norton theorems, piece-wise linear analysis, power considerations, introduction to Laplace transform and the pole-zero description of network characteristics. Physical principles of device operation, silicon diodes, FET's and transistors, conduction in semiconductors, drift and diffusion, temperature effects and device characteristics and limitations, models. Active circuit analysis, distortion, frequency response and multistage amplifiers, stability and Nyquist's Theorem, large signal analysis, multivibrators and power amplifiers. Instructor: Martel.

**EE 40. Fundamentals of Energy Processing Systems.** 9 units (3-0-6); first term. Prerequisites: Ma 2 abc, Ph 2 abc, EE 14 abc, EE 90 abc. Introduction to electrical energy processing systems as distinct from information processing systems. Elementary magnetic devices: generators, motors, and transformers. The special problems of electronic power processing. Instructor: Cuk.

**EE 60.** Communication System Fundamentals. 9 units (3-0-6); third term. Prerequisites: Ma 2 abc, EE 13 ab. Laws of radio and guided transmission, noise as a limiting factor, AM and FM signals and signal-to-noise ratio, sampling and digital transmission, errors, information theory, error correction. Emphasis will be on fundamental laws and equations and their applications rather than on derivations. Instructor: Bridges.

**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 non-linear 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. Instructor: Long.

**EE 91 abc. Experimental Projects in Electronic Circuits.** Units by arrangement; 6 units minimum each term. Prerequisites: EE 14 abc and EE 90 or equivalent. Recommended: EE 114 abc or CS 112, 114, 116 (may be taken concurrently). Open to seniors; others only with consent of instructor. An opportunity to do original projects in electronics and electronic circuits. Selection of significant projects, the engineering approach, demonstration of a finished product through the use of modern electronic techniques. The use of integrated circuit elements, digital and analogue, is encouraged. Printed circuit board facilities are available. Text: Literature references. Instructor: Bacon.

### Advanced Courses

**EE 112 abc.** Active Filter Synthesis. 9 units (2-3-4); first, second, third terms. Prerequisite: *AMa 95 abc.* Realization of electrical filter functions through use of operational amplifiers and digital filters. Laplace and Z-transform theory will be used extensively. Laboratory work will include construction and testing of various filter designs. Digital systems will be realized using a general purpose laboratory digital filter and also by computer modelling. Instructor: Wilts.

**EE 113.** Principles of Pulse and Timing Circuits. 9 units (3-0-6); second term. Prerequisite: EE 14 abc. Switching, timing, wave shaping, and logic circuits to generate the diversity of waveforms and functions used in pulse systems, instrumentation, and computers. Emphasis on techniques of analysis and obtaining appropriate circuit models for solid-state devices in these highly non-linear circuits. Instructor: Long.

**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 115. Radio Frequency Circuits.** 9 units (3-0-6); third term. Prerequisite: EE 14 abc or equivalent. Small and large signal devices and circuits are covered, with applications in radio communications. Special attention is placed upon device frequency limitations and circuit techniques used to optimize their performance in video and tuned amplifiers, oscillators, modulators, detectors, and high-power RF amplifiers. Instructor: Long.

**EE 116. Topics in Modern Electronics.** *6 units (2-0-4). Prerequisites: Ma 2 abc and Ph 2 abc.* Topics in various fields of electronics by guest lecturers from industry. Specific topics and scope announced prior to registration. A seminar format. Graded pass/fail. Offered as announced. Instructors: Staff.

**EE 117 ab. Power Electronics.** 9 units (3-0-6); second, third terms. Prerequisite: EE 14 abc or equivalent. Introduction to repetitively switched power circuits for ac-to-dc, dc-to-ac, and dc-to-dc conversion and/or regulation of voltage or current in high-power applications: power supplies, motor controls, light dimmers, power amplifiers. Components, control techniques, analysis, and design. Instructor: Cuk.

**EE 118. Sampled Data Systems in Communication, Control and Measurement.** 9 *units (3-0-6); first term.* Technological reasons for sampling and the ways errors and system stability are affected. Deterministic and random sampling of random processes. Extrapolation and interpolation methods and their non-stationary error processes. The Z-transform and sampled-data feedback system stability. Instructor: Simon.

**EE 119 ab. Signal Processing Methods.** 9 units (3-0-6); second, third terms. Methods of signal processing including continuous and sampled electronic analog, digital, optical, and hybrid combinations in one and two dimensions. Use of operational amplifiers, charge-coupled devices, digital processors, and coherent and noncoherent optical devices. This course will emphasize digital subsystem design for communication, radar, and signal processing. Instructor: Green.

**EE 120.** Principles of Linear Integrated Circuit Design. 9 units (3-0-6); first term. Prerequisite: EE 14 abc. Device physics, integrated circuit processing, and linear circuit design techniques. Emphasis is placed upon taking advantage of the unique properties of integrated devices and structures in designing linear circuits with performance unattainable by other fabrication techniques. Instructor: Long.

**CS/EE 121.** Microprocessor Laboratory. 9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor; third term. Prerequisite: CS 114 or equivalent. A project laboratory to permit the student to design and build a microprocessor system. Instructor: Ray.

**EE 151 abc. Electromagnetism.** 9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc; AMa 95 abc. Primarily for electrical engineering students. Electrostatics, magnetostatics, Maxwell's equations, waveguides, cavity resonators, and antennas. Topics on propagation in the ionosphere, propagation over the earth's surface, and modern microwave tubes. Instructor: 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.** 9 units (3-0-6); first, second, third terms. Prerequisite: Ma 2 abc, Ph 2 abc. Relevant to communication in its diverse scientific and commercial applications. The first quarter taken alone provides an introduction to the theory of signal detection in the presence of noise; suitable also for students in other areas such as astronomy, physics, and seismology. The second quarter covers communication signals over terrestrial and space links. The third quarter covers communication channels and sources, including data, voice, and video. Instructor: Posner.

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 and rate distortion theory. Error-control systems, especially algebraic and convolutional codes. Decoding algorithms and their implementation complexity. Practical applications to information systems. Not offered in 1978-79.

**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; random and noise waveforms, correlation functions, power spectra; optimum receiver principles; coded systems; error probabilities; channel capacity; waveform communication; rate distortion theory. Instructor: Rauch.

**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); first 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 Electronic 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. Not offered in 1978-79. Instructor: Papas.

**CS/EE 281 abc. Integrated Circuit Design.** 12 units (3-6-3); 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 1978-79. 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 abc. Oceans and Atmospheres. 9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 and Ph 2. Natural physical and chemical processes in the earth's fluid envelope. First term: geophysical fluid dynamics, ocean currents, temperatures, and salinity. Second term: atmospheric dynamics and thermodynamics, radiative transfer, climate change. Third term: atmospheric, oceanic and ionospheric chemistry and photochemistry, global effects of environmental pollution. Instructors: List, Ingersoll, Yung.

Env 112 abc. Hydrologic Transport Processes. 9 units (3-1-5), first term; 9 units (3-0-6), second, third terms. Prerequisites: AMa 95 abc or AM 113 abc (may be taken concurrently); ME 19 abc; and some knowledge of elements of hydrology (may be satisfied by special reading assignments). The hydrologic cycle and its relation to man; statistical analysis and simulation of hydrologic data; dynamic similitude; turbulent shear flow in rivers and estuaries; introduction to stratified flow, turbulent plumes and buoyant jets; hydraulic models. Transport and dispersion of solutes, sediments and heat in rivers, lakes, estuaries and coastal waters; heat transfer, evaporation and density stratification in natural waters. Engineering of outfalls for wastewater and thermal discharges. Flow through porous media, wells, 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: Flagan, Friedlander, 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. Offered in 1979-80. 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: APh/ME 17 abc, ME 19 abc, or equivalents. The application of science and engineering sciences to water supply and treatment for municipal use; treatment and disposal of liquid wastes; unit operations as applied to environmental systems; the designs of works; 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.

**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: Flagan, Seinfeld.

**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. Aerosol Science.** 9 units (3-0-6); second, third terms. Prerequisite: ME 19 ab or ChE 103 abc, or equivalent. Physics and chemistry of small particle behavior with applications to gas cleaning, air pollution, and air chemistry. The first term is concerned with aerosol characterization, and transport and optical properties. The second term deals with the dynamics of particle size distribution functions, 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/Ge 203 abc. Advanced Oceans and Atmospheres. 9 units (3-0-6); first, second, third terms. Prerequisite: Env/Ge 103 abc. First term: atmospheric dynamics and numerical modeling. Second term: remote sensing and radiative transfer. Third term: modern physical oceanography. Offered in alternate years (1979-80). Instructors: Ingersoll, Yung, List.

**Env 206. Special Problems in Biological Engineering Science.** Units by arrangement, any term. Prerequisite: AMa 95 abc. Special topics in the application of engineering principles to biological and medical problems can be explored on mutual agreement between advanced students and one or more of the participating faculty. Instructors: 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 1978-79 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, 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 213). 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 (3-0-6); first, second, third terms. Prerequisites: ME 19 abc and Hy 111 or equivalent. General equations of fluid motion: two- and threedimensional 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; onedimensional steady gas-dynamics, expansion fans, shock waves; two- and threedimensional 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. Shallowwater 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. Not offered every year. 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. Instructors: Staff.

**Hy 213. Advanced Coastal Engineering.** 9 units (3-0-6); third term. Prerequisites: Hy 101 *abc and Hy 113 ab.* Selected topics in coastal engineering such as: harbor resonance, mooring and berthing of ships, structural forces due to waves, tsunamis and other impulsive wave systems. Not offered every year. Instructor: Raichlen.

Hy 300. Thesis Research.

# JET PROPULSION

### **Advanced Courses**

**JP 121 abc. Jet Propulsion Systems and Trajectories.** 9 units (3-0-6); each term. Open to all graduate students and to seniors with permission of the instructor. Modern aspects of rocket, turbine, electrical, and nuclear propulsion systems and the principles of their application to lifting, ballistic, and space flight trajectories. Combustion and burning characteristics of solid and liquid propellants, liquid propellant fuel systems, combustion instability. Subsonic and supersonic compressors and turbines, basic gas turbine propulsion cycle and its variations, inlets and diffusers. Nuclear rockets, nuclear air breathing cycles. Instructors: Marble, Zukoski.

**JP 131. Combustion Technology.** 9 units (3-0-6); third term. Prerequisites: APh/ME 17 and ME 19. Application of fluid dynamic and chemical principles to the study of combustion processes including the theoretical and experimental treatment of laminar and turbulent flames; the combustion of liquid droplets and solid particles; and technical aspects of gas, oil and coal combustion. 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. Nozzles 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 15 abc. Principles of Materials.** 9 units (3-0-6); first, second, third terms. The principles involved in the selection, the thermal treatment, and the mechanical treatment of engineering materials. Metallic materials are of major interest, with some consideration given to ceramics and polymers. The primary emphasis is on the utilization of phase transformations and strengthening mechanisms to obtain desired properties. Instructor: Buffington.

**MS 90. Materials Science Laboratory.** *9 units (1-6-2); third term.* An introductory laboratory designed to acquaint the student with relationships between structure and properties of crystalline solids. Experiments involve structure determination by X-ray diffraction, mechanical property measurements, and crystal defect observation by chemical etching, X-ray topography, and transmission electron microscopy. Individual projects may be performed, depending upon the student's interests and abilities. Instructor: Vreeland.

# **Advanced Courses**

**MS 100.** Advanced Work in Materials Science. The staff in materials science will arrange special courses or problems to meet the needs of students working toward the M.S. degree or of qualified undergraduate students. Graded pass/fail for research and reading.

**MS 105. Mechanical Behavior of Metals.** 9 units (3-0-6); second term. Prerequisites: AM 97 abc, MS 5 abc. A study of the mechanical behavior of metals for engineering applications. Elastic behavior of anisotropic materials and polycrystalline aggregates. Yielding, plastic flow, and strengthening mechanisms, the influence of temperature and rate of loading on plastic deformation. Fracture of metals by ductile flow, brittle cracking, fatigue, and creep. Behavior under impact loading. Instructor: Wood.

**MS 120.** Kinetics of Crystal Imperfections. 9 *units* (3-0-6); *first term*. Treatment of crystal imperfections, their interactions, and their influence on some physical and mechanical properties; taught at the level of Friedel, *Dislocations*. Instructors: Lau, Vreeland.

**MS 121. Solid State Diffusion.** 9 units (3-0-6); second term. Fundamentals of diffusion in the solid state; taught at the level of Manning, *Diffusion Kinetics for Atoms in Crystals*, and Shewmon, *Diffusion in Solids*. Instructors: Buffington, Lau.

APh/MS 126 abc. The Electronic Structure of Metals and Alloys. 9 units (3-0-6); first, second, third term. Prerequisite: an introductory course in quantum mechanics. The basic principles of quantum mechanics and thermodynamics applied to understanding electronic band structure, metallic cohesion, structural stability, phase equilibrium and the kinetics of phase transitions, metastable states, lattice dynamics and elastic behavior, transport properties, superconductivity, magnetism, and the physics of metallic surfaces and thin metals films. Comparison of theory with experimental data and phenomenological concepts will form an integral part of the course with some discussion of current technological areas of application including superconducting devices and high field magnets, magnetic memory devices, radiation damage to metals, and corrosion resistance. Instructor: Johnson.

**MS 130. Metallography and Pyrometry.** 9 units (0-6-3); first term. Prerequisite: MS 15 or equivalent. Metallurgical studies of materials of current technological interest utilizing optical metallography and photomicrography, temperature measurements, and cooling curves to study phase transformations. Instructor: Wood.

**MS 131. Crystal Defects.** 9 units (1-6-2); second term. Prerequisite; MS 120. Techniques used in the study of crystal defects and their influence on physical and mechanical properties; relationship between crystal structure and properties studied in experiments 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 5 a. Experiments on X-ray emission spectra and absorption edges. Determination of crystal structures by the Von Laue and Debye-Scherrer methods. Use of the X-ray spectrometer. Study of preferred orientation in cold worked metals. Application of X-ray diffraction methods to the study of phase diagrams. Instructors: Staff.

**MS 200.** Advanced Work in Materials Science. The staff in materials science will arrange special courses or problems to meet the needs of advanced graduate students.

**MS 205 ab. Dislocation Mechanics.** 9 units (3-0-6); second, third terms. Prerequisite; MS 120. The theory of crystal dislocations in isotropic and anisotropic crystals. Applications of dislocation theory to physical and mechanical properties of crystals taught at the level of Hirth and Lothe, *Theory of Dislocations*. Instructors: Vreeland, Wood.

**MS 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 or instructor's permission. The student is introduced to the field of design in its broadest sense through a coordinated series of short design projects, seminars by practicing designers, and related field trips. Useful graphical and analytical techniques are developed as effective tools for rapid engineering approximations in preliminary layout and design. Elements of mechanisms and computer-aided design are treated along with other basic aspects of design such as selection of materials and standard components, manufacturing methods, functional, economic, and aesthetic considerations. At least one of the projects will involve some actual machine shop experience in the construction of a simple prototype or working model. Instructor: Welch.

**ME 5 abc. Design.** 9 units (1-6-2); first, second, third terms. Prerequisites: ME 1 ab, MS 15 abc, or instructor's permission. The aim of this course is to develop creative ability and engineering judgment through actual project development work involving preliminary design, prototype modeling, and engineering analysis. 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.

#### 314 Subjects of Instruction

**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 the laws of thermodynamics and their underlying physical significance, thermodynamic energy functions, Maxwell relations, and the applications of equilibrium thermodynamics; non-equilibrium thermodynamics such as the analysis of heat engine cycles, and an introduction to statistical mechanics and kinetic theory. Instructor: Goodstein.

**ME 19 abc. Fluid Mechanics and Gasdynamics.** 9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 abc, Ph 1 abc. Basic equations of fluid mechanics, theorems of energy, linear and angular momentum, potential flow, elements of airfoil theory. Flow of real fluids, similarity parameters, flow in closed ducts. Boundary layer theory in laminar and turbulent flow. Introduction to compressible flow. Flow and wave phenomena in open channels. The third term may also include topics related to energy production and conversion; subjects such as the theory of fluid machinery and heat transfer may be introduced. Instructors: Acosta, Brennen, Sabersky.

# **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: APh/ME 17 abc, ME 19 abc, or equivalent. Review of basic equations of fluid flow, energy, and mass transfer. Heat conduction in solids, heat transfer for laminar and turbulent flows in forced and free convection. Introduction to mass transfer and radiation as well as selected topics such as boiling heat transfer, two-phase flow, evaporation and condensation. Instructors: Acosta, Sabersky.

**ME 126. Fluid Mechanics and Heat Transfer Laboratory.** 9 units (0-6-3); third term. Prerequisites: APh/ME 17 abc, ME 19 ab, or equivalent. Students with other background shall obtain instructor's permission prior to registration. Introduction to some of the basic measurement techniques and phenomena in the fields of heat transfer and fluid mechanics. The student may select several short projects from a rather wide list of possible experiments. Specific areas from which experiments may be selected include free and forced convection, boiling heat transfer, combustion, solid-state energy conversion, free surface 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 202 ab. Engineering Two-Phase Flows.** 9 units (3-0-6); first and second terms. Prerequisites: AMa 95 abc, Hy 101 abc, or equivalents. Selected topics in engineering twophase flows with emphasis on practical problems in modern hydro-systems. Fundamental fluid mechanics and heat, mass, and energy transport in multiphase flows. Liquid/vapor/gas (LVG) flows, nucleation, bubble dynamics, cavitating and boiling flows, models of LVG flows; instabilities, dynamics and wave propagation; fluid/ structure interactions. The course will include discussion of two-phase flow problems in conventional, nuclear, and geothermal power plants, marine hydrofoils, and other hydraulic systems. Instructor: Brennen.

#### ME 300. Thesis Research.

Many advanced courses in the field of Mechanical Engineering may be found listed in other engineering options such as: Applied Mechanics, Applied Physics, Hydraulics, Jet Propulsion, and Materials Science.

#### 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: Fall: Burnett, Sieh; Spring: Kanamori, Silver.

#### 316 Subjects of Instruction

**Ge 2. Geophysics.** 9 units (2-1-6); second term. Prerequisites: Ge 1, Ma 2 a, Ph 2 a. An introduction to the physics of the earth. Topics discussed include the figure of the earth, the gravity and magnetic fields of the earth and their variation in space and time, the propagation of seismic waves, the transport of heat within the earth, and global tectonics. Three one-day field trips to sites of geophysical interest are an integral part of the course. Text: *Physics of the Earth*, Stacey. Instructor: Minster.

Ge 4. Introduction to the Solar System. 6 units (3-0-3); third term. An introductory survey course emphasizing 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 compositon. 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; first, second, third terms. Guidance in seeking research opportunities and in formulating a research plan leading to preparation of a Bachelor's Thesis is available from the Division Undergraduate Research Counselor, Professor Epstein. Graded pass/fail.

### **Advanced Courses**

Courses given in alternate years are so indicated. Courses in which the enrollment is less than five may, at the discretion of the instructor, not be offered.

**Ge 100.** Geology Club. 1 unit (1-0-0); first, second, third terms. Presentation of papers on research in geological and planetary sciences by guest speakers. Graded pass/fail. Instructor: 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. Instructor: Muhleman.

**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); third term. Training in the technique of oral presentation. Practice in the effective organization and delivery of reports before groups. Successful completion of this course is required of all candidates for degrees in the division. Instructor: Muhleman.

Env/Ge 103 abc. Oceans and Atmospheres. 9 units (3-0-6); first, second, third terms. *Prerequisites: Ma 2 and Ph 2*. Natural physical and chemical processes in the earth's fluid envelope. First term: geophysical fluid dynamics, ocean currents, temperatures, and salinity. Second term: atmospheric dynamics and thermodynamics, radiative transfer, climate change. Third term: atmospheric, oceanic and ionospheric chemistry and photochemistry, global effects of environmental pollution. Instructors: List, Ingersoll, Yung.

Ge 104 abc. Advanced General Geology. 9 units (3-4-2). Prerequisites: Ch 1 or 2, Ma 1, Ph 1.

**104 a. Minerals as Physical, Chemical, and Geological Systems.** *First term.* Atomic structure and physical properties of the solid state, with emphasis on the important minerals. Topics include relations between bonding forces, structure, composition, properties, and conditions of formation of minerals. The occurrence and properties of the major mineral groups that are important at the earth's surface and in the interior will be studied in the laboratory. Instructor: Rossman.

**104 b. Igneous, Sedimentary, and Metamorphic Rocks.** *Second term.* A study of rocks and the chemical and physical processes affecting their origin. The genesis of igneous rocks and silicate crystal-melt-fluid equilibria. Sedimentary minerals and rocks, processes, physical stratigraphy, and depositional environments. Metamorphic processes, rocks and minor structural features. Instructor: Taylor.

**104 c. Tectonics and Earth History.** *Third term.* Major structural features and tectonic processes of the earth's crust. Principles of paleontology and animal stratigraphy. Elements of the Phanerozoic history of the earth with emphasis on both faunal and physical history. Problems of the Precambrian history of the earth. Instructors: Saleeby, 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 1978-79.

**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: Albee.

**Ge 121 abc.** Advanced Field Geology. 12 units (0-9-3); first, second, third terms. 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, Silver, 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. Offered in alternate years (1979-80). Instructor: Westphal.

**Ge 123. Summer Field Geology.** *30 units (6 weeks). Prerequisites; Ge 104 abc, Ge 105 ab.* Intensive study of three field areas in the Rocky Mountains, Colorado Plateau, Basin and Range Province, Sierra Nevada or Coast Ranges. The work in each area is supervised by a separate staff member, and the selection of areas studied varies from year to year. Emphasis is on stratigraphic and structural interpretation, involving a wide range of sedimentary, plutonic, volcanic, and metamorphic rocks. For each area the student prepares a geologic map, stratigraphic and structural sections, and a geologic report. The course is designed to complement the field training in southern California afforded by Ge 105 and Ge 121. It is required at the end of the junior year for the bachelor's degree in the geology and geochemistry options. The course begins immediately after commencement and runs for six weeks. Instructors: 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 (1978-79). 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 (1979-80). Instructor: To be named.

**Ge 126. Introduction to Quaternary Geology.** *12 units* (3-3-6); *first term. Prerequisite: Ge 107.* An introduction to study of the evolution of the earth's surface during the past million years. Topics include sedimentary, erosional, and tectonic processes involved in the development of landscapes; Pleistocene and Holocene stratigraphy; the use of soils, weathering rates, radiocarbon dating, palynology, and other tools in deciphering recent geological history. The laboratory will involve the use of aerial photographs and an individual research project. Instructor: Sieh.

**Ge 130.** Introduction to Geochemistry. 6 units (2-0-4); first term. Prerequisites: Ch 1, Ma 2 abc, Ph 2 abc. A lecture and problem course on the application of chemical principles to earth problems, involving topics in stable isotopic geochemistry. Instructor: Epstein.

Ge 132. Chemistry of the Earth and Planets. 9 units (3-0-6); second term. Prerequisite: instructor's permission. A critical evaluation of what is known about the chemical composition of the 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. Offered in alternate years (1978-79). Instructor: Burnett.

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 or Ge 105, or instructor's permission. At least nine days of weekend field trips into areas of southwestern United States displaying highly varied geology are involved. Each student is assigned the major responsibility of being the resident expert on a pertinent subject for each trip. Graded pass/fail. Instructor: Sharp.

**Ge 137.** Laboratory Techniques in the Earth Sciences. 9 units (1-4-4); second term. Introduction in the use of tools and techniques used in earth sciences research. Experiments of geological and geochemical interest are done using the electron microprobe, emission spectrograph, spectrophotometer, X-ray diffractometer and spectrometer, mass spectrometers, vacuum extraction lines and other available tools and techniques used in the research projects in the division. Additional units may be elected. Instructor: Epstein.

Ge 150. The Nature and Evolution of the Earth. 6 units (3-0-3). Offered by announcement only. Discussions at an advanced level of problems of current interest in the earth sciences. Students may enroll for any or all terms of this course without regard to sequence. Instructors: Staff and visitors. Ge 153. Planetary Radio Astronomy. 9 units (3-0-6); second term. Prerequisite: instructor's permission. The interpretation of radio astronomy observations of the Moon, Mercury, Venus, Mars, and Jupiter in terms of the planets' surface properties and atmospheric characteristics. Thermal and non-thermal emission mechanisms in planetary atmospheres and surfaces will be discussed with particular emphasis toward the construction of mathematical planetary models which can be tested by all possible observational techniques including radio interferometry, planetary occultation, and radar astronomy. Offered in alternate years (1979-80). 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 (1978-79). Instructors: Ingersoll and Yung.

**Ge 160 abc. Seismological Laboratory Seminar.** 1 unit (1-0-0); first, second, third terms. Presentation of current research in geophysics by students, staff, and visitors. Graded pass/fail. Instructor: Anderson.

**Ge 166.** Physics of the Earth's Interior. 9 units (3-0-6); second term. Interpretation of the observed geophysical data describing the earth's interior in terms of the earth's evolution, ongoing geodynamic processes, and composition and thermal state of the mantle and core. Instructor: Anderson.

**Ge 167. Planetary Physics.** 9 units (3-0-6); first term. Prerequisites: Ph 106 abc, AMa 95 abc or AM 113 abc. Solar system dynamics, with emphasis on slow changes in the orbit and rotation rates of planets and satellites. Topics to be discussed include tidal friction, resonant orbits and rotation rates, gravitational fields of planets and satellites, dynamics of polar wandering and continental drift. Offered in alternate years (1979-80). Instructor: Goldreich.

**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 farand near-field phenomena, significance of earthquakes in plate tectonics and problems pertaining to earthquake prediction. Instructor: Kanamori.

**Ge 177.** Seismotectonics. 9 units (3-3-3); third term. Relationship of seismicity to geologic structures and to tectonic processes: global seismicity patterns; active faults; problems of seismic zoning. Case studies of selected earthquakes with field trips to local areas of special interest. Offered in alternate years (1979-80). Instructor: Allen.

Env/Ge 203 abc. Advanced Oceans and Atmospheres. 9 units (3-0-6); first, second, third terms. Prerequisite: Env/Ge 103 abc. First term: atmospheric dynamics and numerical modeling. Second term: remote sensing and radiative transfer. Third term: modern physical oceanography. Offered in alternate years (1979-80). Instructors: Ingersoll, Yung, List.

Ge 212 ab. Thermodynamics of Geological Systems. 9 units each term (3-0-6); first, second terms. Prerequisite: Ch 21 abc, Ge 115 abc or equivalent. Chemical thermodynamics, with emphasis on applications to geologic problems. Topics to be covered include

heat flow, diffusion, phase transformations, silicate phase equilibria, solid solutions, the effect of  $H_2O$  in silicate melts, and equilibrium in a gravitational field. Text: *Chemical Thermodynamics*, Prigogine and Defay. Offered in alternate years (1978-79). Instructors: Taylor, Wasserburg.

**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 d—Geochronology Seminar.
Ge 213 b—Petrology Seminar.	Ge 213 e—Planetary Science Seminar.
Ge 213 c—Geochemistry Seminar.	Ge 213 f—Geophysics 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 (1978-79). 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 (1979-80). 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 (1979-80). 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 (1979-80). 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 (1979-80). Instructor: Wasserburg.

Ge 221. The Terrestrial Planets. 9 units (4-0-5); first term. A comparative study of the present state and past history of Earth, Moon, Mars, Venus, and Mercury. Offered alternate years (1978-79). Instructor: Melosh.

Ge 225 abc. Current Research in Planetary Science. Required attendance for all Planetary Science graduate students. Others welcome.

**225 a. Student/Faculty Research Conference.** *1 unit (1-0-0); first term.* One hour per week informal review of current research by staff and students. Instructor: Ingersoll.

**225 b. Selected Topics in Planetary Science.** *1 unit (1-0-0); second term.* Review of current research in selected areas. Instructor: Murray.

**225 c. Planetary Research with Spacecraft.** *1 unit (1-0-0); third term.* Review of potential or recently completed scientific exploration by means of spacecraft. Instructor: Muhleman.

#### 322 Subjects of Instruction

**Ge 226. Observational Planetary Astronomy.** *9 units (3-0-6); third term.* Optical and infrared radiation detectors, spectrometers, polarimeters, and photometers will be discussed in the context of the observational study of the planets. Other topics will include the design of observational programs and the assessment of the reliability of data by critical analysis of observational literature. Offered in alternate years (1978-79). Instructor: Westphal.

**Ge 229. Glaciology.** 9 units (3-0-6); offered by announcement only. Origin and behavior of the North American ice sheet, physical conditions and structures of existing glaciers, glacier flow, erosional and depositional processes and products. Instructor: Kamb.

**Ge 230.** Geomorphology Seminar. 5 units; offered by announcement only. Review and critical analysis of current research and literature in geomorphology. On occasion, activities are devoted wholly to field excursions within the southwestern U.S. Instructor: 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 ab. 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. Not offered in 1978-79.

**Ge 248. Tectonophysics.** *9 units (3-0-6); second term.* Response of geologic materials to applied stress. Brittle failure, plastic deformation, and steady state creep of rocks. Application of these principles to large scale geologic structures, principally lithospheric plates. Mechanics of lithospheric plates and mechanisms of plate tectonics. Offered in alternate years (1978-79). Instructor: Melosh.

**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 by announcement only. Instructor: Ahrens.

**Ge 261 abc.** Advanced Seismology. 9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or equivalent. Essential material in modern seismology; elastic wave propagation, ray theory, normal mode theory, free oscillations, applications to determination of earth structure and earthquake source mechanism, interpretation of seismograms, geophysical time series analysis and synthesis. Instructors: Harkrider, Helmberger.

**Ge 264 abc. Theoretical Geophysics.** 9 units (3-0-6); first, second, third terms. Prerequisite: AMa 101 or Ph 129 abc or equivalent. A systematic review of basic continuum theory with special emphasis on geophysical applications. The theory is then applied to selected topics in hydrodynamics, elastic and anelastic processes in planetary dynamics, seismic source theory, heat transport processes, etc. Major methods of mathematical physics are reviewed as required by the topics under study. Instructor: Minster.

Ge 282 abc. Geological Sciences Seminar. 1 unit; first, second, third terms. Presentation of papers by invited investigators. In charge: Melosh.

Ge 297. Advanced Study. Students may register for up to 15 units of advanced study under the direction of a faculty member.

**Ge 299.** Thesis Research. Original investigation, designed to give training in methods of research, to serve as theses for higher degrees, and to yield contributions to scientific knowledge.
GERMAN (See Languages)

# HISTORY

Courses above H 10 are open only to students who have fulfilled the freshman humanities requirements. See page 179 for further information.

### **Undergraduate** Courses

H 1 abc. Introduction to Europe. 9 units (3-0-6); first, second, third terms. From the Middle Ages to the present day. Topics and reading will vary from instructor to instructor, but will usually include feudalism, the Renaissance and Reformation, seventeenth-century England, the French Revolution and Napoleon, the Industrial Revolution, nineteenth-century liberalism and nationalism, Marx, overseas expansion, the Russian Revolution, fascism, the two World Wars, and the Cold War. Instructors: Staff.

H 2 abc. Revolution to Roosevelt. 9 units (3-0-6); first, second, third terms. An examination of American history from 1765 through the New Deal. The first term will cover the period 1765 to 1800; the second, from 1830 to 1877; and the third from the end of the nineteenth century to World War II. Instructors: Staff.

**H 6 abc. American Life and Thought.** 9 units (3-0-6); first, second, third terms. Topics in the development of American culture, explored through an examination of selected social, political, and artistic materials, including essays, novels, and films. Instructors: Staff.

H 8 ab. Introduction to Asia. 9 units (3-0-6); first, second terms. Topics in the history of Asia from Exodus and Confucius to Indira Gandhi and the Yom Kippur War. Some emphasis on Asian religions. Instructors: Staff.

**H 23. Cultural History of Early Medieval Europe.** 9 units (3-0-6); first term. From the end of the Roman Empire to the First Crusade. Shows how classical, Christian, and barbarian cultures combined to form a new civilization. Instructor: Benton.

H 24. Cultural History of the High Middle Ages and Renaissance. 9 units (3-0-6); second term. H 23 precedes but is not a prerequisite for H 24. Europe from the twelfth through the fifteenth centuries. Shows relationship of art, literature, music, and social relations to political, economic, and religious institutions. 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. 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.

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**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 ab. Psychohistory.** 9 units (3-0-6). An examination of the influence of psychological factors in the course of history and of historical forces in the shaping of groups and individuals. Students are encouraged to take both courses in sequence, though each is a self-contained unit and may be taken separately. H/Psy 107a will cover the premodern period and H/Psy 107b the modern period. Instructors: Benton, Breger, Rosenstone.

**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." 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. 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 1978-79. 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. Not offered in 1978-79.

**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 1978-79.

**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. 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 1978-79. 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); second term. A study of selected topics in the history of American thought and attitudes. Instructor: Rosenstone.

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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 1978-79. 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 1978-79. 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 200 for complete details. 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 326 for description.

### **Undergraduate and Graduate Courses**

L 101. Selected Topics in Language. Units to be determined by arrangement with the instructor. Graded pass/fail. Instructors: Staff and visiting lecturers.

L 102 abc. Elementary French. 10 units (3-1-6); first, second, third terms. The course aims at providing a superior reading knowledge plus competence in general conversation. Students who have had French in secondary school or college must consult with the instructor before registering. Instructor: 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. 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: Aebi.

L 132 abc. Intermediate German: 9 units (3-0-6); first, second, third terms. Prerequisite: L 130 abc, or equivalent. Reading of short stories and plays, grammar review, and aural and oral drill. Students who have studied German elsewhere must consult with the instructor before registering. Instructor: Carmely.

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 nineteenthand twentieth-century authors. Conducted in German. Not offered in 1978-79. Instructors: Staff.

L 141 abc. Elementary Russian. 10 units (3-1-6); first, second, third terms. The course covers grammar and builds toward the capacity to understand, speak, read, and write Russian. Students who have had Russian in secondary school or college must consult with the instructor before registering. Instructor: Zaydman.

L/Lit 152 ab. French Literature in Translation: Classical and Modern. 9 units (3-0-6). The first term deals with French "classical" literature of the seventeenth and eighteenth centuries, the second term with the years from 1939 to the present, and with literary responses to "the Absurd." Readings are in English, but students may read French originals. Instructor: A. Smith.

L 153 abc. Intermediate Russian. 9 units (3-0-6); first, second, third terms. Prerequisite: L 141 abc or equivalent. Grammar review, readings, discussion, and reports on material from Russian science, culture, and history. Instructor: Pariser.

L/Lit 154. French Literature in Translation: The French Novel. 9 units (3-0-6); 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 socio-historical 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 1978-79. 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 1978-79. Instructor: B. Thompson.

Lin/SS 105. Computational Linguistics. 9 units (2-1-6); first term. Prerequisite: Lin 101 a or Lin 101 b or equivalent. English as a language for communication with computers. Problems in parsing and semantic data base analysis. Review through readings of

natural language processing systems, including speech recognition and other AI (artificial intelligence) applications. Research required. Taught alternate years; offered in 1978-79. Instructors: B. Thompson, F. Thompson.

# LITERATURE

Courses above Lit 10 are open only to students who have fulfilled the freshman humanities requirements. See page 179 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 2 a.

Lit 2 a. Tragedy. 9 units (3-0-6); first term. Readings in the theory and practice of tragedy, in an effort to understand the nature of the genre, the sources from which it springs, and the different forms it may take. Not offered in 1978-79. Instructors: Staff.

Lit 2 b. Comedy. 9 units (3-0-6); second term. Readings in the theory and practice of comedy (and satire), as above (in Lit 2 a). Not offered in 1978-79. Instructors: Staff.

Lit 2 c. The "I" in Literature. 9 units (3-0-6); second 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. Instructor: Ende.

Lit 3 ab. An Introduction to Classical Literature. 9 units (3-0-6); first and second terms. An introduction to classical literature in translation. During the first term students will read the Greek classics. The second term will emphasize the Latin tradition. Students may do work in the original languages if they choose. Not offered in 1978-79. Instructor: Pigman.

Lit 4. Introduction to Poetry. 9 units (3-0-6); second term. What is poetry? Why does it exist? Why and how should one read it? Working from basic concepts in aesthetics, students will read and discuss a substantial range of poems, from simple to complex. Instructor: Mandel.

Lit 5. Literature of Initiation. 9 units (3-0-6); second 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); first 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. Not offered in 1978-79. 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. Not offered in 1978-79. 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); first term.* A study of male/female roles, relations, and conflicts as a literary theme and problem. Instructors: Splitter, A. Smith.

## **Special Courses**

Lit 13. Reading in English. Units to be determined for the individual by the department. Collateral reading in literature and related subjects, done in connection with regular courses in literature or history, or independently of any course, but under the direction of members of the department. Graded pass/fail. Instructors: Staff. Not available for credit toward humanities-social science requirement.

Lit 15 abc. Journalism. 3 units (1-0-2); first, second, third terms. A study of the elementary principles of newspaper writing and editing, with special attention to student publications at the Institute. Instructor: Hutchings.

Lit 20. Summer Reading. Units to be determined for the individual by the department. Maximum 9 units. Reading in literature, history, and other fields during summer vacation, books to be selected from a recommended reading list, or in consultation with a member of the staff. Critical essays on reading will be required. Graded pass/fail.

Lit 98. Tutorial for Literature Majors. 9 units (2-0-7). Prerequisite: written permission of instructor and convener. An individual program of directed reading and research designed to enable literature majors to undertake the study of an area not covered by regular courses. Instructors: Staff.

HSS 99. See page 326 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. Not offered in 1978-79. Instructor: 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. Not offered in 1978-79. Instructor: 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 107. Techniques of Composition. 9 units (3-0-6); second term. The methods by which ideas are ordered and translated to expository prose. Frequent exercises in writing will be required. Not offered in 1978-79. Instructors: Staff.

Lit 108. Seminar in Creative Writing. 9 units (3-0-6); third term. An introduction to some of the techniques of writing prose and poetry. Students will do their own writing which periodically will be reviewed by the instructor. 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 term: More, Castiglione, Machiavelli, Sidney, Spenser, Shakespeare (sonnets), Marlowe. Second term: Shakespeare (drama), Jonson, Webster, Donne, Marvell, Bacon, Hobbes, Milton. Not offered in 1978-79. Instructor: La Belle.

Lit 114 ab (formerly Lit 123). Shakespeare. 9 units (3-0-6); second, third terms. A chronological study of Shakespeare's plays with emphasis on the development of his technique and vision. First term: the major histories, festive comedies, and the early tragedies. Second term: several of the great tragedies, the problem comedies, and the late romances. The first term is not a prerequisite for the second. Instructor: La Belle.

Lit 115. Advanced Shakespeare Seminar. 9 units (3-0-6); third term. Prerequisite; Lit 114 a 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. Not offered in 1978-79. 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. Instructors: Staff.

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. Not offered in 1978-79. 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); second 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: 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. Not offered in 1978-79. 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. Not offered in 1978-79. Instructors: Staff. 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: 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. Not offered in 1978-79. 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: Penn, D. Smith.

Lit 146 ab (formerly Lit 118). Twentieth-Century American and British Poetry. 9 units (3-0-6); second, third 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.

Lit 147 abc. Introduction to Ancient Greek Language and Literature. 9 units (3-0-6); first, second, third terms. The first quarter provides a foundation in Greek grammar. In the second, students will read simple prose texts by Plato, Xenophon, Lysias or others. The third term will be devoted to poetry by Homer, the lyric poets or tragedians. Students will have a voice in choosing which authors to read. Taught in alternate years; not offered in 1978-79. Instructor: Pigman.

Lit 148 abc. Introduction to Latin Language and Literature. 9 units (3-0-6); first, second, third terms. The first quarter provides a foundation in Latin grammar. In the second, students will read simple prose texts by Cicero, Seneca, Petronius, Livy or others. The third term will be devoted to poetry by Virgil, Catullus, or Horace. Students will have a voice in choosing which authors to read. Taught in alternate years; offered in 1978-79. Instructor: Pigman.

L/Lit 152 ab. French Literature in Translation: Classical and Modern. 9 units (3-0-6). The first term deals with French "classical" literature of the seventeenth and eighteenth centuries; the second term with the years from 1939 to the present, and with literary responses to "the Absurd." Readings are in English, but students may read French originals. Instructor: A. Smith.

L/Lit 154. French Literature in Translation: The French Novel. 9 units (3-0-6); 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 sev-

enteenth 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.

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. Instructors: Apostol, Schep, Griggs.

**Ma 2 abc. Sophomore Mathematics.** 9 units (4-0-5); first, second, third terms. A continuation of the topics introduced in Ma 1 and an introduction to partial differential equations, probability and numerical analysis. Instructors: Dean, Fuller.

**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: Wales, Guralnick.

**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 1978-79.

Ma 91 b. Sturm-Liouville Problems. Units to be arranged; second term. Instructor: De Prima.

Ma 91 c. Numerical Algebra. 11 units (3-2-6); third term. Instructor: J. Todd.

**Ma 92 abc. Senior Thesis.** 9 units (0-0-9); first, second, third terms. Prerequisite: approval of adviser. Open only to seniors who are qualified to pursue independent reading and research. The work must begin in the first or second term and be supervised by a member of the staff. Students will submit a thesis at the end of the year. Graded pass/fail.

**Ma 98. Reading.** 3 units or more by arrangement. Occasionally a reading course under the supervision of an instructor will be offered. Topics, hours, and units by arrangement. Only qualified students will be admitted after consultation with the instructor in charge of the course. Graded pass/fail.

# **Advanced Courses**

(A) The following courses are open to undergraduate and graduate students.

Ma 102 abc. Differential Geometry. 9 units (3-0-6); first, second, third terms. Not offered in 1978-79.

Ma 103. Algebraic Geometry. 9 units (3-0-6); third term. Prerequisite: Ma 5 abc. Not offered in 1978-79.

**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 1978-79.

**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: Graham.

**Ma 109. Delta Functions and Generalized Functions.** 9 units (3-0-6); first term. Prerequisite: Ma 108, AMa 95 or equivalent. Introduction to operational calculus and to delta functions. Laplace transforms. Applications to ordinary and partial differential equations. Instructor: Luxemburg.

**Ma 112 abc. Statistics.** 9 units (3-0-6); first, second, third terms. A complete short course in probability and typical statistical methods. Nonparametrics, estimation, sequential analysis, decision theory, and Bayes procedures. Instructor: Franklin.

**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: Spector.

**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: J. Todd.

**Ma 120 abc.** Abstract Algebra. 9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5. Abstract development of the basic structure theorems of groups, commutative and non-commutative rings, lattices, and fields. Instructor: Dilworth.

**Ma 121 abc. Combinatorial Analysis.** 9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5. Elementary and advanced theory of permutations and combinations. Theory of partitions. Theorems on choice including Ramsey's theorem and the Hall-Konig theorem. Existence and construction of block designs with reference to statistical design of experiments, linear programming, and finite geometries. Instructor: Hall.

**Ma 122 ab. Introduction to Group Theory.** 9 units (3-0-6); second, third terms. Prerequisite: Ma 5 abc. A study of the basic properties of finite groups. Instructor: Collins.

**Ma 123 abc. Matrix Theory.** 9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 abc. Fundamental concepts, matrix equivalences, canonical forms, nonnegative real matrices, integral matrices, combinatorial matrix theory. Instructor: Ryser.

**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 1978-79.

**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: Guralnick.

**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: Power.

**Ma 141 abc. Ordinary Differential Equations.** 9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 or equivalent. Not offered in 1978-79.

**Ma 142 abc.** Introduction to Partial Differential Equations. 9 units (3-0-6), first, second, third terms. Prerequisite; Ma 108 or equivalent. Distribution theory. Local existence and non-existence of solutions: Cauchy-Kovalevsky theorem, local solvability of constant-coefficient operators, examples of locally non-solvable equations. Classical examples: Laplace, heat, and wave operators. Sobolev spaces. Local regularity of elliptic operators and elliptic boundary value problems. Overdetermined systems and elliptic complexes. Applications to geometry and several complex variables, to be chosen from: Hodge theory, deformation theory of complex manifolds, the  $\delta$ -Neumann problem. Instructor: Conn.

**Ma 143 ab. Introduction to Functional Analysis.** 9 units (3-0-6); second, third terms. Prerequisite: Ma 137 a. Point-set topology. General theory of topological vector spaces, Banach spaces, Hilbert spaces. Hahn-Banach extension principle, Banach-Steinhaus uniform boundedness principle, Krein-Milman theorem, closed graph theorem, open mapping theorem. Weak topologies. Banach algebras. Spectral analysis in Hilbert space. Instructor: Power.

**Ma 144 abc. Probability.** *9 units (3-0-6); first, second, third terms.* Basic theory, including characteristic functions and limit theorems, random walk, Markov chains, Poisson process, Brownian motion. Instructors: Lorden, Wendel.

**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: Teleman.

**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 1978-79.

**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 1978-79.

**Ma 160 abc.** Number Theory. 9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 abc or equivalent. Topics selected from: elementary number theory, zeta functions, distribution of primes, modular functions, asymptotic theory of partitions, geometry of numbers, ideal theory in algebraic number fields, units, valuations, discriminants, differents, and local theory. Not offered in 1978-79.

**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 1978-79.

**Ma 190 abc. Elementary Seminar.** 9 units; first, second, third terms. This seminar is restricted to first-year graduate students and is combined with independent reading. The topics will vary from year to year. Graded pass/fail. Instructors: De Prima, Teleman, and staff.

**Ma 191 c. Entire Functions.** 9 units (3-0-6); third term. Prerequisite: Ma 108. Instructor: Luxemburg.

(B) The following courses are open primarily to graduate students.

**Ma 205 ab. Advanced Numerical Mathematics.** 9 units (3-0-6); first, second 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 1978-79.

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. Not offered in 1978-79.

Ma 222 ab. Advanced Group Theory. 9 units (3-0-6); second, third terms. Prerequisite; Ma 120 or Ma 122 or instructor's permission. Discussion of topics related to current areas of interest in group theory. Not offered in 1978-79.

Ma 223 abc. Matrix Theory. 9 units (3-0-6); first, second, third terms. Prerequisite: Ma 120 or equivalent. Algebraic, arithmetic and analytic aspects of matrix theory. Not offered in 1978-79.

**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. Instructor: Dilworth.

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 1978-79.

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. Not offered in 1978-79.

**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: Schaefer, Luxemburg.

**Ma 290. Reading.** Occasionally advanced work is given by a reading course under the direction of an instructor. Hours and units by arrangement.

(C) The following courses and seminars are intended for advanced graduate students. They are research courses and seminars, offered according to demand, and covering selected topics of current interest. The courses offered, and the topics covered, will be announced at the beginning of each term.

Ma 305 abc. Seminar in Numerical Analysis. 6 units. Three terms.

Ma 316 abc. Seminar in Mathematical Logic, 9 units. Three terms. Instructor: Spector.

Ma 320 abc. Special Topics in Algebra. 9 units. Three terms.

Ma 324 abc. Seminar in Matrix Theory. Units to be arranged. Three terms.

Ma 325 abc. Seminar in Algebra. 6 units. Three terms.

Ma 340 abc. Special Topics in Analysis. 9 units. Three terms.

Ma 345 abc. Seminar in Analysis. 6 units. Three terms. Instructor: Luxemburg.

Ma 350 abc. Special Topics in Geometry. 9 units. Three terms.

Ma 355 abc. Seminar in Geometry. 6 units. Three terms.

Ma 360 abc. Special Topics in Number Theory. 9 units. Three terms.

Ma 365 abc. Seminar in Number Theory. 6 units. Three terms.

Ma 390. Research. Units by arrangement.

Ma 392. Research Conference. Three terms.

See also the list of courses in Applied Mathematics.

### MECHANICAL ENGINEERING (See Engineering and Applied Science)

#### MUSIC

**Mu 11. Designed for Listening.** 9 units (3-0-6); first term. Course designed to develop musical perception through the study of compositional practice and organization and performance. Graded pass/fail. Instructor: Schonbach.

**Mu 12. Early Music History.** 9 units (3-0-6); second term. Prerequisite; Mu 11. Course content: the music history of the Renaissance and Baroque periods; analysis of representative forms and styles. (Offered in even-numbered calendar years.) Instructor: Britton.

**Mu 13. Modern Music History.** 9 units (3-0-6); third term. Prerequisite: Mu 12. Course content: music history from 1750 to the present; analysis of representative forms and styles. (Offered even-numbered calendar years.) Instructor: Britton.

**Mu 14. Basic Music Theory.** 9 units (3-0-6); second term. No prerequisite. Course content: basic concepts of music theory, including rhythmic and melodic notation, elementary ear training, chord structures, diatonic chord progression, modulation, and related material. (Offered odd-numbered calendar years.) Instructor: Britton.

**Mu 15. Advanced Music Theory.** 9 units (3-0-6); third term. Prerequisite: Mu 14. Course content: advanced concepts of music theory, including chromatic harmony, contrapuntal techniques, and twentieth-century compositional devices. (Offered odd-numbered calendar years.) Instructor: Britton.

**Mu 16 ab. The Four Hand Piano Literature: History, Analysis, Performance.** 9 units (3-0-6); first, second term. A historical survey of original piano music written for two players at one or two pianos from Bach to the present day (arrangements for eight hands will also be included). Attention will be focused on the stylistic trends of various periods and composers through written work and actual participation. Pianists with varying degrees of performing ability will be admitted to the class at the discretion of the instructor. Instructor: Schonbach.

Mu 101. Selected Topics in Music. Units to be determined by arrangement with the instructor. Instructors: Staff and visiting lecturers.

### PHILOSOPHY

Courses above Pl 10 are open only to students who have fulfilled the freshman humanities requirements. See page 179 for further information.

### **Undergraduate** Courses

**Pl 7 ab. Introduction to Philosophy.** 9 units (3-0-6); first, second terms. A study of the history of philosophy through readings in the sources. The two terms will concentrate, respectively, on modern and contemporary philosophy. Instructors: Staff.

**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.

**PI 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); second term. This course will examine some contemporary views on the elimination of repression in sex, art, and society. Readings from Laing's Politics of Experience, Brown's Life Against Death, and Marcuse's Eros & Civilization. Instructors: Staff.

**Pl 21. Theory of Knowledge.** 9 units (3-0-6); second term. An investigation of selected topics in the theory of knowledge including the difference between knowledge and true opinion; our evidence for belief in material objects and other minds; necessary truth; and the status of appearances. Instructors: Staff.

HSS 99. See page 326 for description.

## **Advanced Courses**

**Pl 102. Selected Topics in Philosophy.** 9 units (3-0-6). Instructors: Staff and visiting lecturers.

**Pl 103. World Views.** 9 units (2-0-7); second term. A study of world views and of the ways in which they are reflected in the literature, art, philosophy, and science of different cultures. Several contrasting views will be selected for detailed study. 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.

**PI 105 abc. Philosophy of Science Seminar.** 9 units (3-0-6). Three-term sequence. Pl 105 a or Pl 105 b strongly recommended as preparation for Pl 105 c. Topics to include the structure and function of scientific methods, concepts, theories, and explanation. Pl 105 c is concerned primarily with the behavioral sciences. Not offered in 1978-79. 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. Instructors: Staff.

**Pl 107. Seminar in the Philosophy of Mind.** 9 units (3-0-6); first term. A study of selected topics on the philosophy of mind. Possibilities include sense-datum theory, mind-brain identity thesis, machine consciousness, Gödel's Theorem and its implications. Instructors: Staff.

**Pl 108 ab. Friedrich Nietzsche**. 9 units (3-0-6); second, third terms. A close reading of Nietzsche's major works including *The Birth of Tragedy, The Gay Science, Beyond Good and Evil, On the Genealogy of Morals, Twilight of the Idols, Ecce Homo.* Instructors: Staff.

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, called A and B. Track B assumes a greater amount of previous preparation in mathematics and physics, and proceeds initially at a faster pace than track A. In both tracks, emphasis is placed upon the application of the fundamental principles through the solution of problems. Graded pass/fail. Instructors: Clauser, Gomez, Politzer, Walker, and assistants.

**Ph 2 abc. Electromagnetism and Quantum Mechanics.** 9 units (4-0-5); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or their equivalent. The second year of a two-year course in introductory classical and modern physics. Topics to be covered include electricity and magnetism, Maxwell's equations, electromagnetic waves and elementary quantum mechanics. The course is offered in two tracks, similarly to Ph 1. Track B is taught at a somewhat higher mathematical level and covers more topics. Instructors: Cowan, Sciulli, Tombrello, Werner, 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 oscillo-scope, the Maxwell top, electrical and mechanical resonant systems, and radioactivity. Instructors: Neugebauer, Mercereau, 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: Neugebauer, Mercereau, 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: Neugebauer, Mercereau, 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: Neugebauer, Mercereau, and assistants.

**Ph 7. Physics Laboratory.** 6 units; third term. Previous laboratory experience, such as obtained in Ph 6 or other sophomore laboratories, is desirable. In this laboratory course, experiments are performed in atomic and nuclear physics. These include studies of the Balmer series of hydrogen and deuterium, the decay of radioactive nuclei, absorption of X-rays and gamma rays, ratios of abundances of isotopes and the Stern-Gerlach experiment. Instructors: Neugebauer, Mercereau, 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: Leighton.

**Ph 77 ab. Advanced Physics Laboratory.** 6 units; first, second, or third terms. A twoterm laboratory course open to junior and senior physics majors. The purpose of the course is to familiarize the student with laboratory equipment and procedures that are used in the research laboratory. The experiments are designed to illustrate fundamental physical phenomena, such as Compton scattering, nuclear and paramagnetic resonance, the photoelectric effect, the interaction of charged particles with matter, etc. Instructor: Barish.

**Ph 78 abc. Senior Thesis Experimental.** 9 units; first, second, third terms. Prerequisite: instructor's permission. This course is intended to provide supervised experimental research experience, and is open only to senior physics majors. Requirements will be set by individual faculty members, but will include a term paper based upon actual laboratory experience. The selection of topics and the final report must be approved

by the Physics Undergraduate Committee. Not offered on pass/fail basis. Instructors: Physics Staff. See note under Ph 79 below.

**Ph 79 abc. Senior Thesis Theoretical.** 9 units; first, second, third terms. Prerequisite: instructor's permission. This course is intended to provide supervised theoretical research experience and is open only to senior physics majors. Requirements will be set by individual faculty members, but will include a term paper based on the work performed. The selection of topics and the final report must be approved by the Physics Undergraduate Committee. Not offered on pass/fail basis. Instructors: Physics Staff.

*Note*: Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with Professor 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. Instructor: Whaling.

### **Advanced Courses**

**Ph 103 abc. Topics in Contemporary Physics.** 9 units (3-0-6); first, second, third terms. Prerequisite: Ph 92 abc or Ph 125 abc. A series of introductory one-term courses on topics of contemporary physics. Students may register for any particular term or terms; they are independent. In 1978-79 only the third term is offered; introduction to plasma physics. Instructor: Gould.

**Ph 106 abc. Topics in Classical Physics.** 9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc, Ma 2 abc. An intermediate course in the application of the basic principles of classical physics to a wide variety of subjects. It is intended that roughly half of the year will be devoted to mechanics, and half to electromagnetism. Topics to be covered include the Lagrangian and Hamiltonian formulations of mechanics, small oscillations and normal modes, boundary value problems, multipole expansions and various applications of electromagnetic theory. Instructors: Garmire, Liepmann, 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: Barnes.

**Ph 118 ab. Electronic Circuits and Their Application to Physical Research**. *9 units* (3-3-3); first, second terms. A course on the fundamentals of analog and digital electronics with emphasis on proven techniques of instrumentation for scientific research. The course will treat both the physical principles and properties of electronic components and circuits and the logical design of digital systems. Common electronic instruments, computer interfaces, and typical digital control logic in scientific research will be used as illustrative examples. The homework will consist mostly of laboratory problems. Instructor: Peck. Graded pass/fail.

**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. Instructors: Koonin, Thorne.

**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: Frautschi.

**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: Zweig.

**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 registation 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. Instructors: Boehm, Vogel.

**Ph 205 abc. Advanced Quantum Mechanics.** 9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125 abc or 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: Mathews.

**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. Graded pass/fail. Not offered in 1978-79.

**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 1978-79.

**Ph 222.** Many Body Theory. 9 units (3-0-6); third term. Prerequisite: Ph 205 or equivalent. Selected topics in the quantum theory of many particle systems are reviewed. Subject matter will include the application of field theory and graphical methods to specific physical problems of interest in condensed matter physics. These problems include the degenerate electron gas, electron-phonon interaction, superconductivity, and superfluid helium. Not offered in 1978-79.

**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. A review of solar and galactic X-ray astronomy will form the setting for the study of X-ray emission mechanisms. The term will be completed by applying the above techniques to the detailed study of binary X-ray sources, solar X-ray emission, and supernova remnants. The second term will be devoted to the continued study of X-ray emitting objects including clusters of galaxies, active galaxies, QSO's, and diffuse emission in the galaxy and in the intergalactic space. The next topic will be gamma ray astronomy and its relationship to galactic structure and cosmic rays. The third term will be devoted to interplanetary plasmas, radiation belts, and the study of solar and galactic cosmic rays. Not offered in 1978-79.

**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: Ramond.

**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 nonstrange particles, problems associated with very high energy interactions. Instructor: Fox.

**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. Instructor: Feynman.

**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: Mashhoon.

**Ph 237 abc. Theoretical Nuclear Physics.** 9 units (3-0-6); first, second, third terms. Prerequisites: Ph 203 abc and Ph 205 abc or equivalent. A lecture and reading course on the microscopic treatment of the nuclear many-body problem. Topics to be covered include many-body techniques as applied to the structure of both nuclear matter and finite nuclei, microscopic and macroscopic descriptions of collective motion, the formalism and application of various nuclear reaction theories, and the use of weak and electromagnetic interactions as probes of nuclear structure. Offered in alternate years with Ph 203. Not offered in 1978-79.

**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 at Caltech and elsewhere. Advanced students in physics and members of the physics staff take part.

**Ph 300. Research in Physics.** Units in accordance with work accomplished. Ph 300 is elected in place of Ph 172 when the student has progressed to the point where his research leads directly toward the thesis for 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. Not offered in 1978-79. Instructors: Staff.

HSS 99. See page 326 for description.

# **Advanced Courses**

**PS 101. Selected Topics in Political Science.** Units to be determined by arrangement with the instructor. Instructor: Bates.

**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.** Political Modernization and Development. *9 units* (3-0-6). Studies of the politics of developing nations. Focuses on the political consequences of rapid social and economic change. Not offered in 1978-79. Instructor: Bates.

**PS 112.** Behavioral Basis of Politics. *9 units* (3-0-6). Studies the development of political attitudes and public opinion. Topics include the role of the mass media, peer groups, and social institutions in the formation and stabilization of political opinions. Instructor: Bates.

**PS 113. Social Inequality and Politics.** *9 units* (*3-0-6*). Studies the role of social classes in politics. Includes classical Marxist literature, plus more recent empirical research on the relationship of social class to political behavior. Instructor: Bates.

**PS 115. Seminar on National Security.** *9 units* (2-0-7). Consideration will be given to such matters as the process of policy formation within the government, the relationship of disarmament and arms control to defense policy, and the role of international organizations in the development of an orderly world society. Instructor: Elliot.

**PS/SS 116.** War, Diplomacy, and International Politics. 9 units (3-0-6). Prerequisite: *Ec/SS 11 b or equivalent*. This course examines the various theories of the sources and resolution of international conflicts. The second half will be devoted to applying these theories to case studies of conflicts such as the First and Second World Wars, the Vietnam War, the Cold War, and the Arab-Israeli crisis. Not offered in 1978-79. Instructor: Cain.

**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? Not offered in 1978-79. Instructor: Ferejohn.

**PS/SS 119. The Politics of the Industrial State.** 9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent. The emphasis of this course will be on the institutions of and the behavior within industrialized democracies of the western world. Instructor: Cain.

**PS 120.** American Electoral Behavior and Party Strategy. 9 *units* (3-0-6); *third term*. 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. Not offered in 1978-79. Instructor: Cain.

**PS 121. Congressional Policy Formation and Legislative Process.** 9 units (3-0-6); second term. An analysis of decisionmaking in legislative bodies with major emphasis on the American Congress. It also includes an investigation into the impact of Congressional structure and practices on the policies adopted by the Federal Government. Instructors: Fiorina, Ferejohn.

**PS/SS 122. Formal Theories in Political Science.** 9 *units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent.* An examination of the axiomatic structure and the behavioral interpretations of game theoretic and social choice models, and selected political models based on them. Instructors: Ferejohn, Fiorina, Plott.

**PS 125.** Peasant Politics. 9 units (3-0-6); second term. The course will study the political role of the peasantry. Particular attention will be paid to rural political organization and the effect of market relationships. Instructor: Bates.

**PS 132.** Strategy in Politics. 9 units (3-0-6); first term. Prerequisite: Ec/SS 11 a or equivalent. Game theory examined on a nontechnical level, considering experimental work and political applications, with a focus on applications. Not offered in 1978-79. Instructors: Fiorina, Ferejohn.

**Ec/PS 134. The Political Economy of Urban Areas.** 9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent. This course will focus on development of a theory of urban government using analytic concepts from microeconomics and political science. Not offered in 1978-79. Instructor: Miller.

**PS 135.** Political Geography of Developing Countries. 9 units (2-0-7); first term. A study of the swift transition from colonialism or an undeveloped state to the present that includes the growth of one-party states; the role of the military; tribal, religious, and class pressures; the internal and external role of boundaries; and new foreign policies. Instructor: Munger.

**PS/SS 136. Bureaucratic Politics.** 9 *units* (3-0-6). *Prerequisite: Ec/SS 11 b or equivalent*. An analysis of the role of the executive branch in public policy formation. A review of the relevant organization theory literature is included. Not offered in 1978-79. Instructor: Miller.

**PS/SS 137. Organizational Theory.** 9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent. An examination of decisionmaking in the context of hierarchical organizations. Applications will be made to various political, governmental, and private organizations. Not offered in 1978-79. Instructor: Miller.

**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. Not offered in 1978-79. 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. Not offered in 1978-79. Instructor: Bates.

**PS 151.** Justice and Obligation. 9 units (3-0-6); third term. An analysis of the concepts of justice and obligation primarily within a social contract framework but with some comparative study of utilitarian, Kantian, and other ethical schemes. Other normative concepts such as that of "the public interest," "rights," and "duty" will be examined as well. Not offered in 1978-79. Instructor: Cain.

**PS/SS 202.** American Electoral Processes. 9 units (3-0-6); first term. Prerequisite: PS/SS 122 (may be taken concurrently). An in-depth analysis of American electoral processes with emphasis on the application of new theory and quantitative techniques. Instructors: Bates, Kousser.

**PS/SS 203. Congress and the Executive.** *9 units (3-0-6); second term. Prerequisite: PS/SS 202.* The course focuses on the analysis of executive and congressional decisionmaking. Emphasis on theory of committee and bureaucratic theory. Instructors: Cain, Miller.

**PS/SS 204. American Federal System.** *9 units (3-0-6); third term. Prerequisite: PS/SS 203.* This course explores the problems raised by the division of political authority between federal, state and local governmental units. Instructors: Miller, 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. Not offered in 1978-79. Instructor: Breger.

**Psy 12. Introduction to Abnormal Psychology.** *9 units (3-0-6); third term.* An introduction to the development of mental and emotional disturbances. Basic theory will be reviewed in relation to selected case material and relevant research. Instructor: Breger.

**Psy 13. Introduction to Social Psychology.** 9 units (3-0-6); third term. A survey of background and current areas in social psychology. Instructors: Staff.

**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 reguirement.

## **Advanced Courses**

**Psy 100 ab. Psychological Development.** 9 units (3-0-6); first, second terms. A study of the psychological development of the individual within a context of biological, cultural, and social evolution. Instructor: Breger.

**Psy 101. Selected Topics in Psychology.** Units to be determined by arrangement with the instructor. Instructors: Staff and visiting lecturers.

H/Psy 107 ab. Psychohistory. 9 units (3-0-6). An examination of the influence of psychological factors in the course of history and of historical forces in the shaping of groups and individuals. Students are encouraged to take both courses in sequence, though each is a self-contained unit and may be taken separately. H/Psy 107 a will cover the premodern period and H/Psy 107 b the modern period. Instructors: Benton, 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. Instructor: Davis.

Ec/SS 11 b. Social Science Principles and Problems—Non-Market Decisions. 9 units (3-0-6); second, third terms. Prerequisite: Ec/SS 11 a or equivalent. This course concentrates on non-market decisions. It focuses on committee and legislative decisionmaking as well as providing an introduction to recent work in the theory of voting and the political process. Instructors: Fiorina, Miller.

**Ec/SS 11 c. Social Science Principles and Problems—Applications to Public Policy.** 9 *units (3-0-6); third term. Prerequisite; Ec/SS 11 b or equivalent.* This course is devoted to current social problems and is designed to show the student that the theoretical tools developed in the first two terms can be used as the basis for rational solutions to pressing social problems. Instructor: Noll.

**SS 98. Reading in Social Science.** Units to be determined for the individual by the department. Elective, in any term. Reading in social science and related subjects, done either in connection with the regular courses or independently of any course, but under the direction of members of the department. A brief written report will usually be required. Graded pass/fail. Not available for credit toward humanities-social science requirement.

## **Advanced Courses**

SS 101. Selected Topics in Social Science. 9 units (3-0-6). Instructors: Staff, Visiting Lecturers.

Lin/SS 103. Psycholinguistics. 9 units (2-1-6); third term. A seminar-type course on language behavior as a reflection of conceptual processes. Language acquisition, aphasia and other language disturbances, linguistic memory and grammar organization, language and the brain, multilingualism. A research project is required. Instructor: B. Thompson.

Lin/SS 104. Sociolinguistics. 9 units (2-1-6). Language in social interaction studied in a seminar-research type course. Experiments required. Readings in language variation (dialects, slang, jargon, scientific and other). Taught in alternate years; not offered in 1978-79. Instructor: B. Thompson.

Lin/SS 105. Computational Linguistics. 9 units (2-1-6); first term. Prerequisite: Lin 101 a or Lin 101 b or equivalent. English as a language for communication with computers. Problems in parsing and semantic data base analysis. Review through readings of natural language processing systems, including speech recognition and other AI (artificial intelligence) applications. Research required. Taught in alternate years; offered in 1978-79. Instructors: B. Thompson, F. Thompson.

**PS/SS 116. War, Diplomacy and International Politics.** 9 units (3-0-6); third term. Prerequisite: Ec/SS 11 b or equivalent. This course examines the various theories of the sources and resolution of international conflicts. The second half will be devoted to applying these theories to case studies of conflicts such as the First and Second World Wars, the Vietnam War, the Cold War, and the Arab-Israeli crisis. Not offered in 1978-79. Instructor: Cain.

**SS 117.** Problems of Urban Society. 9 units (3-0-6); third term. A description of some of the significant urban problems of contemporary America and an investigation of alternative policies. Instructor: Oliver.

**PS/SS 119.** The Politics of the Industrial State. 9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent. The emphasis of this course will be on the institutions of and the behavior within industrialized democracies of the western world. Instructor: Cain.

**PS/SS 122.** Formal Theories in Political Science. 9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent. An examination of the axiomatic structure and the behavioral interpretations of game theoretic and social choice models, and 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. Not offered in 1978-79. 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. Not offered in 1978-79. 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. Not offered in 1978-79. Instructor: Levine. May be taken more than once if the topic is different.

**PS/SS 136. Bureaucratic Politics.** 9 units (3-0-6). Prerequisite Ec/SS 11 b or equivalent. An analysis of the role of the executive branch in public policy formation. A review of the relevant organization theory literature is included. Not offered in 1978-79. Instructor: Miller.

**PS/SS 137. Organizational Theory.** 9 units (3-0-6). Prerequisite: Ec/SS 11 b or equivalent. An examination of decisionmaking in the context of hierarchical organizations. Applications will be made to various political, governmental, and private organizations. Not offered in 1978-79. Instructor: Miller.

**SS 140 ab. Laboratory Experiments in the Social Sciences.** *9 units (3-0-6); second, third terms.* An examination of recent work in laboratory testing in the social sciences with particular reference to work done in social psychology, economics, and political science. Instructor: Plott.

**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 1978-79. 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: Plott, Miller, Ferejohn.

**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. Not offered in 1978-79. 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 Sciences. Units to be determined by arrangement with *instructors*. Instructors: Staff and visiting lecturers.

**PS/SS 202.** American Electoral Processes. 9 units (3-0-6); first term. Prerequisite: PS/SS 122 (may be taken concurrently). An in-depth analysis of American electoral processes with emphasis on the application of new theory and quantitative techniques. Instructors: Bates, Kousser.

**PS/SS 203. Congress and the Executive.** 9 units (3-0-6); second term. Prerequisite: PS/SS 202. The course focuses on the analysis of executive and congressional decisionmaking. Emphasis on theory of committee and bureaucratic theory. Instructors: Cain, Miller.

**PS/SS 204.** American Federal System. 9 units (3-0-6); third term. Prerequisite: PS/SS 203. This course explores the problems raised by the division of political authority between federal, state, and local governmental units. Instructors: Miller, Ferejohn.

**SS 205.** Microeconomic Theory I. 9 units (3-0-6); first term. Prerequisite: Ec 121 a or equivalent. This course is an introduction to economic theory and its applications. It covers problems in modelling and specification as well as maximization. Instructors: Davis, Noll, Plott, Quirk.

**SS 206.** Microeconomic Theory II. 9 units (3-0-6); second term. Prerequisite: SS 205. The course covers classical consumption theory, the theory of production, markets, externalities, and the question of public goods. Instructors: Quirk, Plott, Forsythe, Wilde.

**SS 207.** Microeconomic Theory III. 9 units (3-0-6); third term. Prerequisite: SS 206. The course covers modern economic theory including decision theory, game theory, the role of uncertainty, and investment theory. Instructors: Quirk, Forsythe, Wilde.

**SS 208.** Microeconomic Theory IV. 9 units (3-0-6); third term. Prerequisite; SS 206 and 207 (latter can be taken concurrently). The course focuses on economic dynamics with particular reference to information theory. Instructors: Forsythe, Wilde.

**SS 210 abc. Foundations of Political Economy.** *9 units (3-0-6). Prerequisites: PS/SS 204 and SS 206.* Mathematical theories of individual and social choice applied to problems of welfare economics and political decisionmaking as well as construction of political economics processes consistent with stipulated ethical postulates, political platform formulation, the theory of political coalitions and decisionmaking in political organizations. Instructors: Ferejohn, Fiorina, Plott.

**SS 211 abc. 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: Quirk, Forsythe, Wilde. *Can be repeated for credit.* 

**SS 212 abc. Application of Microeconomic Theory.** *9 units (3-0-6).* This course will be a working seminar in which the tools of microeconomic theory are applied in a systematic fashion to the explanation of events and the evaluation of policy. Instructors: Quirk, Montgomery, Noll. *Can be repeated for credit.* 

**SS 213. Competiton and Antitrust Policy.** 9 units (3-0-6); first 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: Noll.

**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. Not offered in 1978-79. Instructors: Levine and staff.

**SS 222 ab.** Econometrics. 9 units (3-0-6); second and third terms. Prerequisites: Mathematical Statistics and Ec 122. Advanced topics in econometrics with special emphasis on the formulation, estimation, and evaluation of multi-equation systems. Students will be required to complete a major project in measurement. Instructors: Nelson, Grether.

**SS 223.** Advanced Topics in Econometric Theory. 9 units (3-0-6)... Prerequisite: SS 222 ab; may be repeated for credit. This course in quantitative methods is designed for second- and third-year social science graduate students. Subject matter to include theory of identification and estimation of simultaneous equations system. Instructors: Grether, Nelson.

**SS 224.** Advanced Topics in Econometric Methods. 9 units (3-0-6). Prerequisite: SS 222 ab; may be repeated for credit. This course in quantitative methods is designed for second- and third-year social science graduate students. Subject matter includes models with limited dependent variables and distribution lag models. Instructors: Cain, Grether, Kousser, Nelson.

**SS 225.** Advanced Topics in Quantitative Methods for Policy Analysis. 9 units (3-0-6). Prerequisite: SS 222 ab; may be repeated for credit. This course is designed for secondand third-year social science graduate students. Students will analyze recent empirical studies which relate to current policy questions using modern econometric techniques. Instructors: Cain, Grether, Nelson.

**SS 229. Historical Dimensions of Economic Analysis.** 9 units (3-0-6); second term. 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 decisionmaking, small-group and organizational behavior, uncertainty and the tolerance for ambiguity and stress and change. Not offered in 1978-79. Instructor: Grether.

**SS 231 abc. American Politics.** *9 units (3-0-6).* A three-term course in American politics and political behavior. While drawing from contemporary materials, the course will emphasize the historical background of American political institutions. Instructors: Fiorina, Ferejohn.

**SS 232 abc. Historical and Comparative Perspectives in Political Analysis.** *9 units* (3-0-6). *Prerequisite: PS/SS 204.* The course is designed to provide the student of American politics with a knowledge and understanding of developments in both the American past and in other parts of the world. Instructors: Bates, Cain, Kousser.

#### 352 Subjects of Instruction

**SS 233 abc. Public Policymaking.** 9 *units* (3-0-6). *Prerequisite: PS/SS 204*. An examination of the policymaking processes in national, state, and local governments and how various institutions affect policy choices. Not offered in 1978-79. Instructors: Ferejohn, Fiorina, Miller.

SS 234. Research Seminar in Modern Political Science. 9 units (3-0-6); may be repeated for credit. Instructors: Staff.

**SS 235. Bureaucracy and Organization Theory.** *9 units (3-0-6); third term.* An examination of the political economy of organizations. Special attention is given to formal theories capable of explaining such phenomena as the problems of rigidity and control loss, and the patterns of information flow within organizations. Not offered in 1978-79. Instructor: Miller.

**SS 240. Techniques of Policy Research.** 9 units (3-0-6); first term. Prerequisites: PS/SS 202, PS/SS 203, PS/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.

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