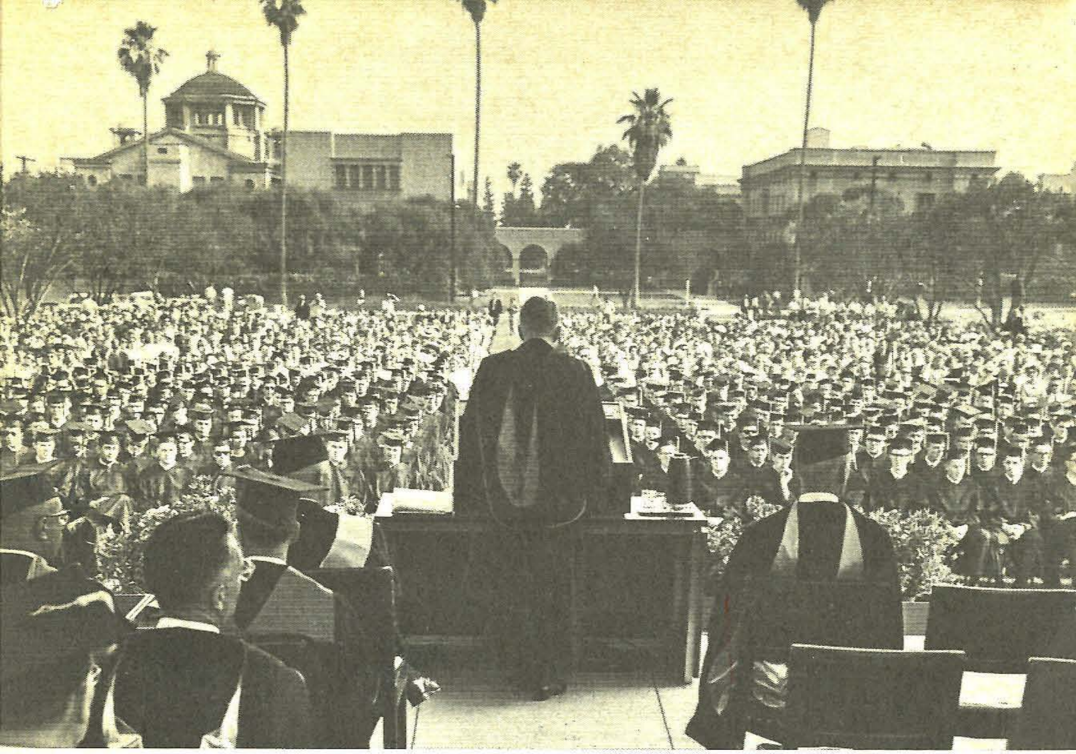

BULLETIN OF THE

CALIFORNIA INSTITUTE OF TECHNOLOGY

VOLUME 74 · NUMBER 3

INFORMATION FOR STUDENTS

1965–1966

1965

SEPTEMBER

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BULLETIN OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY
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PASADENA, CALIFORNIA 91109

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INFORMATION FOR STUDENTS 1965-1966

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA · CALIFORNIA

SEPTEMBER 1965

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ACADEMIC CALENDAR

1965-66

1965	FIRST TERM
September 23	Registration of entering freshmen—8:00 a.m. to 12 noon.
September 23	Registration of undergraduate students transferring from other colleges—8:00 a.m. to 12 noon.
September 23-25	Student Camp.
September 27	General Registration—8:30 a.m. to 3:30 p.m.
September 27	Undergraduate Academic Standards and Honors Committee—3:00 p.m.
September 28	Beginning of instruction—8:00 a.m.
October 15	Last day for adding courses.
October 16	Examinations for the removal of conditions and incompletes.
October 23	Parents' Day.
November 1-6	Mid-Term Week.
November 6	MID-TERM.
November 8	Mid-Term deficiency notices due—9:00 a.m.
November 9	Freshman-Sophomore Mudeo.
November 12	Last day for dropping courses.
November 12	French examination for admission to candidacy for degree of Doctor of Philosophy.
November 19	German examination for admission to candidacy for degree of Doctor of Philosophy.
November 22-26	Pre-registration for second term, 1965-66.
November 25-28	Thanksgiving recess.
November 25-26	Thanksgiving holidays for employees.
December 4	Students' Day.
December 11-17	Final examinations—first term, 1965-66.
December 18	End of first term, 1965-66.
Dec. 19-Jan. 2	Christmas vacation.
December 23-24	Christmas holidays for employees.
December 30	Undergraduate Academic Standards and Honors Committee—9:00 a.m.
December 31	New Year's Day holiday for employees.

1966	SECOND TERM
January 3	General Registration—8:30 a.m. to 3:30 p.m.
January 4	Beginning of instruction—8:00 a.m.
January 21	Last day for adding courses.
January 22	Examinations for the removal of conditions and incompletes.
Jan. 31-Feb. 5	Mid-Term Week.
February 5	MID-TERM.
February 7	Mid-Term deficiency notices due—9:00 a.m.
February 11	Last day for dropping courses.
February 11	French examination for admission to candidacy for the degree of Doctor of Philosophy.
February 18	German examination for admission to candidacy for the degree of Doctor of Philosophy.
February 21-25	Pre-registration for third term, 1965-66.
March 12-18	Final examinations—second term, 1965-66.
March 19	End of second term, 1965-66.
March 20-27	Spring Recess.
March 25	Undergraduate Academic Standards and Honors Committee—9:00 a.m.

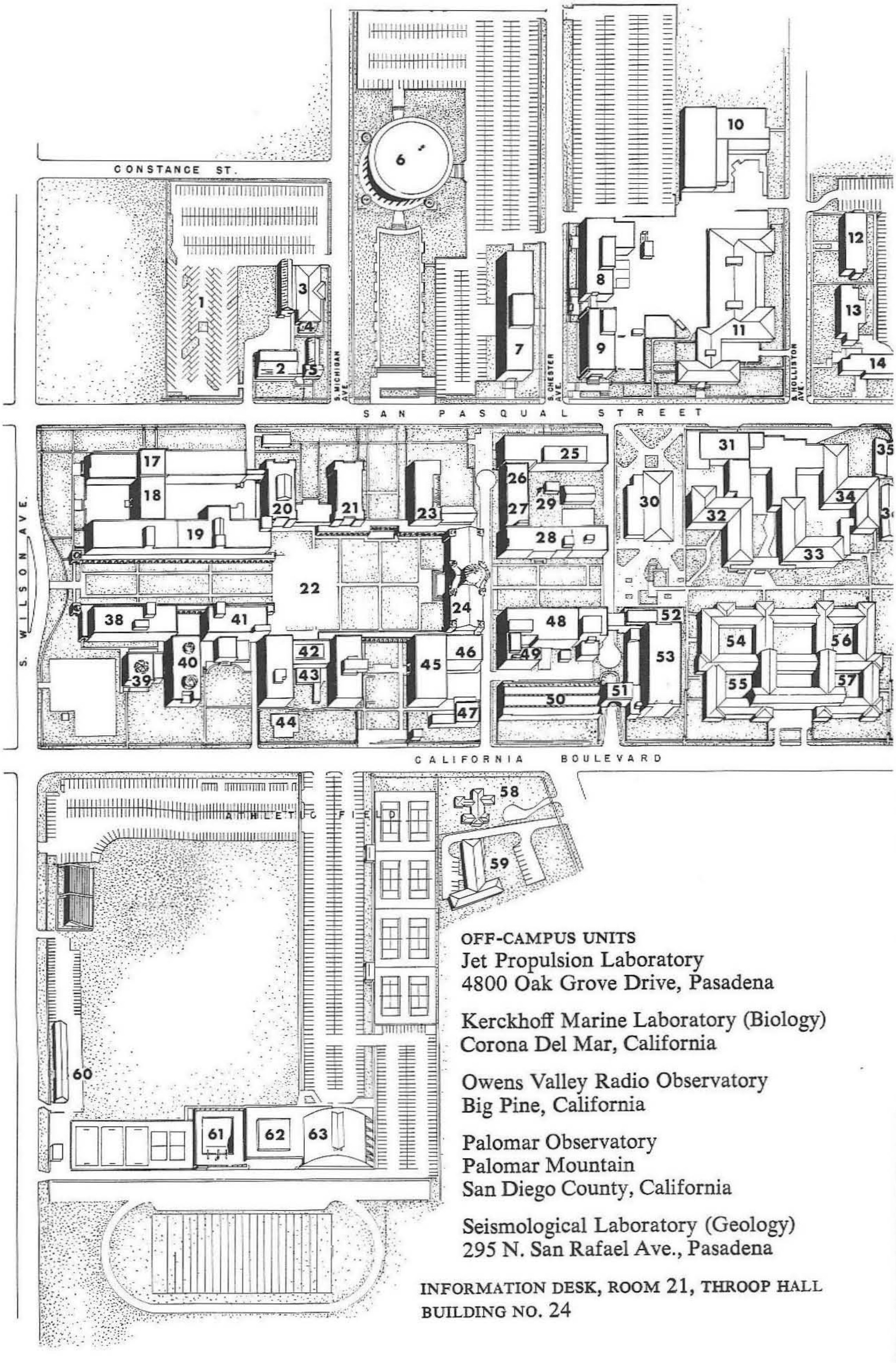
1966 THIRD TERM

March 28	General Registration—8:30 a.m. to 3:30 p.m.
March 29	Beginning of instruction—8:00 a.m.
April 15	Last day for adding courses.
April 16	Examinations for the removal of conditions and incompletes.
April 25-29	Mid-Term Week.
April 30	Last day for obtaining admission to candidacy for Engineers' degrees.
April 30	MID-TERM.
May 2	Mid-Term deficiency notices due—9:00 a.m.
May 6	Last day for dropping courses.
May 6	French examination for admission to candidacy for the degree of Doctor of Philosophy.
May 6-7	Examinations for admission to upper classes, September 1966.
May 13	German examination for admission to candidacy for the degree of Doctor of Philosophy.
May 16	Registration for summer research (graduate students).
May 16-20	Pre-registration for first term, 1966-67, and registration for undergraduate summer research.
May 27	Last day for final oral examinations and presenting of theses for the degree of Doctor of Philosophy.
May 27	Last day for presenting theses for Engineers' degrees.
May 28-June 3	Final examinations for senior and graduate students, third term, 1965-66.
May 30	Memorial Day holiday.
May 30	Memorial Day holiday for employees.
June 4-10	Final examinations for undergraduate students, third term, 1965-66.
June 8	Curriculum Committee—10:00 a.m.
June 8	Faculty Meeting—2:00 p.m.
June 9	Class Day.
June 10	Commencement—4:30 p.m.
June 11	End of third term, 1965-66.
June 17	Undergraduate Academic Standards and Honors Committee—9:00 a.m.
July 4	Independence Day holiday for employees.

1966 FIRST TERM, 1966-67

September 5	Labor Day holiday for employees.
September 22	Registration of entering freshmen—8:00 a.m. to 12 noon.
September 22	Registration of undergraduate students transferring from other colleges—8:00 a.m. to 12 noon.
September 22-24	Student Camp.
September 26	General Registration—8:30 a.m. to 3:30 p.m.
September 27	Beginning of instruction—8:00 a.m.

CAMPUS · CALIFORNIA



OFF-CAMPUS UNITS

Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena

Kerckhoff Marine Laboratory (Biology)
Corona Del Mar, California

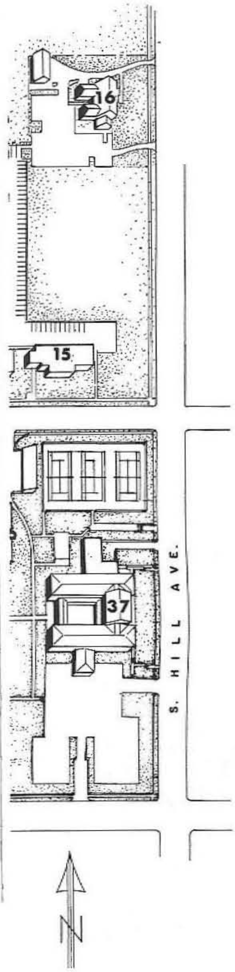
Owens Valley Radio Observatory
Big Pine, California

Palomar Observatory
Palomar Mountain
San Diego County, California

Seismological Laboratory (Geology)
295 N. San Rafael Ave., Pasadena

INFORMATION DESK, ROOM 21, THROOP HALL
BUILDING NO. 24

INSTITUTE OF TECHNOLOGY



1. Site of Chemical Physics Laboratory
2. Campbell Laboratory (Plant Research)
3. Earhart Laboratory (Plant Research)
4. Clark Laboratory (Plant Research)
5. Dolk Laboratory (Plant Physiology)
6. Beckman Auditorium
7. Keck Laboratories (Engineering)
8. Steele Laboratory of Electrical Sciences
9. Booth Computing Center
10. Site of Central Engineering Services Building
11. Physical Plant (Administration and Shops)
12. Keck House (Graduate residence)
13. Mosher-Jorgensen House (Graduate residence)
14. Braun House (Graduate residence)
15. Marks House (Graduate residence)
16. Industrial Relations Center
17. Church Laboratory (Chemical Biology)
18. Alles Laboratory (Molecular Biology)
19. Kerckhoff Laboratory (Biological Sciences)
20. Crellin Laboratory (Chemistry)
21. Gates Laboratory (Chemistry)
22. Site of Millikan Library
23. Dabney Hall (Humanities)
24. Throop Hall (Administration)
25. Spalding Laboratory (Chemical and Electrical Engineering)
26. Chemical Engineering Laboratory
27. Heating Plant
28. Thomas Laboratory (Civil and Mechanical Engineering)
29. Nuclear Engineering Laboratory
30. Winnett Student Center
31. Chandler Dining Hall
32. Page House (Undergraduate residence)
33. Lloyd House (Undergraduate residence)
34. Ruddock House (Undergraduate residence)
35. Residence and Dining Halls Office
36. Building T-4
37. Athenaeum (Faculty Club)
38. Mudd Laboratory (Geological Sciences)
39. Culbertson Hall (Auditorium)
40. Robinson Laboratory (Astrophysics)
41. Arms Laboratory (Geological Sciences)
42. Bridge Laboratory (Physics)
43. Cosmic Ray Laboratory
44. Isotope Handling Laboratory
45. Sloan Laboratory (Mathematics and Physics)
46. Kellogg Radiation Laboratory (Nuclear Physics)
47. Graphic Arts, Receiving Room, and Central Warehouse
48. Guggenheim Laboratory (Aeronautics)
49. Karman Laboratory (Fluid Mechanics and Jet Propulsion)
50. Central Engineering Machine Shop
51. Merrill Wind Tunnel
52. Firestone Laboratory (Flight Sciences)
53. Synchrotron Laboratory
54. Fleming House (Undergraduate residence)
55. Dabney House (Undergraduate residence)
56. Ricketts House (Undergraduate residence)
57. Blacker House (Undergraduate residence)
58. Arden House (Residence of Master of Student Houses)
59. Young Health Center
60. Building T-1 (Air Force ROTC)
61. Alumni Swimming Pool
62. Locker Rooms
63. Brown Gymnasium

Section I

CALIFORNIA INSTITUTE OF TECHNOLOGY OFFICERS AND FACULTY

BOARD OF TRUSTEES*

OFFICERS

MEMBERS OF THE BOARD

HONORARY TRUSTEES

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

*July 1, 1965

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ELECTED COMMITTEES

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Shannon Crandall, Jr.
Lee A. DuBridge
Herbert L. Hahn
Lindley C. Morton
John O'Melveny
Edward R. Valentine
Harry J. Volk

James N. Ewart, *Secretary*

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Edward R. Valentine, *1st Vice-Chairman*
Lindley C. Morton, *2nd Vice-Chairman*

Arnold O. Beckman
J. G. Boswell II
Norman Chandler
Lee A. DuBridge
John O'Melveny
Harry J. Volk

James N. Ewart, *Secretary*

APPOINTED COMMITTEES

(CHAIRMAN AND PRESIDENT ARE EX-OFFICIO MEMBERS)

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J. S. Fluor, *Chairman*
Earle M. Jorgensen, *Vice-Chairman*

Norman Chandler
Shannon Crandall, Jr.
Lindley C. Morton
Simon Ramo

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John O'Melveny
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Harry J. Volk

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John G. Braun
Earle M. Jorgensen
Richard R. Von Hagen
Howard G. Vesper

Lawrence A. Williams

AUDITING COMMITTEE

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Lloyd L. Austin
Shannon Crandall, Jr.

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John G. Braun
Lee A. DuBridge
Herbert L. Hahn
Thomas V. Jones
A. B. Kinzel
William E. Zisch
William H. Pickering } ex-officio &
R. B. Gilmore } non-voting

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Simon Ramo
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J. S. Fluor
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Vice-Chairman: D. C. Elliot

Secretary: H. C. Martel

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Term expires June 30, 1966	*Term expires June 30, 1967*	*Term expires June 30, 1968*
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Term expires June 30, 1966	*Term expires June 30, 1967*
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**J. L. Greenstein	*R. V. Langmuir
**R. D. Owen	*R. P. Sharp

*Automatic nominee for election to second two-year term.

**Serving second two-year term, not eligible for re-election.

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David J. Benney,* Ph.D. . . . . *Engineering*
Archibald Brown,* Ph.D. . . . . *Aeronautics*
Arthur T. Ippen,* Ph.D. . . . . *Engineering*
Paul C. Johnson, Ph.D. . . . . *Engineering Science*
Theodore Hsueh-Huang Pian, Sc.D. . . . . *Aeronautics*
Mackenzie Walser,* M.D. . . . . *Engineering*

ASSOCIATE PROFESSORS

Allan J. Acosta, Ph.D. . . . . *Mechanical Engineering*
Paul J. Blatz, Ph.D. . . . . *Materials Science*
David J. Braverman,** Ph.D. . . . . *Electrical Engineering*
Francis S. Buffington, Sc.D. . . . . *Materials Science*
Albert T. Ellis, Ph.D. . . . . *Applied Mechanics*
Derek H. Fender, Ph.D. . . . . *Biology and Electrical Engineering*
Nicholas George, Ph.D. . . . . *Electrical Engineering*
Floyd B. Humphrey, Ph.D. . . . . *Electrical Engineering*
Toshi Kubota, Ph.D. . . . . *Aeronautics*
Hardy C. Martel, Ph.D. . . . . *Electrical Engineering*
Caleb W. McCormick, Jr., M.S. . . . . *Civil Engineering*
Carver A. Mead, Ph.D. . . . . *Electrical Engineering*
James J. Morgan, Ph.D. . . . . *Environmental Health Engineering*
Marc-Aurele Nicolet, Ph.D. . . . . *Electrical Engineering*
Wheeler J. North, Ph.D. . . . . *Environmental Health Engineering*
Ronald F. Scott, Sc.D. . . . . *Civil Engineering*
Rangasami Sridhar, Ph.D. . . . . *Electrical Engineering*
Nicholas W. Tschoegl, Ph.D. . . . . *Materials Science*
Thad Vreeland, Jr., Ph.D. . . . . *Materials Science*
David F. Welch,*** I.D. . . . . *Engineering Design*
Donald M. Wilson, Ph.D. . . . . *Biology and Electrical Engineering*
Amnon Yariv, Ph.D. . . . . *Electrical Engineering*
Edward E. Zukoski, Ph.D. . . . . *Jet Propulsion*

*In residence 1964-65.
**On leave of absence.
***On leave of absence first term.

VISITING ASSOCIATE PROFESSORS

Rokuro Muki, Ph.D. .... *Applied Mechanics*
Warner L. Peticolas, Ph.D. .... *Materials Science*
George C. Sih, Ph.D. .... *Aeronautics*

SENIOR RESEARCH FELLOWS

Kamalaksha Das Gupta, Ph.D. .... *Materials Science*
Wallace G. Frasher, Jr., M.D. .... *Engineering Science*
Duen-pao Wang, Ph.D. .... *Engineering*
John George Waugh, Ph.D. .... *Engineering*

ASSISTANT PROFESSORS

Boris Auksmann, Ph.D. .... *Engineering Design*
Charles D. Babcock, Jr., Ph.D. .... *Aeronautics*
Fred E. C. Culick, Sc.D. .... *Jet Propulsion*
Andrew L. Gram, Ph.D. .... *Environmental Health Engineering*
Thomas L. Grettenberg, Ph.D. .... *Electrical Engineering*
Din-Yu Hsieh, Ph.D. .... *Engineering Science*
Wilfred D. Iwan, Ph.D. .... *Applied Mechanics*
Paul C. Jennings, Ph.D. .... *Applied Mechanics*
Wolfgang G. Knauss, Ph.D. .... *Aeronautics*
Peter B. S. Lissaman, M.S. .... *Aeronautics*
Peter V. Mason,* Ph.D. .... *Electrical Engineering*
Fredric Raichlen, Sc.D. .... *Civil Engineering*
Miklos Sajben, Sc.D. .... *Aeronautics*
Jerome L. Shapiro, Ph.D. .... *Applied Science*
Bradford Sturtevant,** Ph.D. .... *Aeronautics*
Russell A. Westmann, Ph.D. .... *Civil Engineering*
Ronald H. Willens, Ph.D. .... *Materials Science*

LECTURERS

Isaac M. Horowitz, D.E.E. .... *Electrical Engineering*
Taras Kiceniuk, M.S. .... *Engineering Design*

RESEARCH FELLOWS

Robert J. Arenz, Ph.D. .... *Aeronautics*
Eric Betz, Ph.D. .... *Aeronautics*
Mark C. Biedebach,*** Ph.D. .... *Electrical Engineering*
Sei-ichi Denda,*** Dr.Eng. .... *Electrical Engineering*
Erich Hahne,*** Dr.Ing. .... *Engineering*
Gordon L. Harris, D.Sc. .... *Aeronautics*
Gilbert A. Hegemier, Ph.D. .... *Aeronautics*
Marcos Intaglietta, Ph.D. .... *Engineering Science*
Daniel G. Keehn, Ph.D. .... *Electrical Engineering*
Robert C. Y. Koh, Ph.D. .... *Engineering*
E. John List, Ph.D. .... *Engineering*
Peter C. Lockemann, Dr.Ing. .... *Engineering*
Malcolm McColl, Ph.D. .... *Electrical Engineering*
Yutaka Sasaki, M.D. .... *Engineering Science*
Bernd J. F. Schmidt, Dr.Ing. .... *Aeronautics*
Richard A. Scott, Ph.D. .... *Applied Mechanics*
Hisayoshi Sekiguchi,*** Dr.Eng. .... *Applied Mechanics*
Jerold L. Swedlow, Ph.D. .... *Aeronautics*
Wei-hsuin Yang,*** Ph.D. .... *Materials Science*

*On leave of absence first term.
**On leave of absence.
***In residence 1964-65.

GRADUATE FELLOWS AND ASSISTANTS, 1964-65

Bernard Abel Aimelet, Ing.
Irwin Emanuel Alber, M.S.
Albert Charles Angelovich, B.S.
Gerassimos George Aperghis, B.A.
Johann Arbocz, M.S.
George S. Argyropoulos, M.S.
Gerald Richard Ash, B.S.
Raymond Dean Ayers, M.S.
Orlino C. Baldonado, M.S.
Richmond Barnes, M.S.
Richard George Batt, M.S.
Luc Olivier Bauer, M.S.
Scott Williams Beckwith, B.S.
Wayne Metcalf Beebe, M.S.
George Wood Beeler, Jr., M.S.
Wilhelm Behrens, Dipl.Ing.
Lon Edward Bell, M.S.
Elton Dean Bellinger, B.S.E.
David Bernard Benson, M.S.
Thomas Robert Bierma, B.S.E.
Charles Edgar Billings, S.M.
David Jordan Blakemore, M.S.
Richard Clark Blish II, M.S.
Joseph William Blum, M.S.
George Wallace Bluman, B.Sc.
David Beauregard Bogy, M.S.
Robert Harold Bond, M.S.
Arthur Gerald Brady, B.Sc.
Gary Duane Brinker, S.B.
Richard Runyon Brock, M.S.
Thomas Richard Brussat, B.S.
John Tweedsmuir Buchan, B.Sc.
Carl James Buczek, M.S.
Stanley Butman, S.M.
Jean-Michael Calle, M.S.
Tsiu Chiu Chan, M.S.
Fu-Wu Chang, M.S.
Milton M. T. Chang, B.S.
Chia-Chun Chao, M.S.
Wilfred Peter Charette, M.S.
Jay-Chung Chen, M.S.
José Chirivella-Casanova, Ing.
Don Paul Clausing, M.S.
Donald Henry Close, M.S.
Donald James Collins, M.S.
Pierre-Yves Michel Comte, Ing.
Robert William Conn, B.Ch.E.
John Thomas Cookson, Jr., M.S.
Terrill Alan Cool, M.S.
Wayne Franklin Covington, B.S.
Clark Allan Crane, B.S.
Antonio Crespo-Martinez, Ing.
Richard Clark Crewdson, B.S.
Donald Leslie Cronin, M.S.
Steven Collins Crow, M.S.
Iain George Currie, M.A.Sc.
Dikhan Damlamayan, M.S.
Ted Herbert Davey, M.S.
Lee Walker Davison, M.S.
Guy de Balbine, M.S.
Raymond Kay DeLong, B.S.
Andrea De Mari, M.S.
Peter Nicholas Demopoulos, B.S.
John Randall Dickerson, M.S.
James Johnson Duderstadt, B.Eng.
Claude Jean Durand, Ing.
Robert Ellis Edelson, S.M.
Robert Charles Erdmann, M.S.
Loh-Nien Fan, M.S.
Rena Fersht, M.Sc.
Jay Laurence Finkelstein, B.S.
Hugo Breed Fischer, M.S.
Gary Arnold Flandro, M.S.
Jonathan Akin French, M.S.
Clarence Sigmund Fuzak, Jr., B.S.
Melbourne Fernald Giberson, M.S.
Michael James Gilliom, B.S.
Robert Ridgeway Gilpin, B.Sc.
Georges Pierre Alexis Giraudbit, M.S.
William Andrew Goddard III, B.S.
Steven Jonathan Goldner, B.S.
Jean-Marie François Grange, M.S.
Richard Rutherford Green, B.S.
William Franklin Greenman, M.S.
Douglas Edwin Griffin, B.S.
William Paul Gruber, M.S.
Jean François Guermonprez, Ing.
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Roger Allison Haas, B.E.S.
Lawrence William Hallanger, M.S.
Robert Duane Hanson, M.S.C.E.
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Howard Elliot Harry, Jr., B.S.
Kenneth Gunder Harstad, S.M.
John Gillespie Hartnett, B.S.E.
Ryusuke Hawegawa, M.E.
Edward Gerald Hauptmann, M.S.
Denis Robert Hayner, B.S.
Kenneth Leon Heitner, B.S.
Carl William Hennrich, M.A.E.
Robert Henry Hertel, M.S.
Jack Hubert Hill, M.S.
Chee Leung Ho, M.S.
Alan Lowell Hoffman, M.S.
Lawrence Donald Hofmeister, B.S.
Kum Wah How, Dipl.
Chien-hsin Hsiung, M.S.
Paul Yu-fei Hu, M.S.
Harry Douglas Hunter, B.Sc.
Raul Husid, M.S.
Li-San Hwang, M.S.
Marlyn Tony Jakub, M.S.
David Fielding James, M.S.
Alden Barry Johnson, B.S.
Wolf Dieter Kabiersch, Ing.
Karl Herman Kanus, Jr., M.S.

John Joseph Kenny, M.S.
Vassilios Kerdemelidis, M.S.
James Thomas Kindle, B.S.
Ronald Allan Kleban, M.S.
Alan Frank Klein, M.Ae.E.
Richard Ira Klein, B.E.E.
John Michael Klineberg, M.S.
Gerhard Joachim Klose, M.S.
Hon-Yim Ko, M.S.
John Kent Koester, B.S.
Jen Kai Kung, B.Sc.
Mitsuru Kurosaka, M.S.
Bruce Meno Lake, M.S.
Joseph Po-Keung Lau, M.S.
Stephen Stuart Lavenberg, M.S.
Jen-shih Lee, M.S.
John Seymour Letcher, M.S.
Pat Chiu Leung, B.S.
George Wladimir Lewicki, M.S.
John Eldon Lewis, M.S.
Alexander Chen-Che Liang, B.S.E.
Sheng-rong Lin, M.S.
Stephen Chung-Hsiung Lin, B.S.
Gerald Herbert Lindsey, M.S.
Ericson John List, M.E.
Hans Ludewig, M.S.
Jon Christian Luke, S.M.
Loren Daniel Lutes, M.Sc.
Thomas William MacDowell, B.S.
Harold Mack, Jr., B.S.
John Michael Julius Madey, B.S.
Ramani Mani, M.S.
Dominique René Jacques Marchand, Ing.
Franklin Lester Marshall, M.S.
Sami Faiz Masri, M.S.
William Masaru Matsukado, B.S.
John Wallace Matthews, M.S.
Hugh Michael McAlear, B.S.
David James McCloskey, M.S.
John Thomas McCrickerd, S.B.
Thomas Conley McGill, Jr., B.S.
Patrick Anthony McGovern, M.S.
Stanley Brun Mellsen, M.S.
Robert Philip Miele, M.S.
Roger Leon Minear, B.S.
Donald Wayne Moon, M.S.
Hidehiko Mori, B.S.
Michael Philip Mortell, M.S.
Hans-Karl Chritian Alfred Mueller, M.S.
Timothy Owen Murray, B.S.M.E.
Stanley Norman Nathanson, M.S.
Carlos Navarro-Cantero, Ing.
Michael Louis Neeser, B.S.
James Otis Nichols, M.S.
Navin Chandra Nigam, M.S.
Frederick Reyes Norwood, M.S.
Michael John O'Sullivan, B.Sc.
Nick Panagiotacopoulos, Dipl.
Theodore Wallace Parry, B.S.
S. P. Parthasarathy, M.Sc.
Carl Elliott Patton III, M.S.
Robert Francis Pawula, M.S.
Daniel Curtis Paxton, Jr., B.S.
Harold James Payne, B.S.
Albert Bernard Pincince, B.S.
Robert Leslie Poeschel, M.S.
David Peter Pope, M.S.
A. Jagadesh Prasad, M.E.
Andreas Puhl, M.S.
Terry Neil Rahmeier, M.S.
Philip Wayne Randles, M.S.
Thomas Charles Reihman, M.S.
David Allen Rennels, B.S.
Peter Paul Augustine Rispin, M.Sc.
Richard Dale Rocke, M.S.
Robert Richard R. Rodite, B.S.E.E.
Valentin Rodriguez, B.E.E.
Ignacio Rodriguez-Iturbe, Eng.
James Robert Rose, B.A.Sc.
Robert Rosen, M.S.
William Joseph Rosenberg, B.S.
Louis Edmond Rostand, B.S.
Yilmaz Esraf Sahinkaya, M.S.E.
Gaetan Joseph St. -Cyr, M.S.
Roger Selig Schlueter, B.S.Engr.Sc.
Robert Jay Schmulian, B.S.
John Richard Schuster, M.S.
Henry Gerard Schwartz, Jr., M.S.
Robert Seliger, B.S.
Pattamadai Narasimhan Shankar, B.Sc.
Steven James Sharp, B.S.
Cheng-Chung Shen, S.M.
Richard Franklin Smisek, M.S.
Jerome Allan Smith, M.S.
Kwan-lok So, M.E.
Bernard Claude Solelhac, Ing.
Furman Yates Sorrell, Jr., M.S.
Edmund Eugene Spaeth, M.S.
Walter Albert Specht, Jr., B.S.
William Stavro, M.S.
Alvah Thomas Strickland, B.S.
James Walter Surhigh, B.S.
Alexander James Sutherland, M.E.
Bob Hiro Suzuki, M.S.
Takao Suzuki, M.S.
Christopher Kwong Wah Tam, M.S.
Stephen Ilott Taylor, B.A.Sc.
Ansel Frederick Thompson, Jr., B.S.
Karvel Kuhn Thornber, M.S.
Ivar Harald Tombach, B.S.
Pin Tong, M.S.
Harry Warren Townes, M.S.
John Burgess Trenholme, M.S.
Nien-chien Tsai, B.S.
Chang-chyi Tsuei, M.S.
Arthur P. Leigh Turner, B.S.
Matías José Turteltaub, Ing.
Thomas Janney Tyson, M.S.
Mohan Vachani, B.Tech.
Athanassios Demetrius Varvatsis, Dipl.

Giulio Venezian, B.Eng.Phys.
Keith Jordis Victoria, M.S.
Richard Bernard Wade, M.Sc.Eng.
Charles Chang-Ping Wang, M.S.
Richard William Weeks II, B.S.
Michel Wehrey, Dipl.
Patrick Dan Weidman, M.S.
Martin Erick Weiner, B.S.
Pieter Wesseling, Ing.
Lewis Turner Wheeler, M.S.
Arthur Karl Whitney, B.Sc.
Richard R. Williams, M.S.
Robert Orville Winkler, B.S.
Felix Shek Ho Wong, B.S.
Po Kee Wong, M.Sc.
David Clark Wooten, M.S.
I-min Yang, M.S.
Thomas Man Yang, M.S.
Tyan Yeh, M.S.
James Yoh, M.S.
Chen-shyong Young, M.S.
Laurence Bei-yu Zung, M.S.

Division of Geological Sciences

Robert P. Sharp, *Chairman*

Clarence R. Allen, *Interim Director, Seismological Laboratory*

PROFESSOR EMERITUS

Hugo Benioff, Ph.D. . . . . *Seismology*

PROFESSORS

Clarence R. Allen, Ph.D. . . . . *Geology and Geophysics*
Harrison S. Brown, Ph.D., LL.D., Sc.D. . . . . *Geochemistry*
C. Hewitt Dix, Ph.D. . . . . *Geophysics*
Samuel Epstein, Ph.D. . . . . *Geochemistry*
Barclay Kamb, Ph.D. . . . . *Geology and Geophysics*
Heinz A. Lowenstam, Ph.D. . . . . *Paleoecology*
Charles F. Richter, Ph.D. . . . . *Seismology*
Robert P. Sharp, Ph.D. . . . . *Geology*
Leon T. Silver, Ph.D. . . . . *Geology*
Gerald J. Wasserburg, Ph.D. . . . . *Geology and Geophysics*

VISITING PROFESSORS

Orson L. Anderson, Ph.D. . . . . *Geophysics*
Fritz H. Laves, Ph.D. . . . . *Crystallography*

RESEARCH ASSOCIATES

Ian Campbell, Ph.D. . . . . *Geology*
Thane H. McCulloh, Ph.D. . . . . *Geology*
Eugene M. Shoemaker, Ph.D. . . . . *Astrogeology*

VISITING ASSOCIATES

J. A. Mabbutt, M.A. . . . . *Geomorphology*
Shosei Serata, Ph.D. . . . . *Geophysics*
J. H. McD. Whitaker, M.A. . . . . *Paleontology*

ASSOCIATE PROFESSORS

Arden L. Albee, Ph.D. . . . . *Geology*
Don L. Anderson, Ph.D. . . . . *Geophysics*
Charles B. Archambeau, Ph.D. . . . . *Geophysics*
Arthur J. Boucot, Ph.D. . . . . *Paleontology*
James N. Brune, Ph.D. . . . . *Geophysics*
Bruce C. Murray, Ph.D. . . . . *Planetary Science*
Stewart W. Smith, Ph.D. . . . . *Geophysics*
Hugh P. Taylor, Jr., Ph.D. . . . . *Geology*

SENIOR RESEARCH FELLOWS

Ari Ben-Menahem, Ph.D. . . . . *Geophysics*
Claire C. Patterson, Ph.D. . . . . *Geochemistry*

ASSISTANT PROFESSOR

Donald S. Burnett, Ph.D. . . . . *Nuclear Geochemistry*

RESEARCH FELLOWS

Shawn Biehler, Ph.D. . . . . *Geophysics*
Hiroo Kanamori, Ph.D. . . . . *Geophysics*
Chi-Yu King, Ph.D. . . . . *Geophysics*

Masayo Murozumi, Ph.D. . . . . *Geochemistry*
Robert T. Pidgeon, Ph.D. . . . . *Geology*
Anand Prakash, D.Phil. . . . . *Geophysics*
Ronald G. Senechal, Ph.D. . . . . *Geology*
Robert V. Sharp, Ph.D. . . . . *Geology*
John B. Southard, Ph.D. . . . . *Geology*
Rudolf H. Steiger, Dr. sc. nat. . . . . *Geology*
Ryuichi Sugisaki, D.Sc. . . . . *Geochemistry*
N. J. Vlaar, Ph.D. . . . . *Geophysics*
Alfred M. Ziegler, Ph.D. . . . . *Paleontology*

GRADUATE FELLOWS AND ASSISTANTS, 1964-65

Walter Arabasz, B.S.
James L. Aronson, M.S.
Kevin L. Carey, B.S.
Dean N. Clay, B.Sc.
George R. Clark II, A.B.
Thomas D. Coskren, B.S.
James A. Doutt, B.S.
Jeffrey Friedberg, B.S.
Brent D. Fuller, B.S.
Alexander Goetz, M.S.
Thomas L. Henyey, B.A.
Lincoln S. Hollister, B.A.
Roger L. Hooke, B.A.
Lane R. Johnson, M.S.
Bruce R. Julian, B.S.
Hugh Kieffer, B.S.
James R. Lawrence, B.S.
Dennis Matson, A.B.
Thomas B. McCord, B.S.
S. Douglas McDowell, M.S.
Thomas R. McGetchin, M.S.
John R. McGinley, Jr., M.S.
Richard S. Naylor, B.S.
Richard J. O'Connell, B.S.
Christopher Phelps, B.S.
Alan O. Ramo, M.S.
Charles F. Raymond, A.B.
David J. Roddy, M.S.
Samuel M. Savin, B.A.
Kenneth D. Schmidt, B.S.
Yuch-ning Shieh, B.S.
Douglas Smith, M.A.
Hartmut A. Spetzler, M.S.
Robert J. Tait, B.S.
Ta-liang Teng, B.S.
Lawrence S. Turnbull, B.A.
David B. Wenner, B.S.
Stephen Wolfe, B.A.
Francis T. Wu, B.S.

Division of the Humanities

Hallett D. Smith, *Chairman*

PROFESSOR EMERITUS

George R. MacMinn, A.B. .... *English*

PROFESSORS

J. Kent Clark, Ph.D. .... *English*
Harvey Eagleson, Ph.D. .... *English*
David C. Elliot, Ph.D. .... *History*
Horace N. Gilbert, M.B.A. .... *Business Economics*
Robert D. Gray, B.S. .... *Economics and Industrial Relations*
Edwin S. Munger, Ph.D. .... *Geography*
Rodman W. Paul, Ph.D. .... *History*
Hallett D. Smith, Ph.D. .... *English*
Roger F. Stanton, Ph.D. .... *English*
Alfred Stern, Ph.D. .... *Languages and Philosophy*
Alan R. Sweezy, Ph.D. .... *Economics*
Ray E. Untereiner, Ph.D. .... *Economics*

ASSOCIATE PROFESSORS

Paul Bowerman, A.M. .... *Modern Languages*
Melvin D. Brockie, Ph.D. .... *Economics*
Charles E. Bures, Ph.D. .... *Philosophy*
Paul C. Eaton, A.M. .... *English*
Heinz E. Ellersieck, Ph.D. .... *History*
Peter W. Fay, Ph.D.* .... *History*
Robert A. Huttenback, Ph.D. .... *History*
L. Winchester Jones, A.B. .... *English*
Beach Langston, Ph.D. .... *English*
Oscar Mandel, Ph.D. .... *English*
George P. Mayhew, Ph.D. .... *English*
Robert W. Oliver, Ph.D. .... *Economics*
John R. Weir, Ph.D. .... *Psychology*

ASSISTANT PROFESSORS

John F. Benton, Ph.D. .... *History*
William R. Cozart, Ph.D. .... *English*
Daniel J. Kevles, Ph.D. .... *History*
Thayer Scudder, Ph.D. .... *Anthropology*
David R. Smith, Ph.D* .... *English*
Robert D. Wayne, M.A. .... *German*

LECTURERS

Charles K. Ferguson, Ed.D. .... *Psychology*
Dorothy H. Guyot, M.A. .... *Political Science*
Edward Hutchings, Jr., B.A. .... *Journalism*
Peter M. Miller, Ph.D. .... *English*
Roman Novins, M.A. .... *Russian*
Orpha C. Ochse, Ph.D. .... *Music*
Anita Mason, Lic. ès Lettres .... *French*
Robert R. Wark, Ph.D. .... *Art*

*On leave of absence 1965-66

VISITING LECTURERS

Alan W. Horton, Ph.D.	*International Affairs*
Richard W. Patch, Ph.D.	*International Affairs*
Lawrence Olson, Ph.D.	*International Affairs*
Albert Ravenholt	*International Affairs*

INSTRUCTORS

Herbert W. Booth, M.A.	*Speech*
John F. Crawford, M.A.	*English*
Byrd L. Jones, B.A.	*History*
Roger Noll, B.S.	*Economics*
Robert L. Woodbury, M.A.	*History*
John S. Zeigel, M.A.	*English*

RESEARCH ASSISTANT

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

Division of Physics, Mathematics and Astronomy

Carl D. Anderson, *Chairman*
H. F. Bohnenblust, *Executive Officer*
Jesse L. Greenstein, *Executive Officer*
Gordon J. Stanley, *Director, Owens Valley Radio Observatory*

PROFESSORS EMERITI

Jesse W. M. DuMond, Ph.D. .... *Physics*
Paul S. Epstein, Ph.D. .... *Theoretical Physics*
C. C. Lauritsen, Ph.D., L.L.D. .... *Physics*
William R. Smythe, Ph.D. .... *Physics*
Earnest C. Watson, Sc.D. .... *Physics*

PROFESSORS

Carl D. Anderson, Ph.D., Sc.D., LL. D., Nobel Laureate .... *Physics*
Tom M. Apostol, Ph.D. .... *Mathematics*
Robert F. Bacher, Ph.D., Sc.D. .... *Physics*
Charles A. Barnes, Ph.D. .... *Physics*
Felix H. Boehm,* Ph.D. .... *Physics*
H. F. Bohnenblust, Ph.D. .... *Mathematics*
Robert F. Christy, Ph.D. .... *Theoretical Physics*
Eugene W. Cowan, Ph.D. .... *Physics*
Leverett Davis, Jr., Ph.D. .... *Theoretical Physics*
Charles R. DePrima, Ph.D. .... *Mathematics*
Robert P. Dilworth, Ph.D. .... *Mathematics*
Richard P. Feynman, Ph.D., F.R.S.
Richard Chace Tolman Professor of Theoretical Physics
William A. Fowler, Ph.D. .... *Physics*
Adriano M. Garsia, Ph.D. .... *Mathematics*
Murray Gell-Mann, Ph.D., Sc.D. .... *Theoretical Physics*
Roy W. Gould, Ph.D. .... *Electrical Engineering and Physics*
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W. A. J. Luxemburg,** Ph.D. .... *Mathematics*
Guido Münch, Ph.D. .... *Astronomy*
H. Victor Neher, Ph.D. .... *Physics*
J. Beverley Oke, Ph.D. .... *Astronomy*
Maarten Schmidt, Ph.D. .... *Astronomy*
Richard M. Sutton, Ph.D. .... *Physics*
John Todd, B.Sc. .... *Mathematics*
Alvin V. Tollestrup, Ph.D. .... *Physics*
Robert L. Walker, Ph. D. .... *Physics*
Ward Whaling, Ph.D. .... *Physics*
Gerald B. Whitham, Ph.D., F.R.S. .... *Aeronautics and Mathematics*
Harold Zirin, Ph.D. .... *Astrophysics*
Fritz Zwicky, Ph.D. .... *Astrophysics*

VISITING PROFESSORS

Reimar Lüst, Ph.D. .... *Astrophysics*
Rudolf L. Mössbauer, Ph.D., Sc.D., Nobel Laureate .... *Physics*

*On leave of absence, 1965-66
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B.S., California Institute, 1921; Ph.D., 1924. Research Fellow, 1924-28; International Research Fellow, 1928-29; Assistant Professor, 1929-38; Associate Professor, 1938-45; Professor, 1945-. (154 Crellin) 1963 New York Drive, Altadena.

John Norris Bahcall, Ph.D., *Assistant Professor of Theoretical Physics*
A.B., University of California, 1956; M.A., University of Chicago, 1957; Ph.D., Harvard University, 1960. Research Fellow in Physics, California Institute, 1962-63; Senior Research Fellow, 1963-65; Assistant Professor of Theoretical Physics, 1965-. (204 Kellogg) 188 South Catalina Avenue, Apt.2.

James Maxwell Bardeen, Ph.D., *Research Fellow in Physics*
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Frederick Charles Barker, Ph.D., *Visiting Associate in Physics*
B.Sc., University of Melbourne, 1945; M.Sc., 1947; Ph.D., University of Birmingham, 1949. Senior Fellow, Australian National University (Canberra), 1960. California Institute, 1964-65.

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Charles Andrew Barnes, Ph.D., *Professor of Physics*
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William Alvin Baum, Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
B.A., University of Rochester, 1943; M.S., California Institute, 1945; Ph.D., 1950. Mt. Wilson and Palomar Observatories, 1950-. (Mt. Wilson Office) 1908 North Grand Oaks, Altadena.

Victor Hugo Benioff, Ph.D., *Professor of Seismology, Emeritus*
A.B., Pomona College, 1921; Ph.D., California Institute, 1935. Assistant Professor, 1937; Associate Professor, 1937-50; Professor, 1950-64. Professor Emeritus, 1964-. P.O. Box 468, Mendocino, California.

Ari Ben-Menahem, Ph.D., *Senior Research Fellow in Geophysics*
M.S., Hebrew University, 1954; Ph.D., California Institute, 1961. Research Fellow, 1961-64. Senior Research Fellow, 1964-. (Seismological Lab) 535 South Oakland.

**Part-time

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B.S., University of Connecticut, 1953; M.S., Purdue University, 1955; Ph.D., 1958. Research Chemist, National Institutes of Health, 1963-. California Institute, 1964-66. (013 Kerckhoff) 623 North Marengo.

David John Benney, Ph.D., *Visiting Associate in Engineering*
B.Sc., Victoria University College, New Zealand; 1951; M.S., 1952; B.A., University of Cambridge, 1954; M.A., 1957; Ph.D., Massachusetts Institute of Technology, 1959. Associate Professor of Mathematics, Massachusetts Institute of Technology, 1963-. California Institute, 1964-65.

John F. Benton, Ph.D., *Assistant Professor of History*
B.A., Haverford College, 1953; M.A., Princeton University, 1955; Ph.D., 1959. California Institute, 1965-. (Dabney) 6457 North Lemon Avenue, San Gabriel.

Giovanni Berlucchi, M.D., *Research Fellow in Biology*
M.D., University of Pavia, 1960. California Institute, 1964-65.

Paul Joseph Berry, Ph.D., *Research Fellow in Chemistry*
B.Sc., St. Francis Xavier University, 1952; Ph.D., University of Notre Dame, 1955; B.Th., St. Michael's College, University of Toronto, 1958. California Institute, 1964-65.

Eric Betz, Ph.D., *Research Fellow in Aeronautics*
A.E.T.C., Sydney Technical College, 1941; M.E., University of New South Wales, 1957; Ph.D., 1965. California Institute, 1965-66. (217 Firestone) 1435 Las Lunas Street.

Mark Conrad, Biedebach, Ph.D., *Research Fellow in Electrical Engineering*
B.E., University of Southern California, 1956; M.S., 1958; Ph.D., University of California (Los Angeles), 1964. California Institute, 1964-65.

Shawn Biehler, Ph.D., *Research Fellow in Geophysics*
B.S., Princeton University, 1958; M.S., California Institute, 1961; Ph.D., 1964. Research Fellow, 1964-. (Seismological Lab) 919 East Wapello Street, Altadena.

Amilcare Bietti, Laurea, *Research Fellow in Theoretical Physics*
Laurea, University of Rome, 1960. California Institute, 1964-65.

David Morison Binnie, Ph.D., *Research Fellow in Physics*
B.S., Manchester University, 1952; Ph.D., 1956. Lecturer, Imperial College, London, 1961-. California Institute, 1965-66. (Synchrotron).

Paul J. Blatz, Ph.D., *Associate Professor of Materials Science*
B.S., Fordham University, 1944; Ph.D., Princeton University, 1957. Research Fellow in Aeronautics, California Institute, 1958-59; Senior Research Fellow, 1959-63; Senior Research Fellow in Materials Science, 1963-64; Associate Professor, 1964-. (237 Keck) 156 West 7th Avenue, Claremont.

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

Henri Frederic Bohnenblust, Ph.D., *Professor of Mathematics; Dean of Graduate Studies; Executive Officer, Division of Physics, Mathematics, and Astronomy*
A.B., Federal Institute of Technology, Zurich, 1928; Ph.D., Princeton University, 1931. Professor, California Institute, 1946-. Dean of Graduate Studies, 1956-; Executive Officer, 1964-. (114 Throop; 288 Sloan) 1798 North Pepper Drive, Altadena.

James Frederic Bonner, Ph.D., *Professor of Biology*
A.B., University of Utah, 1931; Ph.D., California Institute, 1934. Research Assistant, 1935-36; Instructor, 1936-38; Assistant Professor, 1938-42; Associate Professor, 1942-46; Professor, 1946-. (128 Kerckhoff) 1740 Homet Road.

Herbert Wesley Booth, M.A., *Instructor in Speech*
B.A., Los Angeles State College, 1954; M.A., 1955. California Institute, 1962-. (306 Dabney) 7080 East Schroll Street, Lakewood.

Henry Borsook, Ph.D., M.D., *Professor of Biochemistry*
Ph.D., University of Toronto, 1924; M.B., 1927; M.D., 1940. Assistant Professor, California Institute, 1929-35; Professor, 1935-. (226 Kerckhoff) 1121 Constance Street.

Arthur James Boucot, Ph.D., *Associate Professor of Paleontology*
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*Leave of absence, 1965-66

Ira Sprague Bowen, Ph.D., Sc.D., *Distinguished Service Staff Member, Mount Wilson and Palomar Observatories*
A.B., Oberlin College, 1919; Ph.D., California Institute, 1926. Instructor, 1921-26; Assistant Professor, 1926-28; Associate Professor, 1928-31; Professor, 1931-45; Director, Mt. Wilson and Palomar Observatories, 1946-64; Distinguished Service Staff Member, 1964-. (Mt. Wilson Office) 2388 North Altadena Drive, Altadena.

Paul Bowerman, A.M., *Associate Professor of Modern Languages*
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David John Braverman,* Ph.D., *Associate Professor of Electrical Engineering*
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Volkmar Braun, D.Sc., *Research Fellow in Chemistry*
D.Sc., University of Munich, 1965. California Institute, 1965-66. (102 Church) 376 South Oakland Avenue.

Melvin David Brockie, Ph.D., *Associate Professor of Economics*
B.A., University of California (Los Angeles), 1942; M.A., 1944; Ph.D., 1948. Instructor, California Institute, 1947-49; Assistant Professor, 1949-53; Associate Professor, 1953-. (10 Dabney) 1730 North Roosevelt Avenue, Altadena.

Charles Jacob Brokaw, Ph.D., *Associate Professor of Biology*
B.S., California Institute, 1955; Ph.D., Cambridge University, 1958. Visiting Assistant Professor, California Institute, 1960; Assistant Professor, 1961-63; Associate Professor, 1963-. (07 Kerckhoff) 301 Iris Street, Corona del Mar.

Norman Herrick Brooks, Ph.D., *Professor of Civil Engineering*
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Archibald Brown, Ph.D., *Visiting Associate in Aeronautics*
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Harrison Scott Brown, Ph.D., Sc.D., LL.D., *Professor of Geochemistry*
B.S., University of California, 1938; Ph.D., Johns Hopkins University, 1941; LL.D., University of Alberta, 1960; Sc.D., Rutgers University, 1964. California Institute, 1951-. (014 Mudd) 5155 Stoneglenn Road, La Cañada.

Morris Brown, Ph.D., *Assistant Professor of Organic Chemistry*
B.S., University of Michigan, 1959; M.S., University of Wisconsin, 1960; Ph.D., Stanford University, 1962. A.A. Noyes Research Instructor in Chemistry, California Institute, 1963-65; Assistant Professor, 1965-. (351 Crellin) 195 South Wilson Avenue, Apt. 21.

James N. Brune, Ph.D., *Associate Professor of Geophysics*
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Edwin Raphael Buchman, D.Phil.Nat., *Research Associate in Organic Chemistry*
Ch.E., Rensselaer Polytechnic Institute, 1922; S.M., Massachusetts Institute of Technology, 1925; Dr.Phil.Nat., University of Frankfurt, 1933. Research Fellow, California Institute, 1937-38; Research Associate, 1938-. (254 Crellin) 446 Devonwood Drive, Altadena.

Francis Stephan Buffington, Sc.D., *Associate Professor of Materials Science*
S.B., Massachusetts Institute of Technology, 1938; Sc.D., 1951. Assistant Professor of Mechanical Engineering, California Institute, 1951-56; Associate Professor, 1956-63; Associate Professor of Materials Science, 1963-. (309 Keck) 1644 Kaweah Drive.

Charles Edward Bugg, Ph.D., *Research Fellow in Chemistry*
B.A., Duke University, 1962; Ph.D., Rice University, 1965. California Institute, 1965-66. (208 Church) 195 South Wilson Avenue.

Charles E. Bures, Ph.D., *Associate Professor of Philosophy*
B.A., Grinnell College, 1933; M.A., University of Iowa, 1936; Ph.D., 1938. Assistant Professor, California Institute, 1949-53; Associate Professor, 1953-. (2 Dabney) 564 South Marengo Avenue.

*Leave of absence, 1965-66

Donald Stacy Burnett, Ph.D., *Assistant Professor of Nuclear Geochemistry*
B.S., University of Chicago, 1959; Ph.D., University of California, 1963. Research Fellow in Physics, California Institute, 1963-65; Assistant Professor of Nuclear Geochemistry, 1965-. (203 Kellogg) 505 Atchison Street.

Michael Cais, D.Sc., *Visiting Associate in Chemistry*
B.Sc., Leeds University, 1950; D.Sc., Technion, 1955. Associate Professor of Chemistry, Technion. California Institute, 1965-66.

Dan Hampton Campbell, Ph.D., Sc.D., *Professor of Immunochemistry*
A.B., Wabash College, 1930; M.S., Washington University, 1932; Ph.D., University of Chicago, 1936; Sc.D., Wabash College, 1960. Assistant Professor, California Institute, 1942-45; Associate Professor, 1945-50; Professor, 1950-. (307 Church) 1154 Mount Lowe Drive, Altadena.

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

Captain Warren J. Carter, B.A., *Assistant Professor of Aerospace Studies*
B.A., University of Oregon, 1955. California Institute, 1964-. (Building T-1) 1499 Carroll Drive, Altadena.

Brian Case, Ph.D., *Research Fellow in Chemistry*
B.Sc., Bristol University, 1962; Ph.D., 1965. California Institute, 1965-66.

Thomas Kirk Caughey, Ph.D., *Professor of Applied Mechanics*
B.Sc., Glasgow University, 1948; M.M.E., Cornell University, 1952; Ph.D., California Institute, 1954. Instructor, 1953-54; Assistant Professor, 1955-58; Associate Professor, 1958-62; Professor, 1962-. (319 Thomas) 1938 Rose Villa Street.

George Roger Chalkley, Ph.D., *Research Fellow in Biology*
Ph.D., Oxford University, 1964. California Institute, 1964-. (024 Kerckhoff) 231 South Catalina Avenue.

David Cheong King Chan, Ph.D., *Research Fellow in Chemistry*
B.S., University of California, 1960; Ph.D., Purdue University, 1964. California Institute, 1965-66.

Sunney Ignatius Chan, Ph.D., *Associate Professor of Chemical Physics*
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Teh-Liang Chang, Ph.D., *Research Fellow in Chemistry*
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Martha Cowles Chase, Ph.D., *Research Fellow in Biology*
B.A., The College of Wooster, 1950; Ph.D., University of Southern California, 1964. California Institute, 1965-66. (272 Church) 1124 East Del Mar Boulevard, Apt. C.

Arthur Cherkin, Ph.D., *Research Fellow in Biology*
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Thomas Hamilton Chilton,** D.Sc., *Visiting Professor of Chemical Engineering*
Ch.E., Columbia University, 1922; D.Sc., University of Delaware, 1943. California Institute, 1965.

Per Rex Christensen, Mag.Scient., *Research Fellow in Physics*
Mag. Scient., University of Copenhagen, 1960. Staff Member, Institute for Theoretical Physics, University of Copenhagen, 1963-. California Institute, 1965-66. (03 Kellogg) 50 West Palm Street, Altadena.

Robert Frederick Christy, Ph.D., *Professor of Theoretical Physics*
B.A., University of British Columbia, 1935; Ph.D., University of California, 1941. Associate Professor, California Institute, 1946-50; Professor, 1950-. (164 Sloan) 1330 South Euclid Avenue.

Donald Sherman Clark, Ph.D., *Professor of Physical Metallurgy; Director of Placements*
B.S., California Institute, 1929; M.S., 1930; Ph.D., 1934. Instructor, California Institute, 1934-37; Assistant Professor, 1937-45; Associate Professor, 1945-51; Professor, 1951-. (24 Throop) 1066 San Pasqual Street.

**Part-time

J. Kent Clark, Ph.D., *Professor of English*
A.B., Brigham Young University, 1939; Ph.D., Stanford University, 1950; Instructor, California Institute, 1947-50; Assistant Professor, 1950-54; Associate Professor, 1954-60; Professor, 1960-. (303 Dabney) 473 Fillmore Street.

William Edwin Clark, Ph.D., *Ford Foundation Research Fellow in Mathematics*
B.A., Sam Houston State Teachers College, 1960; Ph.D., Tulane University, 1964. California Institute, 1964-65.

Donald S. Cohen, Ph.D., *Assistant Professor of Mathematics*
M.A., Cornell University, 1959; Ph.D., New York University (Courant Institute), 1962. California Institute, 1965-.

Emanuel Richard Cohen,** Ph.D., *Research Associate in Engineering Science*
A.B., University of Pennsylvania, 1943; M.S., California Institute, 1946; Ph.D., 1949. Associate Director, North American Aviation Science Center, 1964-. Senior Lecturer, California Institute, 1962-63; Research Associate, 1964-. (229 Thomas) 4633 White Oak Place, Encino.

Marshall Harris Cohen, Ph.D., *Visiting Associate Professor of Radio Astronomy*
B.E.E., Ohio State University, 1948; M.S., 1949; Ph.D., 1952. Associate Professor of Astronomy, Cornell University, 1964-. California Institute, 1965.

Giles Roy Cokelet, Sc.D., *Assistant Professor of Chemical Engineering*
B.S., California Institute, 1957; M.S., 1958; Sc.D., Massachusetts Institute of Technology, 1963. California Institute, 1964-. (217 Spalding) 413 Mariposa, Sierra Madre.

Julian David Cole, Ph.D., *Professor of Aeronautics*
B.M.E., Cornell University, 1944; M.S., California Institute, 1946; Ph.D., 1949. Research Fellow, 1949-51; Assistant Professor, 1951-55; Associate Professor, 1955-59; Professor, 1959-. (309 Firestone) 3447 Glenrose Avenue, Altadena.

Donald Earl Coles, Ph.D., *Professor of Aeronautics*
B.S., University of Minnesota, 1947; M.S., California Institute, 1948; Ph.D., 1953. Research Fellow, 1953-55; Senior Research Fellow, 1955-56; Assistant Professor, 1956-59; Associate Professor, 1959-64; Professor, 1964-. (306 Karman) 1033 Alta Pine Drive, Altadena.

Ralph Porter Collins, Ph.D., *Research Fellow in Biology*
B.A., Michigan State University, 1950; M.S., 1952; Ph.D., 1957. Associate Professor, University of Connecticut, 1964-. California Institute, 1964-65.

Peter Selby Conti, Ph.D., *Research Fellow in Astrophysics*
B.S., Rensselaer Polytechnic Institute, 1956; Ph.D., University of California, 1963. California Institute, 1963-. (201 Robinson) 145 West Purple Sage Lane, Altadena.

Frederick James Converse, B.S., *Professor of Soil Mechanics, Emeritus*
B.S., University of Rochester, 1914. Instructor, California Institute, 1921-33; Assistant Professor, 1933-39; Associate Professor, 1939-47; Professor, 1947-62; Professor Emeritus, 1962-. (107 Thomas) 1416 Wembley Road, San Marino.

William Harrison Corcoran, Ph.D., *Professor of Chemical Engineering*
B.S., California Institute, 1941; M.S., 1942; Ph.D., 1948. Associate Professor, 1952-57; Professor, 1957-. (215 Spalding) 8353 Longden Avenue, San Gabriel.

Robert Brainard Corey, Ph.D., D.Sc., *Professor of Structural Chemistry*
B. Chem., University of Pittsburgh, 1919; Ph.D., Cornell University, 1924. D.Sc., University of Pittsburgh, 1964. Senior Research Fellow, California Institute, 1937-46; Research Associate, 1946-49; Professor, 1949-. (215 Church) 352 South Parkwood Avenue.

Eugene Woodville Cowan, Ph.D., *Professor of Physics*
B.S., University of Missouri, 1941; M.S., Massachusetts Institute of Technology, 1943; Ph.D., California Institute, 1948. Research Fellow, 1948-50; Assistant Professor, 1950-54; Associate Professor, 1954-61; Professor, 1961-. (350 West Bridge) 2215 Monte Vista Street.

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

John Franklin Crawford, M.A., *Instructor in English*
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Peter Linton Crawley, Ph.D., *Associate Professor of Mathematics*
B.S., California Institute, 1957; Ph.D., 1961. Assistant Professor, 1963-65; Associate Professor, 1965-. (374 Sloan) 3570 Landfair Road.

Fred E. C. Culick, Sc.D., *Assistant Professor of Jet Propulsion*
S.B., S.M., Massachusetts Institute of Technology, 1957; Sc.D., 1961. Research Fellow, California Institute, 1961-63; Assistant Professor, 1963-. (204 Karman) 983 East Howard Street.

**Part-time

Everett Clarence Dade, Ph.D., *Associate Professor of Mathematics*
A.B., Harvard University, 1958; Ph.D., Princeton University, 1960. Bateman Research Fellow, California Institute, 1960-62; Assistant Professor, 1962-64; Associate Professor, 1964-. (274 Sloan) 413 South Hudson Avenue.

Ivan John Danziger, Ph.D., *Research Fellow in Astrophysics*
B.S., University of Queensland, 1958; M.Sc., 1960; Ph.D., Australian National University, 1963. California Institute, 1964-. (203 Robinson) 708 South Lake Avenue.

Manik Lal Das, D.Phil., *Research Fellow in Chemistry*
B.Sc., Calcutta University, 1951; M.Sc., 1954; D.Phil., 1959. California Institute, 1964-65.

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M.S., Calcutta University, 1940; Ph.D., University of Liverpool, 1952. California Institute, 1961-. (329 Keck) 1799 East Atchison Street.

Roger Fred Dashen, Ph.D., *Assistant Professor of Theoretical Physics*
A.B., Harvard College, 1960; Ph.D., California Institute, 1964. Research Fellow, 1964-65; Assistant Professor, 1965- (155 Sloan) 765 Alta Vista Drive, Sierra Madre.

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-. (115 Thomas) 373 South Euclid Avenue.

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-. (021 Church) 318 East Laurel Avenue, Sierra Madre.

Craig H. Davis, Ph.D., *Research Fellow in Biology*
Ph.D., University of Washington, 1965. California Institute, 1965-66.

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-. (104 East Bridge) 1772 North Grand Oaks Avenue, Altadena.

Richard Albert Dean, Ph.D., *Associate Professor of Mathematics*
B.S., California Institute, 1945; A.B., Denison University, 1947; M.S., Ohio State University, 1948; Ph.D., 1953. Bateman Research Fellow, California Institute, 1954-55; Assistant Professor, 1955-59; Associate Professor, 1959-. (358 Sloan) 2186 Lambert Drive.

Max Delbrück, Ph.D., *Professor of Biology*
Ph.D., University of Göttingen, 1931. Research Fellow, California Institute, 1937-39; Professor, 1947-. (82 Alles) 1510 Oakdale Street.

Sei-Ichi-Denda, Dr.Eng., *Research Fellow in Electrical Engineering*
B.E., Shinsyu University, 1954; Dr. Eng., Tohoku University, 1964. Technical Officer, Electrotechnical Laboratory, Tokyo, 1954-. California Institute, 1964-65.

Edwin Walter Dennison, Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
B.A., Swarthmore College, 1949; M.A., University of Michigan, 1952; Ph.D., 1954. California Institute, 1963-. (010 Robinson) 1277 Boston Street, Altadena.

Charles Raymond DePrima, 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- (278 Sloan) 3791 Hampstead Road.

Armin Joseph Deutsch, Ph.D., *Staff Member, Mount Wilson and Palomar Observatories*
B.S., University of Arizona, 1940; Ph.D., University of Chicago, 1946. Mt. Wilson and Palomar Observatories, 1951-. (Mt. Wilson Office) 625 Coleman, Altadena.

Robert J. Dickens, B.S., *Research Fellow in Astronomy*
B.Sc., University of London, 1957. Scientific Officer, Royal Greenwich Observatory. California Institute, 1965-66.

Richard Earl Dickerson, Ph.D., *Associate Professor of Physical Chemistry*
B.S., Carnegie Institute of Technology, 1953; Ph.D., University of Minnesota, 1957. Associate Professor, California Institute, 1963-. (201 Church) 1661 Rose Villa Street.

Frank Sigel Dietrich III, Ph.D., *Research Fellow in Physics*
B.A., Haverford College, 1959; Ph.D., California Institute, 1964. Research Fellow, 1964.

Robert Palmer Dilworth, Ph.D., *Professor of Mathematics*
B.S., California Institute, 1936; Ph.D., 1939. Assistant Professor, California Institute, 1943-45; Associate Professor, 1945-51; Professor, 1951-. (286 Sloan) 3121 Doyne Road.

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B.S., California Institute, 1927; A.M., Rice Institute, 1928; Ph.D., 1931. Associate Professor, California Institute, 1948-54; Professor, 1954-. (315 Mudd) 1506 Ramona Avenue, South Pasadena.

Yossef Dothan, Ph.D., *Research Fellow in Theoretical Physics*
M.S., The Hebrew University, Jerusalem, 1962; Ph.D., 1965. California Institute, 1964-. (155 Sloan) 296 North Oakland Avenue.

Robert James Drewer, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Adelaide, 1961; Ph.D., 1964. California Institute, 1964-. (Crellin) 382 North Chester Avenue.

William Jakob Dreyer, Ph.D., *Professor of Biology*
B.A., Reed College, 1952; Ph.D., University of Washington, 1956. California Institute, 1963-. (271 Church) 2369 Highland Avenue, Altadena.

Henry Dreyfuss, *Associate in Industrial Design*
California Institute, 1947-. 500 Columbia Street, South Pasadena.

Robert Brown Drysdale, M.S., *Gosney Research Fellow in Biology*
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Jean Ture Leonard Dubois, Ph.D., *Research Fellow in Physics*
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(See page 40.)

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Daniele Annick Durand,** B.A., *Lecturer in French*
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Pol Edgard Duwez, D.Sc., *Professor of Materials Science*
Metallurgical Engineer, School of Mines, Mons, Belgium, 1932; D.Sc., University of Brussels, 1933. Research Engineer, California Institute, 1942-47; Associate Professor, 1947-52; Professor, 1952-. (305 Keck) 1535 Oakdale Street.

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Lyndsay Gordon Earwaker, Ph.D., *Research Fellow in Physics*
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Paul Conant Eaton, A.M., *Associate Professor of English; Dean of Students*
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Robert Stuart Edgar, Ph.D., *Associate Professor of Biology*
B.Sc., McGill University, 1953; Ph.D., University of Rochester, 1957. Research Fellow, California Institute, 1957; 1958-60; Assistant Professor, 1960-63; Associate Professor, 1963-. (59 Church) 2255 East Oakwood Street.

Heinz E. Ellersieck, Ph.D., *Associate Professor of History*
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David Clephan Elliot, Ph.D., *Professor of History*
M.A., St. Andrew's University, 1939; A.M., Harvard University, 1948; Ph.D., 1951. Assistant Professor, California Institute, 1950-53; Associate Professor, 1953-60; Professor, 1960-. (4 Dabney) 770 Arden Road.

**Part-time

Albert Tromley Ellis, Ph.D., *Associate Professor of Applied Mechanics*
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Sterling Emerson, Ph.D., *Professor of Genetics*
B.Sc., Cornell University, 1922; M.A., University of Michigan, 1924; Ph.D., 1928. Assistant Professor of Genetics, California Institute, 1928-37; Associate Professor, 1937-46; Professor, 1946-. (200 Kerckhoff) 1207 Morada Place, Altadena.

Warren G. Emery, M.S., *Director of Physical Education and Athletics*
B.S., University of Nebraska, 1948; M.S., University of California (Los Angeles), 1959. Coach, California Institute, 1955; Assistant Director, 1963-64; Director, 1964-. (Gymnasium) 1667 Kaweah Drive.

Paul Sophus Epstein, Ph.D., *Professor of Theoretical Physics, Emeritus*
B.Sc., Moscow University, 1906; M.Sc., 1909; Ph.D., University of Munich, 1914. Professor, California Institute, 1921-53; Professor Emeritus, 1953-. (109 E. Bridge) 1484 Oakdale Street.

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B.A., Amsterdam University, 1925; M.A. 1928; Ph.D., 1929; M.D., 1931. Research Assistant, California Institute, 1934-35; Instructor, 1935-40; Assistant Professor, 1940-42; Associate Professor, 1942-47; Professor, 1947-. (324 Kerckhoff) 764 South Oakland Avenue.

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David Shotwell Wood, Ph.D., *Professor of Materials Science*
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Laszlo Zechmeister, Dr.Ing., *Professor of Organic Chemistry, Emeritus*
Diploma of Chemist, Eidgenossische Technische Hochschule, Zurich, 1911; Dr.Ing., 1913. Professor, California Institute, 1940-59; Professor Emeritus, 1959-. (113 Church) 1122 Constance Street.

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B.S., Worcester Polytechnic Institute, 1964

Gerassimós George Aperghis, *Graduate Research Assistant,* Civil Engineering*
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Gerald Richard Ash, *Consolidated Electrodynamics Fellow, Electrical Engineering*
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B.S., California Institute, 1958; M.S., 1959

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Phillip John Chase, *Graduate Research Assistant,* Mathematics*
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B.S., Taiwan Provincial Taipei Institute of Technology, 1958; M.S., California Institute, 1962

Shieu-lang Cheng, *Graduate Teaching Assistant, Dobbins Scholar, Chemistry*
B.S., National Taiwan University, 1963

Ronald Benjamin Chesler, *Graduate Research Assistant, Laws Scholar, Physics*
A.B., University of Pennsylvania, 1961

Arthur Noble Chester, *Howard Hughes Fellow, Physics*
B.S., University of Texas, 1961

Man-Choeng Cheung, *Anthony Scholar, Aeronautics*
B.S., Taiwan Provincial Cheng Kung University, 1964

José Chirivella-Casanova, *National Aeronautics and Space Administration International Fellow, Aeronautics*
Ing., Escuela Técnica Superior de Ingenieros Aeronáuticos (Madrid), 1964

Charles Richard Christensen, *Graduate Teaching Assistant,* Chemistry*
B.E., Vanderbilt University, 1960

Joseph Herman Christie, *North American Aviation Fellow, Chemistry*
B.S., Rensselaer Polytechnic Institute, 1959; M.S., Louisiana State University, 1962

George Richmond Clark II, *Graduate Teaching Assistant,* Geology*
A.B., Cornell University, 1961

Milton John Clauser, *National Science Foundation Fellow, Physics*
S.B., Massachusetts Institute of Technology, 1961

Don Paul Clausing, *National Science Foundation Co-operative Fellow, Materials Science*
B.S., Iowa State University, 1962; M.S., California Institute, 1962

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B.Sc., McGill University, 1963

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B.S., University of Washington, 1959

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B.Ch.E., Pratt Institute, 1964

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Donald Gerald Coyne, *Mayr Foundation Fellow, Graduate Teaching Assistant, Physics*
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B.S., University of California (Los Angeles), 1961

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B.S., United States Air Force Academy, 1964

Oakley Hamilton Crawford, *Graduate Research Assistant, Laws Scholar, Chemistry*
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Donald Leslie Cronin, *Graduate Research Assistant,* Mechanical Engineering*
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William Michael Denny, *Graduate Research Assistant, Murray Scholar, Physics*
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B.A., Pomona College, 1961

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B.E.S., University of Florida, 1964

Assadour Hagop Hadjian, *Drake Scholar, Civil Engineering*
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Ralph Stuart Hager, *Graduate Research Assistant, Murray Scholar, Physics*
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Thomas Arthur Halgren, *Graduate Teaching Assistant, Murray Scholar, Chemistry*
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Lawrence William Hallanger, *United States Steel Foundation Fellow, Applied Mechanics*
B.S., Harvey Mudd College, 1961; M.S., California Institute, 1962

David Marvin Hanson, *Graduate Teaching Assistant, Murray Scholar, Chemistry*
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B.S., University of Minnesota, 1957; M.S.C.E., 1958

Roy Woodrow Harding, Jr., *Graduate Teaching Assistant, Leonard Scholar, Biology*
B.S., George Washington University, 1962

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B.S., West Virginia University, 1963

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B.Sc., Mount Allison University (Canada), 1958; B.Sc. (Spec.), Imperial College of Science and Technology (University of London), 1960

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B.E., Nagoya University (Japan), 1962; M.E., 1964

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B.S., Tufts University, 1959

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B.A., University of California (Santa Barbara), 1962

Edward Gerald Hauptmann, *Shell Companies Foundation Fellow, Mechanical Engineering*
B.Sc., University of Alberta, 1960; M.S., California Institute, 1961

Michael George Hauser, *National Science Foundation Fellow, Physics*
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Denis Robert Hayner, *Graduate Teaching Assistant,* Mechanical Engineering*
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Mathilde Jeannette Hebb, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*
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B.S., Webb Institute of Naval Architecture, 1964

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Robert Jack Hemstead, *Woodrow Wilson Foundation Fellow, Mathematics*
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B.A.E., University of Virginia, 1959; B.E.E., 1960; M.A.E., 1961

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Floyd Leigh Herbert, *Graduate Research Assistant,* Astronomy*
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Robert Henry Hertel, *Graduate Research Assistant,* Electrical Engineering*
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B.S., University of Oklahoma, 1952; M.S., 1954

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James Henry Nelson, *Graduate Teaching Assistant, Murray Scholar, Chemistry*
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John Edward Newbold, *Graduate Teaching Assistant, Dobbins Scholar, Biology*
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B.Sc., University of Allahabad, 1955; B.E., University of Roorkee, 1958;
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Maurice Joseph Nugent, Jr., *Graduate Research Assistant,* Chemistry*
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Richard John O'Connell, *Graduate Research Assistant, Murray Scholar, Geology*
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Robert West O'Connell, *National Science Foundation Fellow, Astronomy*
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B.S., University of the Philippines, 1960; B.S.Chem., 1961

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Stephen Charles Smith, *Graduate Teaching Assistant,* Chemistry*
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Kwan-lok So, *National Science Foundation Trainee, Aeronautics*
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B.S., California Institute, 1957

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B.S., Trinity University, 1961; M.S., 1962

Robert John Spiger, *National Science Foundation Co-operative Fellow, Graduate Teaching Assistant, Physics*
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James Henry Strauss, Jr., *United States Public Health Service Fellow, Blacker Scholar, Biology*
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Alvah Thomas Strickland, *National Science Foundation Trainee, Mechanical Engineering*
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B.S., Wayne State University, 1964

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B.E. (Hons), University of Auckland, 1961; M.E., 1962

Bob Hiro Suzuki, *National Aeronautics and Space Administration Trainee, Aeronautics*
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Jerold Lindsay Swedlow, *Dobbins Scholar, Aeronautics*
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Robert James Tait, *Graduate Research Assistant, Anthony Scholar, Geology*
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Richard Forsythe Taylor, *Woodrow Wilson Foundation Fellow, Mathematics*
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Stephen Ilott Taylor, *Graduate Teaching Assistant,* Civil Engineering*
B.A.Sc., University of British Columbia, 1963

Richard King Teague, *Graduate Teaching Assistant,* Chemical Engineering*
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John Burgess Trenholme, *International Cooperation Administration Fellow, Materials Science*
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B.Eng., McGill University, 1963

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B.S., Swarthmore College, 1964

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B.S., University of Arizona, 1964

Martin Eric Weiner, *National Science Foundation Trainee, Materials Science*
B.S., California Institute, 1964

Robert William Weinman, *Graduate Teaching Assistant,* Physics*
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B.S., University of Illinois, 1963

John Campbell Wells, *National Science Foundation Fellow, Physics*
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B.S., University of Cincinnati, 1963

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Dipl., University of Heidelberg, 1964

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Ing., Technological University of Delft, 1964

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B.S., Yale University, 1963

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John Michael White, *Graduate Teaching Assistant,* Chemistry*
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B.Sc., Washington University, 1964

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B.S., California Institute, 1961

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B.S., Bucknell University, 1964

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B.S., The City College of New York, 1964

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

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Section II

GENERAL INFORMATION

THE California Institute of Technology is an independent, privately supported and privately controlled institution, officially classed as a university, carrying on undergraduate and graduate instruction and research, principally in the various fields of science and engineering.

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

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

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

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

Beginning in the fall of 1965, the Institute will also offer options toward the Bachelor of Science degree in the fields of English literature, history, and economics—subjects which are included in the Division of the Humanities. Students electing a humanities option will pursue the same curriculum as all other students during the freshman year, and will continue with the regular sophomore courses in mathematics, physics, and chemistry. During the last two years, they may specialize in a chosen field of humanities, 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. This combination of cultural and scientific training—first offered by the Institute in 1920—is now being followed by other leading institutions of science and engineering, for it provides students with the opportunity to prepare themselves to fulfill their responsibilities as citizens and members of the community.

It is in the Division of the Humanities that the Institute offers its work in nonscientific subjects, including literature, history, government, economics, philosophy, geography, psychology, and anthropology. All freshman and sophomore students take required courses in English literature and history, and a wide range of elective courses is available during the third and fourth years, to which juniors and seniors devote approximately one-quarter of their time. Those electing options in a humanities field will, of course, undertake more extensive work in their chosen subject and related subjects. Formal instruction in the humanities is supplemented by lectures and conferences with distinguished visiting scholars, some of whom are carrying on research at the Huntington Library and Art Gallery, and others, including scholars in international fields who are members of the American Universities Field Staff.

The Institute also encourages a reasonable participation in extracurricular activities, largely managed by the students themselves. These include student publications, debating, dramatics, music, and public affairs. All freshmen and sophomores are required to take physical education, and juniors and seniors may elect to take such work largely through participation in a well-rounded program of intercollegiate and intramural sports.

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

In the graduate section the Institute offers courses leading to the degree of Master of Science, which normally involves one year of graduate work; the engineer's degree in 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 the Institute. Graduate students constitute a comparatively large portion (over 50 percent) of the total student body. Engaged themselves on research problems of varying degrees of complexity, and taught by faculty members who are also actively engaged in research, they contribute materially to the general atmosphere of intellectual curiosity and creative activity which is engendered on the Institute campus.

In order to utilize Institute resources most effectively, two general lines of procedure are followed. First, the Institute restricts the number of fields in engineering and science in which it offers undergraduate and graduate study, believing that it is better to provide thoroughly for a limited number of curricula than to risk diffusion of personnel, facilities, and funds in attempting to cover a wide variety of fields. Second, and in line with this policy of conservation of resources, the student body is strictly limited to that number which can be satisfactorily provided for. The size of the undergraduate group is limited by the admission of 180 freshmen each September. Admission is granted, not on the basis of priority of application, but on a careful study of the merits of each applicant, including the results of competitive entrance examinations, high school records, and interviews by members of the Institute staff. Applicants for admission with advanced standing from other institutions and for admission to graduate study are given the same careful scrutiny. These procedures result, it is believed, in a body of students of exceptionally high ability. A high standard of scholarship is also maintained, as is appropriate for students of such high competence.

Pasadena is at the foot of the San Gabriel Mountains, 15 miles from Los Angeles. In the foreground, the Caltech campus.

HISTORICAL SKETCH

The California Institute of Technology, as it has been called since 1920, developed from a local school of arts and crafts, founded in Pasadena in 1891 by the Honorable Amos G. Throop and named, after him, Throop Polytechnic Institute. It had at first been called Throop University, but the title was soon considered too pretentious. The Institute included, during its first two decades, a college, a normal school, an academy, and, for a time, an elementary school and a commercial school. It enjoyed the loyal support of the citizens of Pasadena, and by 1908 the Board of Trustees had as members Dr. Norman Bridge, Arthur H. Fleming, Henry M. Robinson, J. A. Culbertson, C. W. Gates, and Dr. George Ellery Hale. It was the dedication, by these men, of their time, their brains, and their fortunes that transformed a modest vocational school into a university capable of attracting to its faculty some of the most eminent of the world's scholars and scientists. A statement in the Throop Institute Bulletin of December 1908 shows the situation at this time and the optimism of the friends of the Institute:

"Although Throop Institute requires from $80,000 to $90,000 a year to pay its operating expenses and meet its current obligations, the financial condition of the school was never sounder than at present. Its revenues are not sufficient to pay its expenses, but good friends are each year found willing and able to contribute to its deficiency fund. It is in the certainty of a continuance of this confidence in its work and mission that its officers and trustees are pressing forward toward a realization of larger plans for the Institute."

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

The realization of these aims meant specializing, so the Trustees decided in 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 after 1914 as Throop College of Technology, would have again raised its sights, leaving to others the training of mere efficient technicians and concentrating its own efforts on Roosevelt's "hundredth man." On November 29, 1921, the Trustees declared it to be the express policy of the Institute to pursue scientific researches of the greatest importance and at the same time, "to continue to conduct thorough courses in engineering and pure science, basing the work of these courses on exceptionally strong instruction in the fundamental sciences of mathematics, physics, and chemistry; broadening and enriching the curriculum by a liberal amount of instruction in such subjects as English, history, and economics; and vitalizing all the work of the Institute by the infusion in generous measure of the spirit of research."

Perhaps some causes of this change were the rapid growth of southern California between 1911 and 1921, the springing up everywhere of high schools and vocational schools which relieved Throop of some of its responsibilities, and the increasing public interest in scientific research as the implications of modern physics became better known. But the immediate causes of the change in the Institute at Pasadena were men. George Ellery Hale still held to his dream. Arthur Amos Noyes, Professor of Physical Chemistry and former Acting President of the Massachusetts Institute of Technology, served part of each year as Professor of General Chemistry and Research Associate from 1913 to 1919, when he resigned from M.I.T. to devote full time to Throop as Director of Chemical Research. In a similar way Robert Andrews Millikan began, in 1916-17, to spend a few months a year at Throop as Director of Physical Research. In 1921, when Dr. Norman Bridge agreed to provide a research laboratory in physics, Dr. Millikan resigned from the University of Chicago and became administrative head of the Institute as well as director of the Norman Bridge Laboratory. The name of the Institute was changed in 1920 to its present one.

The great period of the Institute's life began, then, under the guidance of three men of vision—Hale, Noyes, and Millikan. They were distinguished research scientists, and they soon attracted graduate students. In 1920 the enrollment was 9 graduate students and 359 undergraduates under a faculty of 60; a decade later there were 138 graduate students, 510 undergraduates, and a faculty of 180. At the present time there are about 700 undergraduates, 750 graduate students, and a faculty (including postdoctoral fellows) of about 600.

HALE

NOYES

MILLIKAN

The Institute also attracted financial support from individuals, corporations, and foundations. In January 1920 the endowment had reached half a million dollars. In February of that year it was announced that $200,000 had been secured for research in chemistry and a like amount for research in physics. Other gifts followed from Trustees and friends 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. (Within two years, if anyone had known where to look, he could have found four future Nobel Laureates on the campus.) He had attracted to the Institute such men as Charles Galton Darwin, Paul Epstein, and Richard C. Tolman. In 1924 the Ph.D. degree was awarded to nine candidates.

CALTECH'S NOBEL LAUREATES

Top row: Robert A. Millikan, Thomas Hunt Morgan, Carl D. Anderson, Linus Pauling, Edwin M. McMillan, William B. Shockley. Bottom row: George W. Beadle, Donald A. Glaser, Rudolf L. Mössbauer, and Charles H. Townes.

It was inevitable that the Institute would enlarge its field; it could not continue to be merely a research and instructional center in physics, chemistry, and engineering. But the Trustees pursued a cautious and conservative policy, not undertaking to add new departments except when the work done in them would be at the same high level as that in physics and chemistry. In 1925 a gift of $25,000 from the Carnegie Corporation of New York made possible the opening of a department of instruction and research in geology. A seismological laboratory was constructed, and Professors John P. Buwalda and Chester Stock came from the University of California to lead the work in the new division. Later gifts, especially from Mr. and Mrs. Allan C. Balch and the gift of the Arms and Mudd laboratories, contributed further to the establishment of the geological sciences at Caltech.

In 1928 the California Institute began its program of research and instruction in biology. There had been a chair of biology, named for Charles Frederick Holder, in the old Throop Institute, but it was not until the efforts of the C.I.T. Trustees, the General Education Board, the Carnegie Institution of Washington, and William G. Kerckhoff were combined that a program of research and teaching at the highest level was inaugurated. Thomas Hunt Morgan became the first chairman of the new Division of Biology and a member of the Executive Council of the Institute. Under Morgan's direction the work in biology developed rapidly, especially in genetics and biochemistry. Morgan received the Nobel Prize in 1933.

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

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

Although the emphasis upon the humanities or liberal arts as an important part of the education of every scientist and engineer was traditional even in the Throop College days, a reiterated insistence upon this principle was made when Hale, Noyes, and Millikan created the modern Caltech. In 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. In 1928 Mr. and Mrs. Joseph B. Dabney gave the Dabney Hall of Humanities, and friends of the Institute provided an endowment of $400,000 for the support of instruction in humanistic subjects. Later, Mr. Edward S. Harkness added a gift of $750,000 for the same purpose.

Largely on the initiative of Henry M. Robinson, the California Institute Associates were organized in 1925. These men and women, now numbering 300, are the successors of those early dedicated pioneers who saw in Throop College the potentiality of becoming a great and famous institution. The Institute Associates, by their continued support, have played a vital part in the Institute's progress. In 1949 the Industrial Associates Program was organized as a mechanism for providing corporations with the opportunity of supporting fundamental research at the Institute and of keeping in touch with new developments in science and engineering.

For the five years beginning with the summer of 1940, the Institute devoted an increasingly large part of its personnel and facilities to the furthering of national defense and the war effort. The Institute's work during this period fell for the most part into two main categories: special instructional programs, and research on the development of the instrumentalities of war. The first included participation in the Engineering, Science and Management War Training Program, in which a total of over 24,000 students were enrolled in Institute-supervised courses: advanced meteorology for Army Air Force cadets; advanced work in aeronautics and ordnance for Army and Navy officer personnel; and the provision of instruction (as well as housing and subsistence) for a unit of the Navy V-12 Engineering Specialists. The research and development work was carried on for the most part under nonprofit contracts with the Office of Scientific Research and Development. These contracts had a total value of more than $80,000,000 and at their peak involved the employment of more than 4,000 persons. Rockets, jet propulsion, and anti-submarine warfare were the chief fields of endeavor. The Jet Propulsion Laboratory in the upper Arroyo Seco continues, under Institute management, a large-scale program of research. It was operated under contract with the Department of the Army until 1958 when it was transferred to the newly established National Aeronautics and Space Administration. JPL is now devoted wholly to the science and technology of space exploration. The laboratory launched the first U. S. satellite, Explorer I, in 1958; the Ranger VII, VIII, and IX moon probes in 1964 and 1965; and also the Mariner II and IV probes to Venus and Mars.

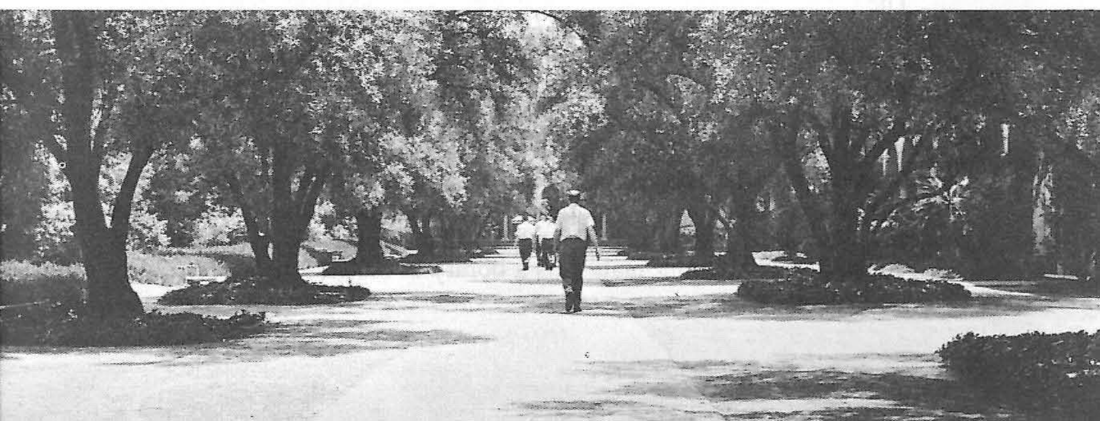
In 1945 Robert A. Millikan retired as chairman of the Executive Council but served as vice chairman of the Board of Trustees until his death in 1953. Dr. Lee A. DuBridge became president of the California Institute on September 1, 1946.

Today the Institute has over 9000 alumni scattered all over the world, many eminent in their fields of engineering and science. Six of them have received Nobel Prizes: Carl D. Anderson (B.S. '27, Ph.D. '30), Edwin M. McMillan (B.S. '27, M.S. '29), Linus Pauling (Ph.D. '25), William Shockley (B.S. '32), Donald A. Glaser (Ph.D. '50), and Charles H. Townes (Ph.D. '39).

As the Institute has developed in effectiveness and in prestige, it has attracted a steady flow of gifts for buildings, for endowment, and for current operations. The gifts invested in plant now total $50,000,000 and those invested in endowment about $70,000,000. Very substantial grants and contracts from the federal government support many important research activities.

In recent years new developments have taken place in all of the divisions. In 1948 the Palomar Observatory and the 200-inch Hale telescope were dedicated. In 1949 the Earhart Plant Research Laboratory was completed; in 1950 the Thomas Laboratory of Engineering; and in 1951 a cosmic ray laboratory. The next year a synchrotron was constructed for the study of atomic nuclei. In 1954 the generosity of the alumni and of the late Scott Brown, a member of the Associates, provided a gymnasium and swimming pool. In 1955 the completion of the Norman W. Church Laboratory for Chemical Biology pointed to new activities in an important field of science. The Eudora Hull Spalding Laboratory of Engineering, an important addition to the facilities available for instruction and research in chemical and electrical engineering, was completed in 1957. A new radio astronomy observatory—one of the finest in the world—was completed in the Owens Valley in 1959 and is now being substantially enlarged.

Olive Walk, which bisects the campus



In February 1958 the Trustees announced the launching of a drive to secure $16,100,000 to finance 18 needed buildings and an enlarged faculty salary fund. The goal was later raised and by April 1962 the pledges to this campaign totaled over $19,350,000. The first unit, a physical plant building, was completed in May 1959; and construction was completed by June 1961 of a new mathematics and physics building, the gift of the Alfred P. Sloan Foundation; of a new laboratory of molecular biology, the gift of Dr. Gordon A. Alles (B.S., '22, Ph.D., '26) and the U.S. Public Health Service; of the Campbell Plant Research Laboratory, the gift of the Campbell Soup Company and the U.S. Public Health Service; the W. M. Keck Engineering Laboratories; three undergraduate student houses (the Page, Lloyd, and Ruddock Houses); and the Harry Chandler Dining Hall.

During 1961-62, there were completed four graduate houses (the Keck, Mosher-Jorgensen, Marks, and Braun Houses), the Firestone Flight Sciences Laboratory (gift of the Firestone Tire and Rubber Company), and the Karman Laboratory of Fluid Mechanics and Jet Propulsion (gift of the Aerojet-General Corporation). The P. G. Winnett Student Center was completed in the summer of 1962. The Willis H. Booth Computing Center was completed in 1963 and the beautiful Arnold O. Beckman Auditorium in 1964. Construction has begun on the Robert A. Millikan Memorial Library (gift of Dr. Seeley G. Mudd) and on the Harry G. Steele Laboratory of Electrical Sciences. Design and funding plans are under way for a laboratory of chemical physics and one for high-energy physics. Funds will soon be needed for several other essential academic, housing, and other facilities, and there is an urgent need for funds to cover increased expenses for the expanding program of education and research.

THE INDUSTRIAL RELATIONS CENTER

The Industrial Relations Center was established in 1939 through special gifts from a substantial number of individuals, companies, and labor unions and is maintained by gifts from Donors and annual contributions from Sponsors. The basic objectives of the Center are to increase and disseminate a knowledge and understanding of the philosophies, principles, policies, and procedures affecting employer-employee relationships, including the motivation, development, compensation, and supervision of rank-and-file, professional, and managerial personnel, without duplicating unnecessarily the work of other organizations. Its program is guided by the Committee on the Industrial Relations Center, consisting of Trustees and Faculty.

The Center provides a variety of services to its Sponsors in return for their regular financial support: (1) It conducts research on managerial, economic, psychological, and other related problems pertaining to employer-employee relationships. Special emphasis has been given to employee benefits through the work of the Benefits and Insurance Research Section. (2) The Center assists representatives of Sponsors, who participate in special conferences and workshops, to develop and improve specific personnel programs for use in their companies. (3) It counsels with representatives of Sponsors, on request, concerning individual company problems of management and personnel administration. (4) The Center maintains a library of materials on industrial relations and management, with emphasis on the personnel practices of many companies. Reference assistance is available. (5) The Center also assists Sponsors in the development and self-development of (a) supervisors and other line or operating management at various levels and (b) members of the personnel administrative staff. This assistance is through regular meetings and conferences held on campus or through special programs developed for specific companies.

Each of these services supplements, and is supplemented by, the other services. As a result of its activities, the Center issues a variety of publications including bulletins, circulars, and research monographs.

One of its special services is conducting employee opinion polls for specific companies. The individual surveys have proved of value to organizations of various sizes in many industries. The general results supplement the other research and teaching activities.

The Center participates in the education of undergraduate and graduate students of the California Institute of Technology, emphasizing the fundamentals of supervision and working with people.

The increasing complexity of business operations has emphasized the fact that a manager must not only know how to do the work being supervised but must also know how to supervise—a separate and distinct function.

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

In all of its activities the Center cooperates with a large number of trade and professional organizations and with other colleges and universities to pool resources and to avoid unnecessary duplication of effort. The Caltech Industrial Relations Center is affiliated with the Industrial Relations Center of the University of Chicago.

The office, library, and conference rooms of the Center are located on the campus at 383 South Hill Avenue, but the mailing address is simply Industrial Relations Center, California Institute of Technology, Pasadena, California 91109.

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

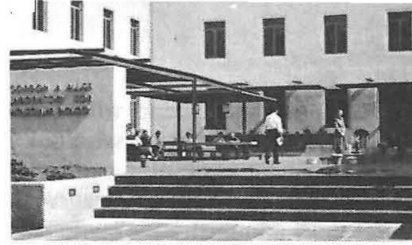
THE WILLIS H. BOOTH COMPUTING CENTER

The Computing Center, established some years ago as part of the Engineering Division, has recently been expanded and is separately administered as a general facility for the research and educational activities of all divisions of the Institute.

The Center contains an extensive computing system, and a staff of computer scientists, programmers, and computer engineers engaged in basic research on information processing systems and in serving the general computing requirements of the Institute.

The data processing equipment consists of a central system of intercon-

Throop Hall

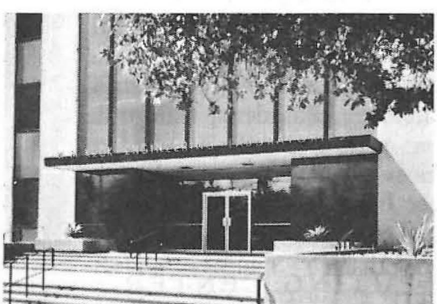


Gordon A. Alles Laboratory for Molecular Biology

Firestone Flight Sciences Laboratory

Winnett Student Center

Willis H. Booth Computing Center



W. M. Keck Engineering Laboratories

Karman Laboratory of Fluid Mechanics and Jet Propulsion

Athenaeum

nected computers supported by a large variety of communication channels extending to several of the campus laboratories. The peripheral equipment associated with these channels includes data transmission control devices, input-output stations for direct connection to experimental research equipment, and remote users' consoles for direct communication with human beings involved in creative programming research and other man-machine relationships.

The principal computers are an IBM 7094, an IBM 7040, and a Burroughs 220. The IBM 7040 functions primarily as the communication control computer and sets up problems for the IBM 7094 on a large high-speed disc memory. A core buffered multiplexor (the IBM 7288) controls the flow of information in the individual communications lines. The Burroughs 220 can be used separately for instruction purposes or as an auxiliary processor for the system. The remote stations have been developed jointly with the various laboratories of the Institute for a variety of basic research and instructional applications.

In October 1965 an extensive addition is to be made to the facility. This includes an IBM 360/50, two IBM 1800 computers, and a large array of new memory units, remote typewriter consoles, and cathode ray consoles.

BUILDINGS AND FACILITIES

THROOP HALL, 1910. The administration building; erected with funds supplied by a large number of donors, and named for the Honorable Amos G. Throop, founder of Throop Polytechnic Institute from which the California Institute of Technology developed.

GATES AND CRELLIN LABORATORIES OF CHEMISTRY: first unit, 1917; second unit, 1927; third unit, 1937. The first two units were the gift of Messrs. C. W. Gates and P. G. Gates of Pasadena; the third unit was the gift of Mr. and Mrs. E. W. Crellin of Pasadena.

CULBERTSON HALL, 1922. Named in honor of Mr. James A. Culbertson of Pasadena, vice president of the Board of Trustees, 1908-1915.

NORMAN BRIDGE LABORATORY OF PHYSICS: first unit, 1922; second unit, 1924; third unit, 1925. The gift of Dr. Norman Bridge of Los Angeles, president of the Board of Trustees, 1896-1917.

HIGH VOLTAGE RESEARCH LABORATORY, 1923. Erected with funds provided by the Southern California Edison Company. Retired in 1959 with basic research completed, and rebuilt in 1960 as the Alfred P. Sloan Laboratory of Mathematics and Physics.

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

DABNEY HALL OF THE HUMANITIES, 1928. The gift of Mr. and Mrs. Joseph B. Dabney of Los Angeles.

GUGGENHEIM AERONAUTICAL LABORATORY, 1929. Erected with funds provided by the Daniel Guggenheim Fund for the Promotion of Aeronautics. A substantial addition was erected in 1947.

WILLIAM G. KERCKHOFF LABORATORIES OF THE BIOLOGICAL SCIENCES: first unit, 1928; second unit, 1939; annex, 1948. The gift of Mr. and Mrs. William G. Kerckhoff of Los Angeles.

DOLK PLANT PHYSIOLOGY LABORATORY, 1930. Named in memory of Herman E. Dolk, Assistant Professor of Plant Physiology from 1930 until his death in 1932.

ATHENAEUM, 1930. A clubhouse for the use of the California Institute Associates and the staffs of the California Institute, the Huntington Library, and the Mount Wilson Observatory. The gift of Mr. and Mrs. Allan C. Balch of Los Angeles. He was president of the Board of Trustees, 1933-1943.

UNDERGRADUATE HOUSES, 1931:

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

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

Fleming House. Erected with funds provided by some twenty donors and named in honor of Mr. Arthur H. Fleming of Pasadena, president of the Board of Trustees, 1917-1933.

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

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

W. K. KELLOGG RADIATION LABORATORY (Nuclear Physics), 1932. The gift of Mr. W. K. Kellogg of Battle Creek, Michigan.

HENRY M. ROBINSON LABORATORY OF ASTROPHYSICS, 1932. Erected with funds provided by the International Education Board and the General Education Board, and named in honor of Mr. Henry M. Robinson of Pasadena, member of the Board of Trustees, 1907-1937, and of the Executive Council of the Institute.

SYNCHROTRON LABORATORY, 1933. Originally Optical Shop, erected with funds provided by the International Education Board and the General Education Board. Following completion of the 200-inch Hale telescope the building was converted into the Synchrotron Laboratory.

CHARLES ARMS LABORATORY OF THE GEOLOGICAL SCIENCES, 1938. The gift of Mr. and Mrs. Henry M. Robinson of Pasadena, in memory of Mrs. Robinson's father, Mr. Charles Arms.

SEELEY W. MUDD LABORATORY OF THE GEOLOGICAL SCIENCES, 1938. The gift of Mrs. Seeley W. Mudd of Los Angeles, in memory of her husband.

CLARK GREENHOUSE, 1940. The gift of Miss Lucy Mason Clark of Santa Barbara.

FRANKLIN THOMAS LABORATORY OF ENGINEERING: first unit, 1945; second unit, 1950. Funds for the first unit were allocated from the Eudora Hull Spalding Trust with the approval of Mr. Keith Spalding, Trustee. Named in honor of Dean Franklin Thomas, Professor of Civil Engineering and first chairman of the Division of Engineering, 1924-1945.

EARHART PLANT RESEARCH LABORATORY, 1949. The gift of the Earhart Foundation of Ann Arbor, Michigan.

COSMIC RAY LABORATORY, 1952.

ALUMNI SWIMMING POOL, 1954. Provided by the Alumni Fund through contributions of alumni of the Institute.

SCOTT BROWN GYMNASIUM, 1954. Erected with funds provided by a trust established by Mr. Scott Brown of Pasadena and Chicago, a member and director of the California Institute Associates.

NORMAN W. CHURCH LABORATORY FOR CHEMICAL BIOLOGY, 1955. Erected with funds provided through gift and bequest by Mr. Norman W. Church of Los Angeles, a member of the California Institute Associates.

EUDORA HULL SPALDING LABORATORY OF ENGINEERING, 1957. Erected with funds allocated from the Eudora Hull Spalding Trust.

ARCHIBALD YOUNG HEALTH CENTER, 1957. The gift of Mrs. Archibald Young of Pasadena, in memory of her husband, a member and director of the California Institute Associates.

PHYSICAL PLANT BUILDING AND SHOPS, 1959. Erected with funds provided by many donors to the Caltech Development Program.

CAMPBELL PLANT RESEARCH LABORATORY, 1960. Erected with funds given by the Campbell Soup Company of Camden, New Jersey, and by the Health Research Facilities Branch of the National Institutes of Health, Bethesda, Maryland.

GORDON A. ALLES LABORATORY FOR MOLECULAR BIOLOGY, 1960. Erected with the gift of Dr. Gordon A. Alles of Pasadena, Research Associate in Biology at the Institute, an alumnus and a member of the California Institute Associates, 1947-1963; and with funds provided by the Health Research Facilities Branch of the National Institutes of Health.

UNDERGRADUATE HOUSES, 1960. Erected with funds provided by the Lloyd Foundation and other donors to the Caltech Development Program.

Lloyd House. Named in memory of Mr. Ralph B. Lloyd and his wife Mrs. Lulu Hull Lloyd of Beverly Hills. He was a member of the Board of Trustees, 1939-1952.

Page House. Named in honor of Mr. James R. Page of Los Angeles, a member of the Board of Trustees from 1931 to 1962 and chairman from 1943 to 1954.

Ruddock House. Named in honor of Mr. Albert B. Ruddock of Santa Barbara, a member of the Board of Trustees since 1938 and chairman from 1954 to 1961.

HARRY CHANDLER DINING HALL, 1960. The gift of the Chandler family, the Pfaffinger Foundation, and the Times Mirror Company of Los Angeles.

W. M. KECK ENGINEERING LABORATORIES, 1960. The gift of the W. M. Keck Foundation, and the Superior Oil Company of Los Angeles.

GRADUATE HOUSES, 1961:

Braun House. Erected with funds provided by the trustees of the Carl F. Braun Trust Estate in his memory.

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

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

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

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

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

FIRESTONE FLIGHT SCIENCES LABORATORY, 1961. The gift of the Firestone Tire and Rubber Company.

WINNETT STUDENT CENTER, 1962. The gift of Mr. P. G. Winnett of Los Angeles, a member of the Board of Trustees.

WILLIS H. BOOTH COMPUTING CENTER, 1963. Erected with funds given by the Booth-Ferris Foundation of New York, and by the National Science Foundation. Named in memory of Mr. Willis H. Booth, a member of the California Institute Associates.

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

LIBRARIES

The General Library, as the center of the Institute library system, houses the administrative office, which serves nine departmental libraries located in as many buildings on the campus. The departmental libraries house the collection of books, periodicals, and basic reference works in aeronautics, astronomy and astrophysics, biology, chemistry, chemical engineering, geology, humanities, industrial relations, and physics. The General Library houses the collections in mathematics and engineering, as well as the master catalog for the entire system. The campus libraries collectively subscribe to about 3,500 periodicals and contain about 150,000 volumes.

OFF-CAMPUS FACILITIES

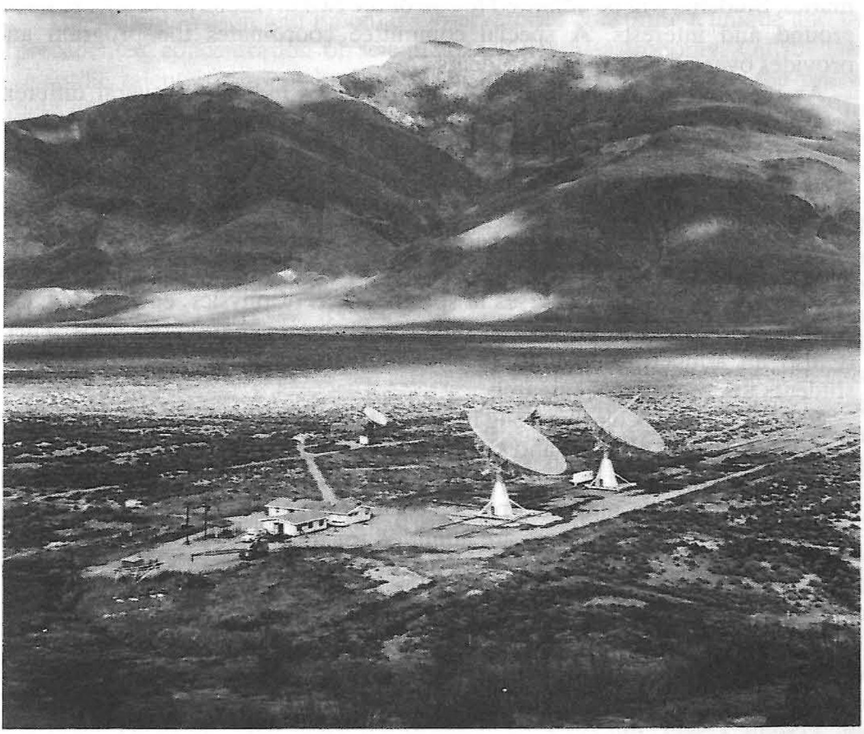
KRESGE SEISMOLOGICAL LABORATORY, 1928 (of the Division of the Geological Sciences), 220 North San Rafael Avenue, Pasadena. Named in recognition of a gift from The Kresge Foundation of Detroit, Michigan.

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

PALOMAR OBSERVATORY, San Diego County, 1948. Owned by the Institute and, with the Mount Wilson Observatory, operated jointly by the Carnegie Institution of Washington and the Institute.

DONNELLEY SEISMOLOGICAL LABORATORY, 1957 (of the Division of the Geological Sciences), 295 North San Rafael Avenue, Pasadena. The gift of Mr. and Mrs. C. Pardee Erdman of Santa Barbara, The Kresge Foundation of Detroit, and the James Irvine Foundation of San Francisco. Named in honor of Mrs. Erdman's father, Mr. Reuben H. Donnelley.

OWENS VALLEY RADIO OBSERVATORY, near Bishop, 1958.



Radio observatory in Owens Valley near Bishop, California

The 200-inch telescope at the Palomar Observatory

STUDY AND RESEARCH

The Sciences

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. A special committee coordinates the program and provides over-all guidance to students.

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 (see page 281); these are to be supplemented according to the student's interests from the courses offered under Mathematics, and from the whole range of Institute courses in specific areas of physics, engineering, etc. Further advanced courses will be added as this new program develops. There is also an applied mathematics colloquium in which visitors, faculty, and students discuss current research.

Research is particularly strong in fluid dynamics (including magnetohydrodynamics, plasma physics, and kinetic theory), elasticity, dynamics and celestial mechanics, numerical analysis, differential equations, integral equations, asymptotic methods, and other related branches of analysis.

Entering graduate students are admitted for the Ph.D. program. Details of the scholastic requirements for the Ph.D. degree in Applied Mathematics are given under Section IV (page 235). The master's degree may be awarded in exceptional cases. The general Institute regulations (see Section IV) require the candidate for the master's degree to take at least 135 units of graduate work as a graduate student at the Institute, including 81 units of advanced graduate work in applied mathematics and 54 units of free electives.

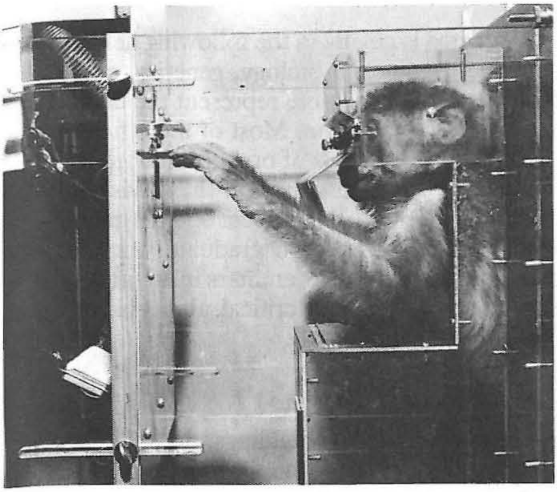
Astronomy

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

The Mount Wilson and Palomar Observatories constitute a unique and unprecedented concentration of scientific facilities in astronomy. Outstanding scientific talent is present both in the field of astronomy and in the related field of physics. The California Institute of Technology and the Carnegie Institution of Washington recognized the advantages in the creation of a great astronomical center in which a unitary scientific program would be pursued under favorable circumstances and which would draw young men of ability to graduate studies where they might familiarize themselves with powerful tools of exploration. For this purpose, a plan for the operation of the two observatories, under which they now function as a single scientific organization, under the direction of Dr. H. W. Babcock, was approved by the Trustees of the two institutions. Under this plan all the equipment and facilities of both observatories are made available for the astronomical investigations of the combined staff and students. The unified research program is paralleled by undergraduate and graduate training in astronomy and astrophysics by members of the Institute faculty, the staff of Mount Wilson and Palomar Observatories, and the Radio Observatory.

In 1956 work started in radio astronomy, and advanced study and research in this field are under way. A 32-foot paraboloid and two precision 90-foot-diameter, steerable paraboloids suitable for high frequencies are now in operation at a field station near Bishop. The two are used together as a variable-spacing interferometric radio telescope for exact position finding. In 1965 construction began on additional antennae of 130-foot diameter, to be used in conjunction with the present equipment. This is one of the most advanced installations in this new, rapidly growing field. Special receivers, masers, and other advanced techniques make it possible to identify the most distant radio sources, study their spatial distribution and physical properties, and also to study the planets. The radio astronomy group works in close cooperation with the optical astronomers in Pasadena; the program of study in the two fields is essentially the same, except for specialized advanced courses. 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 space science.

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



Psychobiologists study discrimination performance in split-brain animals

Biology

UNDERGRADUATE AND GRADUATE WORK

Biology is today one of the most rapidly expanding and exciting of the sciences. Advances of a spectacular kind are being made in our understanding of living things. This is in large part so because it has been found possible to apply the methods, concepts, and approaches of mathematics, physics, and chemistry to the investigation of such biological problems as the manner in which molecules, genes, and viruses multiply themselves; the nature of enzyme reaction and of enzymatic pathways; the mechanisms of growth and development; and the nature of nerve activity, brain function, and behavior. There is great and increasing demand for experimental biologists, and qualified individuals will find opportunities for challenging work in basic research and in the applied fields of medicine, agriculture, and chemical industry.

Because of the preeminent position of the California Institute of Technology in both the physical and biological sciences, students at the Institute have an unusual opportunity to be introduced to modern biology. The undergraduate option is designed to give the student an understanding of the basic facts, techniques, and logic of biology as well as a solid foundation in physical science. Emphasis is placed on the general and fundamental properties of living creatures, thus unifying the traditionally separate fields of the life sciences. The undergraduate option serves as a basis for graduate study in any field of biology or for admission to the study of medicine.

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

Graduate work leading to the Ph.D. degree is chiefly in the following fields: biochemistry, biophysics, cell biology, developmental biology, genetics, neurophysiology, plant physiology, and psychobiology. These represent the fields in which active research is now going on in the Division. Most of these fields are approached at the molecular as well as higher levels of organization; thus, no separate discipline of "molecular biology" is recognized in the Division. The disciplines of biochemistry and biophysics, of course, encompass most directly the area of molecular biology. The emphasis in graduate work is placed on research. This is supplemented by courses and seminars in advanced subjects aimed at developing the student's insight and critical ability as an investigator.

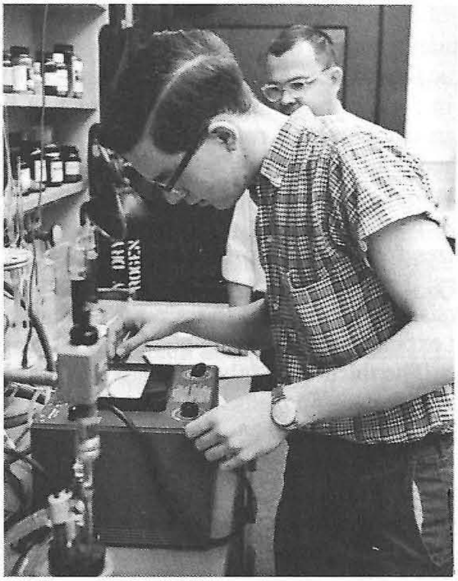
PHYSICAL FACILITIES

The campus biological laboratories are housed in three buildings, the William G. Kerckhoff Laboratories of the Biological Sciences, the Gordon A. Alles Laboratory for Molecular Biology, and the Norman W. Church Laboratory for Chemical Biology. The Alles Laboratory links the Kerckhoff and Church laboratories at all floor levels. The three laboratories contain classrooms and undergraduate laboratories, a biology library, an annex housing experimental animals, and numerous laboratories equipped for biological, biochemical, biophysical, and physiological research at the graduate and doctoral level. The constant-temperature equipment includes rooms for the culturing of the Institute's valuable collection of mutant types of Drosophila and Neurospora and complete facilities for plant and animal tissue culture.

Adjacent to the campus the Plant Research Center consists of the Campbell Plant Research Laboratory, the Earhart Plant Research Laboratory, and the Dolk and Clark Greenhouses. In the Earhart Laboratory all the elements of climate, such as light, temperature, humidity, wind, rain, and gas content of air can be controlled simultaneously. These laboratories offer the opportunity to study plants under different synthetic climatic conditions, yet with reproducibility of experimental results.

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

Reference should also be made to the Biological Systems Laboratory, which houses the joint research programs of the Biology and Engineering Divisions dealing with data processing systems and systems theory as they relate to the nervous system and sensory perception (see page 153).



Selected freshmen are permitted to do honors research in chemistry

Chemistry and Chemical Engineering

The laboratories of chemistry consist of four adjacent units. Gates Laboratory and Gates Annex are the gift of Messrs. C. W. Gates and P. G. Gates. Crellin Laboratory, which was completed in 1937, affords space approximately equal to that of the first two units and is the gift of Mr. and Mrs. E. W. Crellin. The Norman W. Church Laboratory for Chemical Biology, completed in 1955, is shared equally with the Division of Biology.

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

Construction of a new laboratory for chemical physics will be started in the fall of 1965 and should be completed in early 1967. This building will have many special facilities for research in chemical physics and physical inorganic chemistry.

The chemical engineering facilities are located in the Eudora Hull Spalding Laboratory of Engineering and in the adjoining Chemical Engineering Laboratory. These laboratories are well equipped for instruction in chemical engineering and for research programs involving studies of the phase relations and thermodynamic properties of fluids at moderately high pressures and temperatures, reaction kinetics, the transfers of material and energy in fluid systems, the structure of liquids, and the mechanics of dispersions and suspensions.

UNDERGRADUATE WORK

There are two undergraduate options in the Division, one in chemistry and the other in chemical engineering, and the curricula are the same for the first two years. Study in these options leads, especially when followed by graduate work, to careers in teaching and research in colleges and universities, in research in government and industry, in operation and control of manufacturing processes, and in management and development positions in chemical industry.

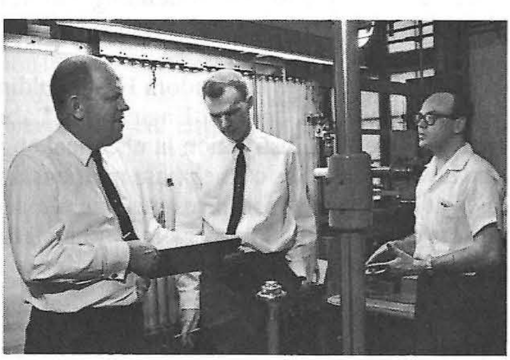
The first-year general chemistry course, which is taken by all freshman students, emphasizes fundamental principles and their use to systematize descriptive chemistry. The laboratory work in the first two terms is essentially quantitative analysis, but is designed to train the student to plan, execute, and critically interpret experiments involving quantitative measurements of various physical quantities. The third-term laboratory work involves a system of qualitative and semi-quantitative analysis and is used to extend and organize the student's knowledge of inorganic chemistry.

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

Throughout the third year both the chemistry and chemical engineering options require a basic course in physical chemistry, as well as courses in analytical chemistry and physical chemistry laboratory. This is the year, however, where the requirements of the options begin to diverge. The chemistry option provides time for some of the elective courses described on page 251, whereas the chemical engineering option requires professional courses which include chemical engineering thermodynamics and engineering mathematics.

In the fourth year the chemistry option has no required professional courses but permits specialization by electives of an advanced nature. The chemical engineering curriculum contains courses in industrial chemistry, adaptive design, transport phenomena, applied chemical thermodynamics, unit operations, and chemical engineering laboratory, as well as electives in engineering and science.

Undergraduate research is emphasized in both options and students are encouraged even in the freshman year to participate in research in association with staff members. Over the past years these researches have resulted in a significant number of publications in scientific journals.



Chemical engineers discuss a problem in thermal transpor

GRADUATE WORK 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 effective stimulus to awaken, develop, and give direction to the creative force.

Soon after the graduate student arrives in the laboratories, he attends a series of orienting seminars that introduce him to the active research interests of the staff. He is then expected to talk in detail with each of several staff members whose fields attract him, eventually to settle upon the outlines of a problem that interests him, and to begin research upon it early in his first year. He can elect to do research which crosses the boundaries of areas that are commonly distinguished by schismatic names; for in this relatively compact division a man is encouraged to go where his scientific curiosity drives him; he is not confined to a biochemical or physical or organic laboratory. A thesis that involves more than one advisor is common, and interdisciplinary programs with biology, physics, and geology are open and recommended.

For an advanced degree, no graduate courses in chemistry are specifically required, but the student may plan a program of advanced courses (see pp. 297-302) in consultation, at first with a representative of the divisional committee on graduate study, and later with his research advisor.

An extensive program of seminars enables the student to hear of and discuss notable work in his own and other areas. In the weekly Divisional Research Conference, members of the staff and distinguished visitors present accounts of research of broad interest. More specialized seminars are devoted to such subjects as theoretical chemistry, physical organic chemistry, crystal structure analysis, and biological chemistry. Graduate students are encouraged also to attend seminars in other divisions.

Before the end of the winter term of his second year, the student should be ready to seek formal admission to candidacy for the Ph.D. degree. He then presents a research report that describes and justifies what he has done and what he hopes to do, and propositions, or brief scientific theses, that he has originated and can defend. The independence, creativity, and intellectual maturity that he demonstrates in his presentation provide the basis for the decision as to his admission to candidacy.

The Division has both M.S. and Ph.D. programs, but most students work directly toward the Ph.D. Requirements for the master's degree in chemistry are given on page 265; those for the doctor's degree on page 221.

AREAS OF RESEARCH

A detailed listing of individual research interests is to be found on page 302, in the description of course Ch 280. These can be grouped into the following general areas of interest:

1. *Structural chemistry*, including X-ray diffraction, nuclear magnetic resonance and electron-spin resonance spectroscopy, optical and electron-impact spectroscopy and mass spectrometery. Substances under study include crystalline enzymes, nucleic acids and nucleotides, intermetallic compounds, inorganic chelates, antibiotics, and liquids.

2. *Chemical dynamics*, including studies of organic, inorganic, and biochemical reaction mechanisms, the mechanisms of electrochemical and photochemical processes, and molecular beam kinetics.

3. *Theoretical chemistry*, involving molecular quantum mechanics, computer "experiments" in chemical kinetics, and the theory of relaxation processes.

4. *Biochemistry*, including studies of oxidation and proteolytic enzymes, the determination of amino acid sequences of proteins, the systematic modification of proteins, the physical chemistry of solutions of macromolecules, and the fundamental processes of photosynthesis.

5. *Synthetic chemistry*, with recently increased emphasis on the synthesis of natural products and also including synthesis of theoretically interesting small molecules.

GRADUATE WORK IN CHEMICAL ENGINEERING

Instruction and research in chemical engineering is offered leading to the degrees of Master of Science and Doctor of Philosophy.

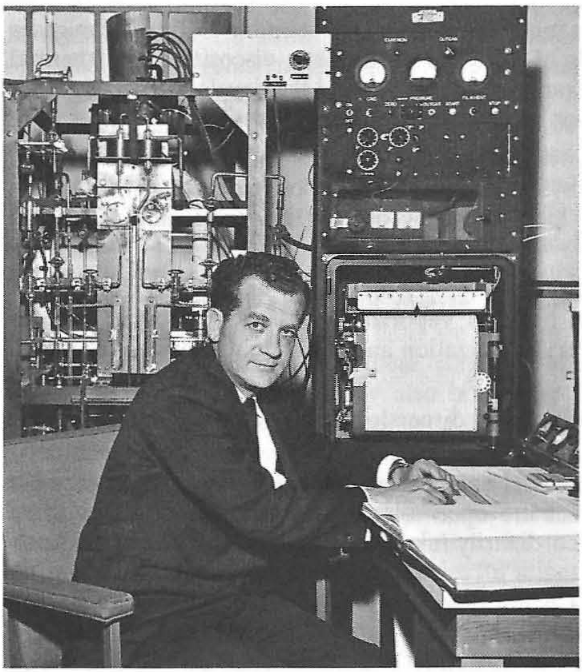
The Institute was one of the earliest schools to use the engineering science approach to chemical engineering. The emphasis in both instruction and research is on basic subjects rather than on specialized material relating primarily to particular industries or processes. It is believed that the basic subjects essential to constructive thinking in engineering are most easily mastered with sympathetic and continuous instruction, whereas the material of applied nature is more properly learned in the industrial environment.

The general objective of the graduate work in chemical engineering is to produce men 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.

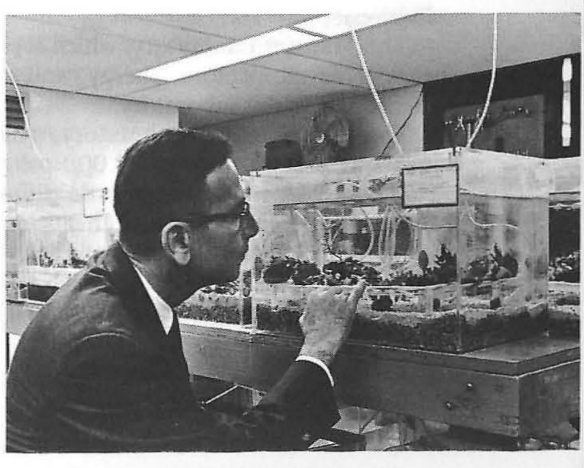
Degrees. The master's degree is intended for students who plan to pursue careers in design, process engineering, development, or management. The degree is normally obtained in one academic year. The requirements include ChE 102 Applied Physical Chemistry and ChE 167 abc Introduction to Chemical Engineering Research, the latter involving two terms of research under the supervision of a chemical engineering staff member. In addition there are electives, which may include humanities as well as graduate courses from other branches of science and engineering. A thesis is not required for the master's degree. The master's degree is not a prerequisite for Ph.D. work; however, at the cost of about one term of added residence it can be earned by those intending ultimately to obtain the Ph.D. degree.

The work leading to the Ph.D. degree prepares students especially 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. In addition to acquiring proficiency at a high level in several areas vital to chemical engineering and satisfying Institute requirements in foreign languages and a minor program, the Ph.D. candidate must complete a significant program of scientific investigation and prepare a thesis describing this research. Usually the first year of graduate work is principally devoted to course work in chemical engineering and in the minor program. The re-

Students and staff prepare drilling equipment for deep coring in ice, Blue Glacier, Washington



A mass spectrometer for research in stable isotope geochemistry



Paleoecology in action—ecologically controlled growth experiments search program is also started during this period. During the second year the student is expected to spend at least half time on his research, and to complete his minor and the departmental examinations. Some time is available for elective courses. It is expected that the research project will occupy full time during the third year. Thus, if summers are spent on research and other academic pursuits, the Ph.D. requirements should be completed in three calendar years.

Ph.D. requirements are shown in more detail on page 221.

Instruction and Research. The major areas in which graduate research is currently concentrated are:

1. Reaction kinetics and combustion including both homogeneous and catalytic oxidation reactions; plasma chemistry; the decomposition of inorganic sulfur compounds; and both experimental and theoretical studies of oscillatory combustion.

2. Transport phenomena including turbulent heat and mass transfer in gases and liquids; measurements of diffusion coefficients, viscosities, and thermal conductivities over a wide range of pressures; and the development of mathematical methods for solution of complex transfer problems.

3. Liquid state physics involving studies of forces and configurations at the molecular level in simple systems; determination of structure by X-ray diffraction; other studies of local order by optical, magnetic, and ultrasonic experiments.

4. Thermodynamics and phase behavior including the volumetric and phase behavior of hydrocarbons; heats of vaporization of hydrocarbons; thermodynamic properties of water; optimization and dynamic response of chemical reactors.

5. Mechanics of suspensions and dispersions.

Graduate courses in chemical engineering are described starting on page 293. The 100-series courses are open to first-year graduate students while those in the 200 series are ordinarily taken only by more advanced students.

Facilities and Equipment. Chemical engineering is housed in the Eudora Hull Spalding Laboratory of Engineering and in the Chemical Engineering Laboratory which is contiguous to Spalding. The laboratories are well equipped both for instruction and for research and include the following major subdivisions:

The Transfer Laboratory, which is equipped for measurements of turbulent transfer of momentum, energy, and material. Combustion studies are also carried out in this laboratory.

The High Pressure Laboratory, which is equipped for precision measurements at pressures up to 15,000 psi and, in one case, to a temperature of 1500° F. Measurements include diffusion coefficients in liquids, gases, viscosity, thermal conductivity, heats of vaporization, Joule-Thomson coefficients, and volumetric and phase behavior of fluids.

The Kinetics Laboratory, which contains several research-scale chemical reactors, chiefly of the flow type, and appropriate equipment for the measurement of pressures, temperatures, and flow rates. Extensive use is made of gas chromatography for analysis.

The Liquid State Physics Laboratory, which is equipped for X-ray diffraction measurements on cryogenic fluids at moderate pressures. Apparatus is also available for refractive index, ultrasonic velocity and absorption, and magnetic experiments over a range of temperature and pressure.

The instructional laboratories are equipped for making precise measurements of transport and other phenomena.

Specialized Institute facilities are also available to students and staff. The Computing Center, which has exceptional capabilities, is described on page 117.

Geology

The Division of Geological Sciences is closely allied with the other active and creative fields of science and engineering at Caltech. Accordingly, a favorable intellectual atmosphere exists for education and research in geology, geobiology, geochemistry, geophysics, and aspects of planetary science. The geographic position and geological setting of the Institute are nearly ideal for students and research workers, who can derive materials, ideas, and inspiration from the wide variety of easily accessible field environments. The staff as listed on an earlier page of this catalog represents a variety of allied and integrated interests and is active in both teaching and research.

Physical facilities, both natural and man-made, are excellent. All the classroom instruction and most of the laboratory research in geology and geochemistry, as well as part of that in geophysics, are carried on in the Arms and Mudd laboratories. These are modern, five-story buildings which were specifically designed for these activities and to provide office space for the staff and students. They also house the Division Library; paleontologic, rock, and mineral collections; a laboratory for planetary studies; organic constituents laboratory; spectrographic, X-ray, and X-ray fluorescent equipment; wet chemical laboratories; an electron microprobe facility; and facilities for rock and mineral analyses, sedimentation studies, thin and polished section work, and other requirements for comprehensive studies in the earth sciences. A new suite of laboratories for mineral separation and analyses is available for student use.

Extensive facilities are provided for the application of techniques of nuclear chemistry to problems in the earth sciences. These facilities include chemical laboratories for trace-element studies, a silicate analysis laboratory, and mass spectrometric and counting facilities for isotopic work. Available equipment includes mass spectrometers, emission counters, an induction furnace, and extensive mineral separation facilities in addition to the usual geological and chemical items.

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

The Seismological Laboratory of the California Institute, with ample space and excellent facilities, including a computer and extensive shops in the Donnelley and Kresge laboratories, is located about three miles west of the campus on crystalline bedrock affording firm foundation for the instrument piers and tunnels. The central laboratory, together with seventeen outlying auxiliary stations in southern California—built and maintained with the aid of cooperating companies and organizations—constitutes an outstanding center for education and research in seismology. Other phases of geophysical training and investigation are carried on in the regular campus buildings. Also, lunar and planetary observations are being carried out at the Mt. Wilson and Palomar Observatories with moderate-size reflecting telescopes especially designed and built to meet the needs of Division personnel.

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

The student body is purposely kept small and usually consists of no more than 50 graduate students and 15-20 undergraduates. The small size of the student group and large size of the staff give a highly favorable ratio of students to staff and result in close associations and contacts which enhance the value of the educational program.

UNDERGRADUATE WORK

The aim of the undergraduate program in the geological sciences is to provide thorough training in basic geological disciplines and, wherever possible, to integrate the geological studies with and build upon the courses in mathematics, physics, chemistry, and biology taken during the earlier years at the Institute. Special emphasis is also placed on field work because it provides first-hand experience with geological phenomena that can never be satisfactorily grasped or understood solely from classroom or laboratory treatment. Options are offered in geology (including paleontology and paleoecology), geophysics, geochemistry, and planetary science. Sufficient flexibility in electives is provided to permit a student to follow lines of special interest in related scientific or engineering fields. Research in pertinent aspects of planetary science is increasing. Men who do well in the basic sciences and at the same time have a compelling curiosity about the earth and its natural features are likely to find their niche in the geological sciences, especially if they possess a flexible and imaginative mind that enables them to grapple with complex problems involving many variables. Most students majoring in the earth sciences now find further training at the graduate level highly desirable, and even necessary.

Men trained in the earth sciences find employment in research and teaching in colleges and universities, and research in a wide variety of other professional endeavors. Many work for the petroleum industry, both in the field and in the laboratory, on theoretical as well as applied problems. Some eventually become administrators and executives. Mining companies, railroads, large utilities, and other organizations engaged in development of natural resources employ men trained in the geological sciences, as do a number of government agencies such as the U.S. Geological Survey and the Bureau of Reclamation.

GRADUATE WORK

The number of courses required within the Division for an advanced degree is held to a minimum to permit individuality and flexibility in the various programs. Facilities are available for research and study in such subjects as geochemistry, geophysics, seismology, paleoecology, paleontology, petrology, geomorphology, glaciology, structural geology, stratigraphy, sedimentation, tectonophysics, mineral deposits, and planetary science.

The Division is especially interested in graduate students who have a sound and thorough training in physics, chemistry, biology, and mathematics as well as geology. Applicants with majors in these subjects and with a strong interest in the earth sciences will be given equal consideration for admission and appointment with geology majors.

MATHEMATICS

UNDERGRADUATE WORK

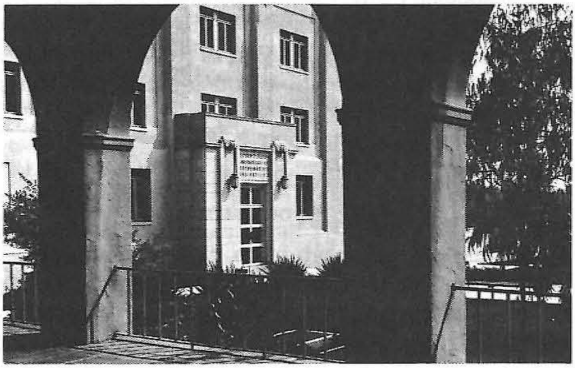
The four-year undergraduate program in mathematics leads to the degree of Bachelor of Science. The purpose of the undergraduate option is to give the student an understanding of the broad outlines of modern mathematics, to stimulate his interest in research, and to prepare him for later work, either in pure mathematics or allied sciences. Unless a student has done exceptionally well in his freshman and sophomore years, he should not contemplate specializing in mathematics. An average of at least "B" in his mathematics courses is expected of a student intending to major in mathematics.

Since the more interesting academic and industrial positions open to mathematicians require training beyond a bachelor's degree, the student who expects to make mathematics his profession must normally plan to continue, either here or elsewhere, with graduate work leading to the degree of Doctor of Philosophy. The undergraduate should bear this in mind in choosing his course of study. In particular he is urged to include at least one year, and preferably two years, of language study in his program. Overloads in course work are strongly discouraged; students are advised instead to deepen and supplement their course work by independent reading. The excellent mathematics library with its large collection of journals is housed in the general library in the Norman Bridge Laboratory. In addition, there is a reference library of duplicate books and periodicals located on the third floor of the Sloan Laboratory of Mathematics and Physics. Books that are not on reserve for special courses may be borrowed from the general library. Current periodicals may be consulted in either library.

Normally the undergraduate will have joined the option by the beginning of his sophomore year. He is required to take the course Ma 5 abc during his second year. Students transferring from another option at the end of the sophomore year who have not yet taken this course will take it as their selected course in mathematics during their junior year concurrently with

Ma 108, and will also take two selected courses in mathematics during their senior year.

The schedule of courses in the undergraduate mathematics option is flexible. It enables the student to adapt his program to his needs and mathematical interests and gives him the opportunity of becoming familiar with creative mathematics early in his career. Each term during his junior and his senior year the student will normally take 18 units of courses in mathematics, including the required course Ma 108. These courses are chosen from the subjects of instruction listed under A on page 331 of this catalog. The courses Ma 102, 103, 104, 109, 112, 116 and AMa 105 are recommended to juniors and seniors. The other courses demand more maturity and prerequisites. They are recommended to seniors only.



Offices for the staff and graduate students in mathematics are housed in the Alfred P. Sloan Laboratory of Mathematics and Physics

GRADUATE WORK

Graduate work in mathematics is planned to give the student a broad knowledge of classical and modern mathematics and to stimulate him to do creative and independent work. The normal course of study leads to the Ph.D. degree and requires three or four years. Exceptional ability and graduate work done elsewhere may shorten this time.

The general Institute requirements for the Ph.D. degree are listed in Section IV under A and D. Additional requirements for mathematics are found on pages 233-234; they give information on placement examinations, admission to candidacy, and final examinations.

Entering graduate students are normally admitted directly to the Ph.D. program, since the Institute does not offer a regular program in mathematics leading to the master's degree. This degree may be awarded in exceptional circumstances either as a terminal degree or as a degree preliminary to the Ph.D. degree. The general Institute requirements (see parts A and B of Section IV) specify that the candidate for the master's degree must take 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. The remaining 54 graduate units are electives from any field.

The candidate for the master's degree will be expected to have acquired, in the course of his studies as an undergraduate or graduate student, a comprehensive knowledge of the main fields of mathematics comparable to 180 units of work in mathematics at the Institute with course numbers greater than 90. This general knowledge will be tested through an oral examination. This examination can be waived at the discretion of the department.

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

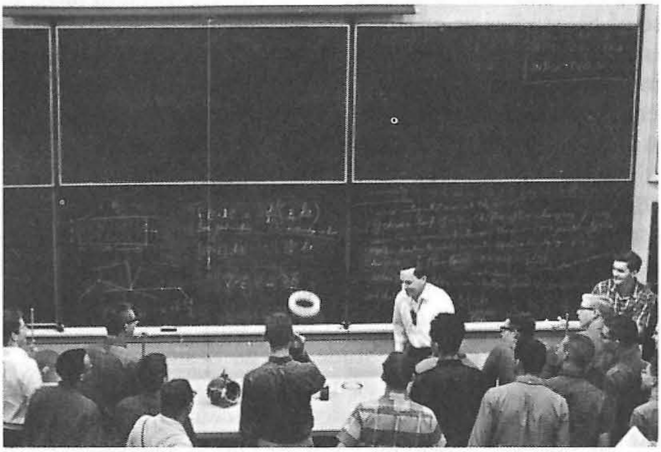
The courses in the second category are numbered between 200 and 299. They are taken normally by second-year and more advanced graduate students. They are usually given in alternate years. The 300 series includes the more special courses, the research courses, and the seminars. They are given on an irregular basis depending on demand and interest.

The first-year graduate program, in addition to the elementary seminar Ma 190, will consist as a rule of two or three 100-series courses. The student is reminded of the language requirements and of the requirements for a subject minor or a distributed minor. It is advisable for a student to satisfy these requirements as early as possible. In particular, the student should fill out the form listing his intended courses outside of mathematics and secure approval for this part of his plan of study.

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

Research. Although supervision and guidance will be provided by members of the staff of the Institute, the thesis research, including the choice of a topic, is the responsibility of the student. Proper guidance can be given in almost any field in pure or applied mathematics and is not restricted to the immediate interests of the staff in mathematics. At present these interests include: group theory; algebraic and analytic theory of numbers; algebraic geometry; lattice theory; matrix theory; combinatorial analysis; ordinary and partial differential equations; measure and integration theory; Fourier and harmonic analysis; functional analysis; numerical analysis; differential geometry; topology; probability; some areas of applied mathematics.

A program of applied mathematics has been organized as a joint program of the Division of Physics, Mathematics and Astronomy, and the Division of Engineering and Applied Science. The course of study will lead 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. For details, see the separate section on applied mathematics.

Financial Aid. Besides the help provided by the nationwide fellowship programs, financial assistance may be provided by tuition scholarships and research or teaching assistantships. A scholarship and an assistantship may be held concurrently. The duties required of an assistant are light enough to allow the student to carry a full program of study.

Physics

UNDERGRADUATE WORK

The distinctive feature of the undergraduate work in physics at the California Institute is the creative atmosphere in which the student at once finds himself. This results from the combination of a large and very productive graduate school with a small and carefully selected undergraduate body.

In order to provide the thorough training in physics required by those who are going into scientific or engineering work, two full years of general physics are required of all students. This first course in physics introduces modern ideas at the beginning of the first year and develops these along with the principles of classical mechanics and electricity as they apply to the dynamics of particles. More complex problems including the mechanics of continuous media, electromagnetic fields, and atomic structure will be treated in the second year. Those who want to major in physics take intensive courses during their junior and senior years that provide a more than usually thorough preparation for graduate work. The curriculum provides for the teaching of classical and modern physics from the first year through the entire undergraduate course of study. Elective courses during the junior and senior years provide flexibility which enables the student to select a program to fit his individual requirements. Many of the undergraduate students who elect physics are also given an opportunity to participate in some of the thirty to sixty research projects which are always under way and the graduate seminars which are open to undergraduates at all times.

GRADUATE WORK

Graduate students working toward the Ph.D. degree should complete the requirements for admission to candidacy for the doctor's degree as soon as possible (see page 231). The courses required to be passed either regularly or by examination provide an unusually thorough grounding in the fundamentals of physics, and the student learns to use these principles in the solution of problems. After the first year of graduate work, students with special technical training will find it comparatively easy to obtain part-time work during the summer on one or another of the research projects in physics. Students so employed are also expected to register for 15 or more units of research.

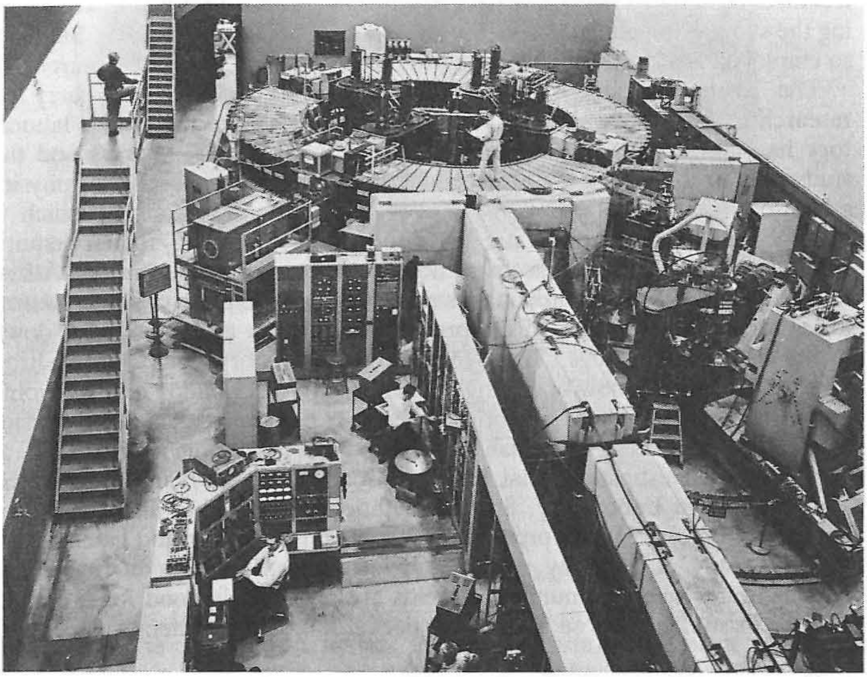
The Norman Bridge Laboratory of Physics is equipped to carry on research in most of the principal fields of physics. An addition to this laboratory has been especially constructed for the work in cosmic rays and the study of elementary particles. Special facilities for research in nuclear physics are also provided in the W. K. Kellogg Radiation Laboratory, which is equipped with three electrostatic generators and a variety of auxiliary equipment. A 12-mev tandem electrostatic accelerator is installed in the Alfred P. Sloan Laboratory of Mathematics and Physics, which also contains laboratories for the investigation of the properties of matter at temperatures down to the milli-degree range. The Synchrotron Laboratory houses an electron accelerator which is now operating at energies up to 1.5 billion electron volts. Work in high-energy physics bridges the gap between the nuclear physics research in the Kellogg and Sloan laboratories and the cosmic ray and elementary particle investigations that have been carried on for many years in the Norman Bridge Laboratory. Special facilities are available in the Norman Bridge Laboratory for the precision investigation of X-rays and gamma rays and the study of beta ray spectra. Opportunities for study in theoretical physics in any one of a number of fields are particularly good for a limited number of students whose ability and background qualify them for theoretical work.

The student may either select his own problem in consultation with the department or work into one of the research projects already under way.

There is a general seminar or research conference each week which is regularly attended by all research workers and graduate students. In addition, a weekly theoretical seminar is conducted for the benefit of those interested primarily in mathematical physics and there are several seminars on special fields of work such as nuclear physics, X-rays, and high-energy physics.

For graduates in physics the main outlets are positions in colleges and universities, in the research laboratories of the government, and in the increasing number of industrial research laboratories of the country.

In order to make it possible for students to carry on their researches even after they have satisfied the requirements for the Ph.D. degree, a number of postdoctoral research fellowships are available.



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

Engineering

UNDERGRADUATE WORK

"The four-year Undergraduate Course in Engineering," as prescribed in the Educational Policies of the Institute, "shall be of general, fundamental character, with a minimum of specialization in the separate branches of engineering. It shall include an unusually thorough training in the basic sciences of physics, chemistry, and mathematics, and a large proportion of cultural studies."

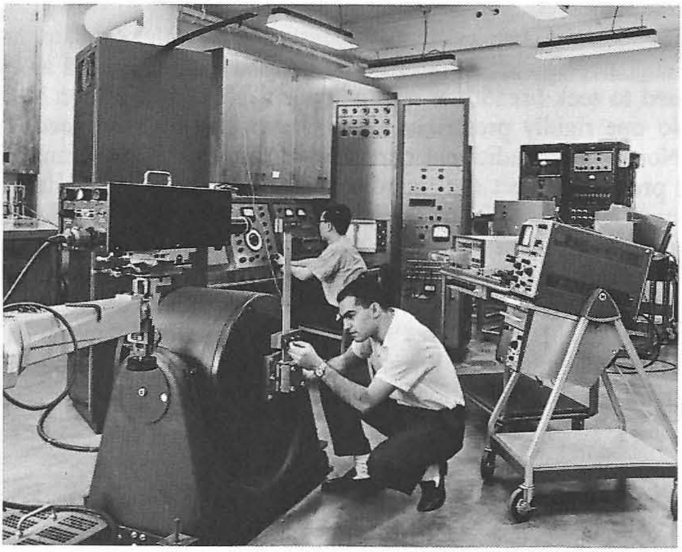
The course is designed to give the greatest possible flexibility as preparation for graduate study and for professional practice. The course involves four years of study leading to the degree of Bachelor of Science. The first year is common for all students at the Institute. At the end of this year a student who elects engineering is assigned an advisor in his general field of interest and together they develop a program of study for the next three years. This program includes the Institute-wide requirements in physics, mathematics, and humanities, and an additional, or third year, of advanced mathematics. Beyond these specifications the student and his advisor choose from a wide range of engineering and science electives to build a solid foundation for the kind of engineering activity toward which the student aims. For most students, graduate study in a specialized branch of engineering will be the goal. These men may wish to elect some foreign language also as graduate preparation. For others, immediate industrial work is the objective, and ultimately administration. Such students will be able to build a course of study from specialized professional courses and more general engineering science subjects suitable for more immediate engineering practice. Among such professional courses are a number which are nominally graduate subjects but which may be elected by undergraduates with adequate preparation.

The engineering curriculum is thus extremely flexible and a student will be advised to seek breadth as well as reasonable concentration in a technical area. No one rigidly prescribed curriculum can serve the needs of all students. Nor do the traditional curricula of the specialized branches of engineering properly reflect the interdisciplinary character of modern engineering. Consequently, the California Institute of Technology has adopted a single engineering curriculum strong in the sciences and humanities, with great flexibility of choice among the engineering sciences. This four-year bachelor's program leads logically toward graduate study in some specialized engineering field. It recognizes the increasing national growth in graduate engineering education and through good counseling and elective freedom builds an adequate preparation.

GRADUATE WORK

Graduate study and research opportunities exist in aeronautics, applied mechanics, chemical, civil, electrical, and mechanical engineering, engineering science, and materials science. An interdivisional program in applied mathematics is offered as explained on page 139. The courses leading to the degree of Master of Science normally require one year of work following the bachelor's degree and are designed to prepare the engineer for professional work of a more specialized and advanced nature. A second year of graduate work leads to the degree of Aeronautical Engineer, Civil Engineer, Electrical Engineer, or Mechanical Engineer. In addition, advanced work is offered in aeronautics, applied mathematics, applied mechanics, chemical engineering, civil engineering, electrical engineering, mechanical engineering, materials science, and engineering science leading to the degree of Doctor of Philosophy. In all phases of the graduate program students are encouraged to include in their courses of study a considerable amount of work outside of their specialized fields, particularly in mathematics and physics.

The Division of Engineering and Applied Science includes those curricula and facilities which are a part of the options of civil, electrical, or mechanical engineering, aeronautics, applied mathematics, applied mechanics, materials science, and engineering science in which degrees designated with these options are given. In addition, the Division includes subjects and research facilities in which no specific degree is offered, but which form a part of a student's course of study or are available to him as optional work. These subjects are hydraulics and hydrodynamics, jet propulsion, nuclear energy, physical metallurgy, polymers, biological engineering sciences, and environmental health engineering. Some of the specialized laboratory facilities available for instruction and research are the various wind tunnels; the Computer Center, which includes the analog and digital computers; the Dynamics Laboratory; Nuclear Measurements Laboratory; and the several facilities for work in hydraulic structures, hydrodynamics, physical metallurgy and properties of materials, hydrology, water supply, environmental health, and biological systems.



Student research in the Shock and Vibrations Laboratory

AERONAUTICS

The Graduate School of Aeronautics and the Guggenheim Aeronautical Laboratory, widely known as the GALCIT, were established in 1928 at the California Institute with the aid of the Daniel Guggenheim Fund for the Promotion of Aeronautics. In 1948 a Jet Propulsion Center, to provide facilities for study in that field, was established by the Daniel and Florence Guggenheim Foundation (see page 156). At about the same time an addition to the original Guggenheim Laboratory was constructed in an attempt to cope with the demands which twenty years of growth had imposed. The subsequent attainment of supersonic flight, and the more recent opening of what has been called the "Space Age," by the first Russian and United States orbiting satellites, tremendously increased both the scope and the research facility requirements of the field involving both science and engineering which is here called aeronautics. Generous donors have recently made it possible for the California Institute to more nearly satisfy the needs thus created. Both the Karman Laboratory of Fluid Mechanics and Jet Propulsion (a gift of the Aerojet-General Corporation) and the Firestone Flight Sciences Laboratory (donated by the Firestone Tire and Rubber Company) were completed and occupied during the academic year 1961-62. Together with the original Guggenheim Laboratory, to which they are contiguous, they constitute an integrated group of Graduate Aeronautical Laboratories (also known as GALCIT) in which the enlarged activities resulting from the extension of the aeronautical environment into space can adequately be accommodated. In particular, the Jet Propulsion Center is now able to concentrate its major activities in the Karman Laboratory rather than having its work scattered in several Institute buildings as has been necessary in the past. The Karman Laboratory also contains extensive facilities for researches in true hydrodynamics (using water as the fluid) which have long been a part of the Institute's program. The staffs housed in this group of laboratories are actively engaged in the fields of aeronautics, jet propulsion, hydrodynamics, space flight, and the allied sciences. The following are the major areas in which postgraduate instruction and advanced research are currently concentrated:

1) Fluid mechanics including classical hydrodynamics and aerodynamics; turbulence; stochastic and molecular approaches; hypersonic and rarefied gas flows including the effects of very high temperatures; magnetohydrodynamics and plasma physics.

2) Solid mechanics relating to the properties of materials; statics and dynamics of elastic, plastic, and viscoelastic bodies; fracture; finite strains; elastic waves; thermal stress; shell theory and photoelasticity.

3) Performance, structural mechanics, and flight dynamics of aircraft and spacecraft, including air and space vehicle performance, stability and control with the associated aerodynamic, propulsive, and environmental inputs; multistage rocket performance; aeroelasticity; orbital mechanics, trajectories, reentry mechanics and thermodynamics.

4) Jet and rocket propulsion of aircraft and spacecraft (see page 156).

In all four of the above areas primary emphasis is placed on the underlying mathematics, physics, and chemistry and on their application to the solution of the scientific and engineering problems involved.

The group of Graduate Aeronautical Laboratories contains very complete and diversified facilities in support of the above program. The 200-m.p.h., 10-foot-diameter wind tunnel which has been in continuous service for nearly 35 years continues to be a valuable tool for low-speed research and model testing. The fluid mechanics laboratory contains several smaller wind tunnels and a considerable amount of special apparatus and equipment suitable for the study of basic problems connected with turbulent flows. The problems of transonic, supersonic, and hypersonic flows may be investigated in other wind tunnels specifically designed for such purposes. In these tunnels velocities up to 10 times the speed of sound can be attained. Shock tubes, plasmajets, inverse pinch facilities, mercury tunnels, and other special items of laboratory apparatus are available for studies of extreme temperature, rarefied gas, and magnetohydrodynamic effects. The solid mechanics laboratories contain standard and special testing machines for research in aircraft and spacecraft structures and materials. Fatigue machines are also available as is photoelastic equipment for the study of stress distribution by optical methods. Special apparatus, including very high speed cameras, is used in studies of elastic waves, stress propagation, panel flutter, and the mechanics of static and dynamic fracture. The laboratory facilities for jet propulsion and hydrodynamics are described in the sections on the Jet Propulsion Center and on Hydrodynamics, starting on page 156. The laboratories also include excellent shop and library facilities, conference and study rooms, in addition to the usual lecture halls and offices.

Another activity which had its origin at the GALCIT and with which the aeronautics and jet propulsion groups continue to maintain close contact is the Jet Propulsion Laboratory. Currently it has a staff of 4000 persons, of which some 1350 are professional engineers or scientists. The Laboratory is owned and supported by NASA and is administered by the Institute. Its primary responsibility is the "development of spacecraft and the carrying out of unmanned lunar and interplanetary exploration." This includes an extensive supporting research and advanced technical development program on the fundamental problems of propulsion; fuels and combustion; high-temperature materials; rocket-motor design, guidance, and control; and electronic instrumentation for tracking and telemetering. Among the experimental facilities are two supersonic wind tunnels (a 20-inch tunnel capable of speeds of 4.8 times the velocity of sound and a 21-inch hypersonic wind tunnel capable of speeds of 7 to 9 times sound velocity); a space environmental simulator; over a dozen rocket and thermal jet test cells; large laboratories devoted to space sciences, refractory materials, hydraulics, instrumentation, chemistry, combustion, heat transfer; and high-speed digital and analog computers. The Laboratory extends the use of these facilities to properly accredited Institute students who are doing thesis work.

As in the fields of physics, chemistry, and mathematics, emphasis is placed primarily upon the development of graduate study and research; but provision has also been made in the four-year undergraduate course for work leading to such graduate study and research. This affords a broad and thorough preparation in the basic science and engineering upon which aeronautics rests.

The graduate courses may be taken either by students who have completed a four-year course at the Institute, or by students from other colleges who have had substantially the same preparation. The field of aeronautics is so many-sided that a student who has completed the undergraduate course either in engineering or in applied science will be admitted to the first-year graduate course. The second-year work, however, may be taken only by students who have completed the first-year course at the Institute or who have had substantially the same preparation elsewhere.

Still more advanced study and research are offered for the degree of Doctor of Philosophy. This degree is given under the same general conditions as those that obtain in the other courses offered at the Institute.

Applied Mathematics

(See pages 124 and 139)

Applied Mechanics

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

Research studies in these areas which illustrate current interests include: linear and nonlinear vibrations, random vibrations, structural dynamics and design for earthquake and blast loads, wave propagation in bounded elastic and viscoelastic media, diffraction of elastic waves by cavities and inclusions, boundary layer problems in plates and shells, finite dynamic deformations of elastic media, stratified flow, unsteady cavity flow, and rheology of blood in small tubes.

The work for the degree of Master of Science in Applied Mechanics ordinarily consists of three terms of formal instruction in basic courses in applied science. Students are given considerable latitude in selecting these courses, in consultation with the staff, and are encouraged to elect basic courses in mathematics and physics as well as courses in other options of the Division of Engineering and Applied Science. Students who have completed four-year B.S. programs in undergraduate options such as applied mechanics, engineering science, physics, mathematics, or engineering options having a strong background in applied mathematics, will in general be eligible to apply for admission to M.S. candidacy status.

The degree of Doctor of Philosophy in Applied Mechanics will ordinarily involve a 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.

In addition to the regular facilities of the Division of Engineering and Applied Science, such as the extensive digital computing facilities of the Computing Center, and the special facilities for studies in solid and fluid mechanics of the Graduate Aeronautical Laboratories, certain special facilities have grown up in connection with applied mechanics activities. The Dynamics Laboratory is equipped with a good selection of modern laboratory apparatus and instrumentation for experimental research in shock and vibration, and the Earthquake Engineering Research Laboratory contains specialized equipment for the analysis of complex transient loading problems, and for the recording and analysis of strong-motion earthquakes. Several analog computers are also available. Other specialized laboratories include the Heat Transfer Laboratory, which contains a forced convection heat transfer loop, and the Laboratory of Microhydrodynamics and Rheology, with equipment for precision viscosimetry and studies in streaming birefringence.

Biological Engineering Sciences

Graduate study and research in areas involving the application of the engineering sciences to problems of biological significance are of continually increasing importance at the California Institute of Technology. The primary areas of interest at present are in the fields of biosystems, environmental health engineering, transport processes, and circulatory mechanics. Close cooperation exists among the different groups and joint seminars are held frequently.

Students interested in any of these fields may work for advanced degrees in engineering science or any of the other branches of engineering at Caltech, including chemical engineering. Details of the program are worked out by the student and his advisor depending on individual interest.

Biological Systems Laboratory. (See page 153)

Environmental Health Engineering. Population growth and industrial expansion place increasing strains on our water supplies and air resources. The environmental health group is concerned with the engineering aspects of the protection and control of our atmosphere and water supplies.

Research is currently in progress in the W. M. Keck Laboratory of Environmental Health Engineering on several phases of waste-water reclamation including the adsorption and desorption of viruses, the fate of chemical pesticides in surface waters, and the removal of trace concentrations of radioisotopes from sewage. Studies are also under way on the biochemical stablization of urine in space vehicles and the dispersion and fate of wastes in the ocean.

Extensive work in aerosol physics with application to air pollution problems is also in progress. Included are theoretical studies of the size spectra of dispersed phases, and aerosol filtration by fibrous filters. Experiments on filtration of solid particles from air are being carried out in a low-speed wind tunnel built for the purpose in the Keck Laboratories.

Transport Processes. A number of studies of interfacial transfer in systems of physiological interest are being carried out in the W. M. Keck Engineering Laboratories. An investigation of convective diffusion in blood is under way in an apparatus specially designed for the control of the blood velocity at a membrane interface. The results will have application to the design of membrane oxygenators (heart-lung machines) and to material transfer in the large vessels of the circulatory system. This investigation has been assisted by several medical institutions in the Los Angeles area. Studies have also been initiated on the theory of particle and gas transport in the lungs and the theory of convective diffusion in the proximal tubule of the kidney. This work is being carried out in close cooperation with Chemical Engineering.

Circulatory Mechanics. Studies on the effects of the rheological properties of blood and the vascular structures on flow, particularly in the microcirculation, are being carried on in collaboration with the Cardiovascular Research Laboratory of Loma Linda University. Studies are currently being made of the rheology of complex suspensions, and blood in Couette flow and in flow through tubes of diameters in the size range of interest in microcirculatory studies (5 to 500 micra). Also in progress are living microcirculatory tests of small animals. This research is being correlated with work on larger animals by active participation in work at the Cardiovascular Research Laboratory, located at the Los Angeles County Hospital, about nine miles from the California Institute of Technology.

Facilities are available in the Thomas Engineering Laboratory for measurement of viscosity, streaming birefringence, tube flow, and still and cine photomicrography, as well as for the necessary chemical and physiological preparations. Equipment has also been developed for measurement of the rheological properties of vessel walls.

CHEMICAL ENGINEERING

(See pages 129-135)

CIVIL ENGINEERING

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

Civil engineering is a branch of engineering covering a broad spectrum of interests concerned with man's relationship to the environment. Problems which the profession is called upon to handle range from the analysis of structures subjected to dynamic loadings to radioactive waste disposal, from arctic soil problems to sediment transportation in streams.

Advances in recent years in the general field of engineering have encouraged a reappraisal of civil engineering education and increased the scope of research in that field. New problems have presented exciting challenges to the civil engineer well trained in the fundamentals of his profession. For this reason, in the advanced study of civil engineering at the Institute, emphasis is placed on the application of mathematics and basic scientific principles to the solution of civil engineering problems, and the student is discouraged from depending on handbooks and empirical formulas. The general areas in which advanced work is offered are: (1) structural engineering and applied mechanics, (2) soil mechanics and foundation engineering, (3) hydraulics: hydrodynamics, hydraulic engineering, hydrology, and coastal engineering, and (4) environmental health engineering.

The emphasis in the undergraduate school of the Institute is on the basic subjects in science and engineering. In particular, strong emphasis is placed on physics, mathematics, and solid and fluid mechanics. The first year of graduate study involves more specialized engineering subjects, but the student working for the Master of Science degree is encouraged not to overspecialize in one particular field of civil engineering.

Greater specialization is provided by work for the engineer's and for the doctor's degree. The candidate for these degrees is allowed wide latitude in selecting his program of 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.

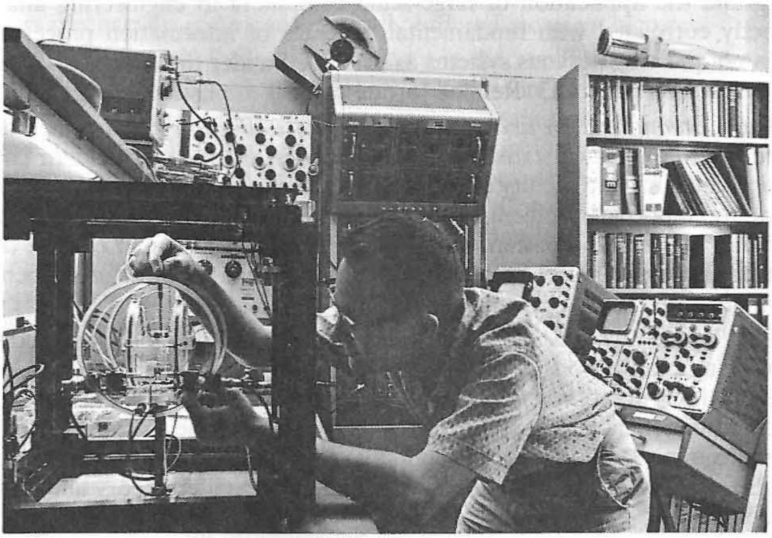
In some instances, a student who has not specialized in civil engineering as an undergraduate will be admitted for graduate study. As preparation for advanced study and research, a good four-year undergraduate program in mathematics and the sciences may be substituted for a four-year undergraduate engineering course with the approval of the faculty. However, for students with a science background, the master's degree program will usually require two years instead of the usual one year for students with an engineering background. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his program in consultation with a member of the faculty. In some cases, the student may be required to make up deficiencies in engineering science courses at the undergraduate level. However, in every case the student will be urged to take some courses which will broaden his understanding of the over-all field of civil engineering, as well as courses in his specialty. Most graduate students are also required to take further work in applied mathematics.

Excellent research facilities are available to qualified graduate students in all of the general areas of civil engineering which have been mentioned. Facilities for structural engineering and soil mechanics are located in the Thomas Laboratory of Engineering. Hydraulic research is carried on in the Laboratory of Hydraulics and Water Resources, which is located in the W. M. Keck Engineering Laboratories, and is described in detail under the section on Hydrodynamics (page 157). The Laboratory for Environmental Health Engineering is also located in the W. M. Keck Engineering Laboratories. Work in this field is closely integrated with research in hydraulics and water resources, as well as with biology and chemistry. It is also included among the Biological Engineering Sciences as described on page 148.

In recent years, graduate students and members of the staff have pursued a variety of research programs including analysis of structures subjected to dynamic loadings (such as earthquakes); the use of digital computers for structural analysis; soil deformation under stress; lunar soils studies; permafrost; investigation of laws of sediment transportation in streams; the flow of stratified fluid; wave-induced harbor oscillations; design criteria for various hydraulic structures; aerosol filtration; radioactive waste disposal; water reclamation; and the disposal of wastes in the ocean.

Electrical Engineering

Electrical engineering at the Institute is a growing, dynamic field. It no longer emphasizes power systems and standard electronics, but has expanded into several diverse and exciting areas. New materials and techniques, and the concepts and approaches of physics, mathematics, and data processing are being applied in a wide variety of studies, including plasma dynamics, electromagnetic radiation, quantum electronics, new solid state materials and devices, circuit function design, control systems, communication theory, machine learning, and sensory perception. The broad spectrum of problems falling within this branch of engineering provides exceptional and challenging opportunities for both theoretical and experimental work.



Graduate student investigating the solid state physics of thin films

The distinctive feature of undergraduate courses in electrical engineering is the strong emphasis on the underlying fundamental principles as opposed to techniques and applications. This, coupled with the abundance of mathematics and physics courses in the curriculum, the variety of elective choice, and the creative atmosphere in which the student finds himself, provides an excellent background for either advanced graduate work or industrial employment.

For many students the four-year program leading to the Bachelor of Science degree is followed by additional graduate work for the Master of Science degree in Electrical Engineering, usually completed in one year. For exceptional students, instruction is offered leading to the degrees of Electrical Engineer and Doctor of Philosophy. The graduate curriculum is sufficiently flexible to allow the student to select courses closely aligned with his particular field of interest. Students are encouraged to participate in graduate seminars and in research projects with the electrical engineering faculty.

Laboratory facilities are available for a wide variety of research activities. At present electrical engineering activities are housed mainly in the Spalding Laboratory on campus. A new building, the Harry G. Steele Laboratory of Electrical Sciences, is currently under construction and scheduled for occupancy about January 1966. This will be a modern, 55,000-square-foot laboratory building located immediately north of the Booth Computing Center and designed specifically for the research needs of the electrical engineering faculty and students.

The *Willis H. Booth Computing Center* (see page 117) provides comprehensive facilities for research and instruction on the basic principles of information processing and their electronic instrumentation. This includes work on switching and computer system theory, switching circuits, advanced programming and the application of large-scale computers to engineering analysis. Directly correlated with fundamental concepts of information processing is research on living nervous systems as described under the *Biological Systems Laboratory* on page 153. Related formal courses are listed on page 327.

The *Communication and Control Systems Laboratory* is a center of research in the fields of statistical communication theory and modern control theory. Students and faculty of the laboratory are actively engaged in research on many important problems of communication and control theory, such as machine learning and pattern recognition, signal selection and coding, detection of signals in noise, spectral estimation, optimal control and stochastic optimal control.

The *Plasma Dynamics Laboratory* is involved in studying wave phenomena in plasmas and methods of producing laboratory plasmas. Facilities are available for the generation and diagnosis of a variety of plasmas. Current studies involve theoretical and experimental investigations of the scattering of microwaves from non-uniform plasma columns. Also under investigation are hydromagnetic waves in a plasma-filled waveguide, the detailed theory and application of Langmuir probes, and nonlinear beam-plasma interactions.

The *Electromagnetic Radiation Laboratory* is devoted to theoretical and experimental studies of electromagnetic radiation phenomena. It provides facilities for the investigation of basic problems arising from recent developments in antenna theory and design, quantum electronics, and plasma physics. Theoretical research now in progress includes topics in the mathematical theory of diffraction, wave propagation and oscillations in plasmas, artificial dielectrics, and surface wave antennas. Experimental work in progress includes the study of magnetohydrodynamics, and microwave interactions with plasmas.

The *Quantum Electronics Laboratory* is engaged in research in the area of generation and control of coherent light and in the study of related physical phenomena. Research projects now in progress include: interaction of coherent light with atomic systems, non-linear effects in laser media, non-linear optics, light-hypersound interactions and electromagnetics of optical resonators. The facilities include a laser fabrication setup and equipment for spectroscopic studies in the ultraviolet, visible, near and medium infrared region.

The *Solid State Electronics Laboratories* engage in studies of the physical properties of solids, device electronics, and circuit applications. Research projects now in progress include tunneling phenomena in thin dielectric layers, generation of infrared radiation in small-gap semiconductors, recombination and injection mechanisms in semiconductors, generalized theory of field-effect and diffusion transistors, and analysis and design of multiple-loop feedback systems. Facilities are available for vacuum evaporation and deposition, and for a variety of measurements on materials and devices.

Research in the *Magnetics Laboratory* centers around the investigation of ferromagnetic anisotropy and flux reversal, the two effects which are the basis of modern digital magnetic devices. Anisotropy studies in thin films of nickel, iron, and cobalt alloys are concerned with both field-induced and magneto-crystalline anisotropy, with a goal of understanding both the origin and consequences of the anisotropy. Studies of the flux-reversal mechanism in films and toroids and ferromagnetic resonance experiments are used to investigate the loss mechanism in ferromagnetically ordered atomic structures.

The *Biological Systems Laboratory* is the result of a newly created joint research program with the Biology Division on sensory perception and the nervous system as they relate to data processing systems and the theory of systems analysis. This laboratory contains facilities for direct research on sensory systems, including a newly developed experiment control and data reduction system directly connected to the Computing Center. This makes possible the real-time computer control of complex experiments on biological preparations, together with accurate recording and precise analysis of the resulting data.

This laboratory has been developed to integrate the disciplines of neural biology and systems theory. It is available for research sponsored either jointly or individually by the Biology and Engineering Divisions.

Engineering Science

Advanced programs of study leading to the degree of Master of Science and Doctor of Philosophy in Engineering Science are offered by the Division of Engineering. These programs are designed to meet the needs of currently developing fields of engineering and applied science that are not emphasized in already established engineering disciplines. The general requirements for advanced degrees in engineering science are similar to those in the other fields of engineering and include for the doctorate the completion of satisfactory thesis research. The program for the Master of Science degree in Engineering Science is described on page 268. The fields of study may include such topics as fluid mechanics, dynamics of deformable solids, rheology of biological fluids, reactor physics, plasma physics, combustion, and other applications of modern physics and chemistry to engineering.

Note: Students wishing to pursue graduate studies in nuclear engineering may apply for admission in this option. Such applicants are encouraged to apply for AEC Special Fellowships in nuclear science and engineering, details of which may be obtained from the Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tennessee.

Materials Science

The Division of Engineering offers programs of study leading to the degrees of Master of Science and Doctor of Philosophy in Materials Science. Graduate courses and research on solids is offered in the following general fields:

1. Electrical Properties
2. Magnetic Properties
3. Mechanical Properties
4. Dynamical Properties
5. Alloy Systems
6. Radiation Effects
7. Fracture Mechanics
8. Polymer Properties
9. Mechanics of Granular Media

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. The student is allowed considerable freedom in choosing his courses. However, he must obtain the approval of his advisor for the program and any subsequent changes. Formal thesis work is not required, although laboratory courses are provided as elective courses so that the student can utilize the basic equipment and techniques employed in a variety of research fields.

Work toward the degree of Doctor of Philosophy in Materials Science usually requires a minimum of two years following completion of the master's degree program. Ordinarily, at least one year of this time is devoted to research work leading to a doctoral thesis. The course work and thesis work are planned by the student and his advisory committee so as to fit best the background and interests of the student.

Instruction and research in materials science is available. Current research activities include: properties of thin metallic and insulating films, anisotropy with respect to magnetic and electrical properties, electron transport processes, relationship between mechanical properties and structure, fracture and fatigue damage in metals and polymers, behavior of metals under dynamic loading conditions, model representation of material behavior for viscoelastic media on both micro and macro scales, structure of alloys, kinetics of phase transformation, crystal structure and properties of metastable phases, theoretical and experimental studies of deformation processes, diffusion in solids, radiation effects on physical and mechanical properties of materials, and studies in the mechanics of granular materials.

Work in metallic materials is carried on in the Laboratory of Engineering Materials occupying two floors of the W. M. Keck Engineering Laboratories. These facilities include a 2-mev electron accelerator and a helium cryostat. Special laboratories are provided for studies on the mechanics of materials and for the dynamic application of stress.

The work on the magnetic and electrical properties of materials is carried on in the Spalding Engineering Laboratory. The work in the field of polymers and fracture mechanics is done with extensive facilities in the Keck Laboratories and Firestone Flight Sciences Laboratory. Facilities are available for work with granular materials in the Thomas Laboratory of Engineering.

Mechanical Engineering

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

The undergraduate program of instruction in mechanical engineering is organized within the engineering option for the Bachelor of Science degree. The first-year graduate program is open to qualified students who have completed the four-year engineering course for the Bachelor of Science degree from the Institute, or have had substantially the same preparation in other colleges. The first four years at the Institute are concerned with basic subjects in science and engineering and in the humanities. The first graduate year, therefore, is somewhat more specialized, with options in general mechanical engineering, jet propulsion, or nuclear engineering. A schedule of subjects is specified for each of these first-year graduate options which may be modified with the approval of the student's advisor and the faculty in mechanical engineering to satisfy the special interest of the student.

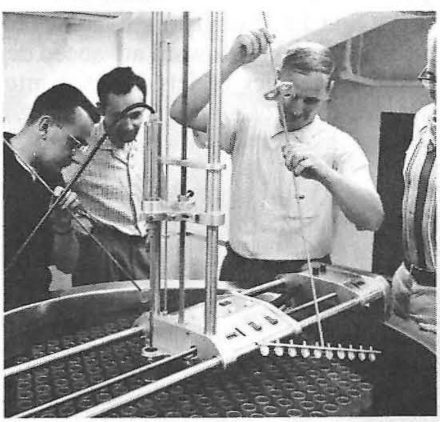
Greater specialization is provided by the work for the engineer's or doctor's degree. The student is allowed considerable latitude in selecting his course of subjects, and is encouraged to elect related course work of advanced character in the basic sciences. The engineer's degree of Mechanical Engineer is considered as a terminal degree for the student who wishes to obtain advanced training more highly specialized than is appropriate to the degree of Doctor of Philosophy. Research work leading to a thesis is required for the engineer's degree and for the doctor's degree.

Facilities for advanced work in mechanical engineering are provided in four general areas: (1) hydrodynamics, (2) design, mechanics, and dynamics, (3) thermodynamics and heat power, and (4) nuclear energy. Extensive facilities are available in hydrodynamics as described on page 157. A Dynamics Laboratory is provided for the study of problems in vibration, transient phenomena in mechanical systems, and experimental stress analysis by means of special mechanical and electronic equipment. Work in the field of thermodynamics and heat power is implemented by laboratories containing internal combustion engines and heat-transfer apparatus. Work is in progress on certain phases of gas turbines which provides problems and facilities research in this field.

An additional activity of interest to all advanced students in engineering is the Analysis Laboratory. This laboratory is built around an analog computer, which merges the various interests in applied mechanics, applied mathematics, and electrical engineering in the solution of problems. The computer is valuable not only for the solution of specific research problems but also as research in itself in the development of new elements to extend the usefulness of the computer to more general mathematical analysis.

Close connections are maintained by the mechanical engineering staff with the many industries and governmental research agencies in the area which provide new, basic problems and facilities for study and research in the broad field of mechanical engineering.

Determination of neutron flux distribution in a subcritical nuclear reactor



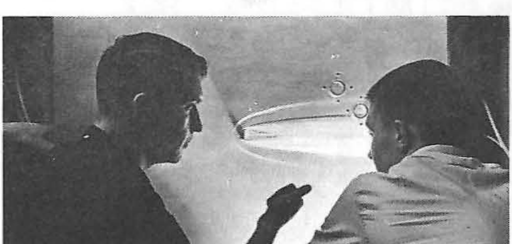
Jet Propulsion

During 1948 a Jet Propulsion Center was established at the California Institute of Technology by the Daniel and Florence Guggenheim Foundation. This Center was created specifically to provide facilities for postgraduate education and research in jet propulsion and rocket engineering, with particular emphasis on peacetime uses: to provide training in jet propulsion principles, to promote research and advanced thinking on rocket and jet-propulsion problems, and to be a center for peacetime commercial and scientific uses of rockets and jet propulsion. The Guggenheim Jet Propulsion Center is a part of the Division of Engineering of the California Institute of Technology. All instruction in the Guggenheim Center is on the graduate level.

The solution of the engineering problems in jet propulsion requires new techniques as well as drawing on the knowledge and practice of the older branches of engineering, in particular mechanical engineering and aeronautics. Thus it is appropriate that the program of instruction includes material from both of these engineering fields. In general, students entering the course work in jet propulsion will have had their undergraduate preparation in mechanical engineering or aeronautics, but the courses are also available to students whose preparation has been in applied mechanics, engineering science, or physics. The complete program of instruction in jet propulsion for first-year graduate students is available to those candidates for the degree of Master of Science in Mechanical Engineering electing the jet propulsion option. Candidates for the degree of Master of Science in Aeronautics may take some of the courses in jet propulsion as electives. Candidates for the degree of Aeronautical Engineer or Mechanical Engineer may elect an option in jet propulsion for more advanced courses and research in this field.

Students admitted to work for the degree of Doctor of Philosophy in Aeronautics, Applied Mechanics, Engineering Science, or Mechanical Engineering may take part of their courses of instruction in jet propulsion and choose a research problem in jet propulsion as a thesis topic. The degree of Doctor of Philosophy does not carry a designation specifying the field of jet propulsion.

The Jet Propulsion Center is located in the new Karman Laboratory of Fluid Mechanics and Jet Propulsion. Facilities for experimental research are available to students working toward advanced degrees. The dynamics of two-phase flows, the mechanics of jets injected into a supersonic stream, heat transfer to the electrodes of plasma accelerators, and ionization rates in gases represent a few of the topics that are currently under investigation.



An experiment in cavitation behind a flat plate

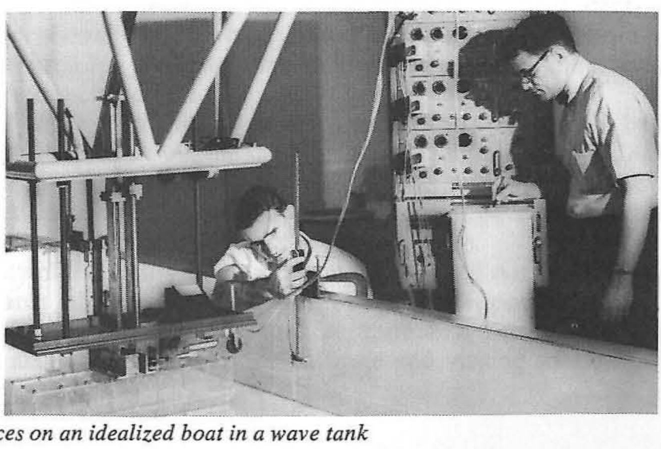
Hydrodynamics

Instruction and research in hydrodynamics and hydraulic engineering are concerned with various subjects which complement other Institute work in fluid mechanics. Current interests in this field include, for example, water waves, hydrodynamics of submerged or floating bodies, physics of cavitation, jets and cavity flows, flows of stratified fluids, turbulence and diffusion, open channel flow, sediment transportation, and flow through porous media. No specific degree in Hydrodynamics is given; however, advanced students working in this field may select enrollment and obtain degrees in Applied Mechanics, Civil Engineering, Mechanical Engineering or Engineering Science, depending upon their field of interest. The laboratories described below provide excellent facilities for graduate student research.

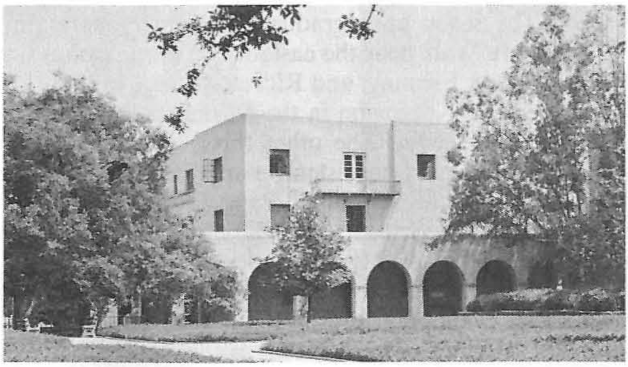
Hydraulic Machinery Laboratory. The purpose of this laboratory is to carry out basic research in the hydrodynamics of centrifugal and axial flow turbomachines and components thereof. The facilities include basins, dynamometers, pumps, venturis, and calibrating tanks.

Hydrodynamics Laboratory. This laboratory is located in the Karman Laboratory of Fluid Mechanics and Jet Propulsion. It contains three major experimental facilities—the high-speed water tunnel, the free-surface water tunnel and the controlled-atmosphere launching tank. The high-speed water tunnel has a closed working section 14 inches in diameter and an alternate two-dimensional working section 6 by 30 inches, in which a maximum flow velocity of 85 feet per second can be obtained. The free-surface water tunnel can provide a maximum velocity of 27 feet per second in a working section 20 by 20 inches and 8 feet in length. The ambient pressure in the launching tank can be controlled down to 1/11 atmospheric pressure for modeling water entry and underwater trajectories.

Hydraulics and Water Resources Laboratory. The W. M. Keck Engineering Laboratories provide space for an expanded basic research program in various phases of fluid mechanics and hydraulic engineering related to development and control of water resources. The facilities include: four recirculating tilting frames for research in open channel flow, density currents and sediment transport (one is 130 feet long with cross section 43 inches wide by 24



Measuring wave forces on an idealized boat in a wave tank inches deep, and others are respectively 60 feet, 40 feet, and 18 feet long); two fixed flumes for studies of boundary layer growth at low velocity, density currents, and flow in hydraulic structures; a low-turbulence water tunnel; a wave basin (32 feet long by 16 feet wide); a tank 8 feet long for studies of groundwater flow; special tanks and circulation systems needed in research; miscellaneous equipment for a variety of student laboratory experiments; and extensive electronic instrumentation systems. Research projects are an integral part of the academic program and are carried out by the faculty, and by graduate students as thesis projects.



Dabney Hall of the Humanities

The Humanities

Throughout its history the California Institute has placed a strong emphasis upon the humanities as an important and necessary part of the education of a scientist or engineer. At the undergraduate level all students are required to devote a substantial part (between one-fifth and one-fourth) of their curriculum to humanistic studies. At the graduate level, humanities courses are required for the Master of Science degree in Aeronautical Engineering, Civil Engineering, and Astronomy, and are recommended in other options. At the doctoral level, a Ph.D. minor may be taken in Economics, Philosophy, History, or English, with a Ph.D. major in any branch of science or engineering.

Beginning with the academic year 1965-66, the California Institute offers undergraduate options in English, history, and economics, leading to the B.S. degree in Humanities. 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, physics, and American history in the sophomore year. In the last two years, students in these options will take 60 units of electives in science, mathematics, or engineering courses as well as the advanced work in their humanities option. The purpose of the humanities options at the California Institute 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, 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.

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.

Student Life

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

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

Since the demand for rooms may exceed the supply, newly entering students are advised to file room applications with the Master of Student Houses immediately upon being notified by the Dean of Admissions of admittance to the Institute. All freshmen are expected to live in the Houses. Those who have reason to believe they should live elsewhere should discuss the matter with the Dean of Freshmen.

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

Ruddock

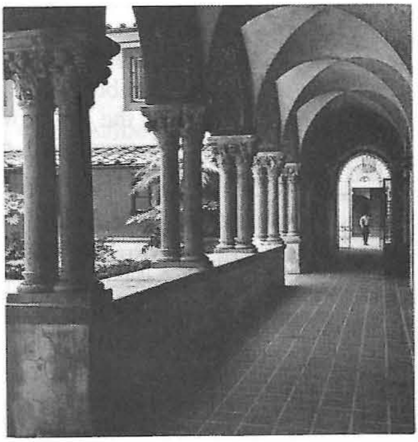
Lloyd

Page

Blacker

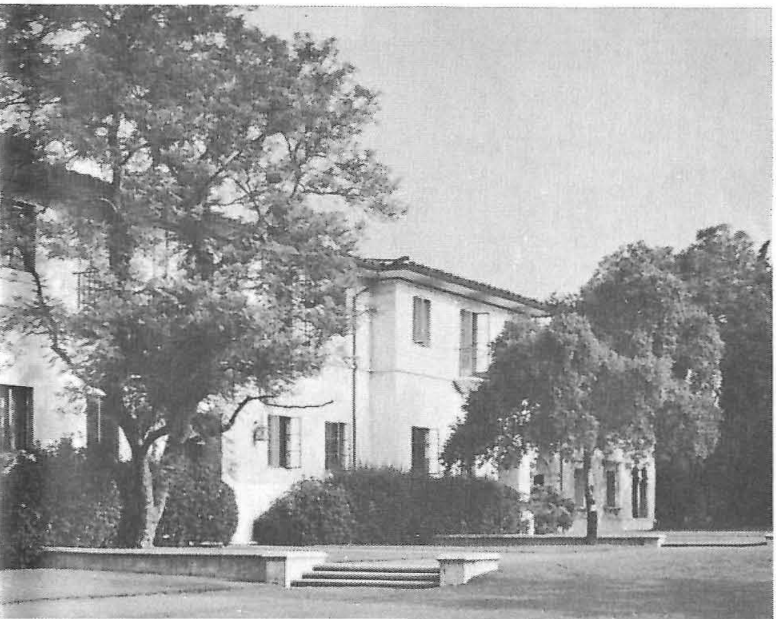
Dabney

Fleming



Ricketts

UNDERGRADUATE HOUSES

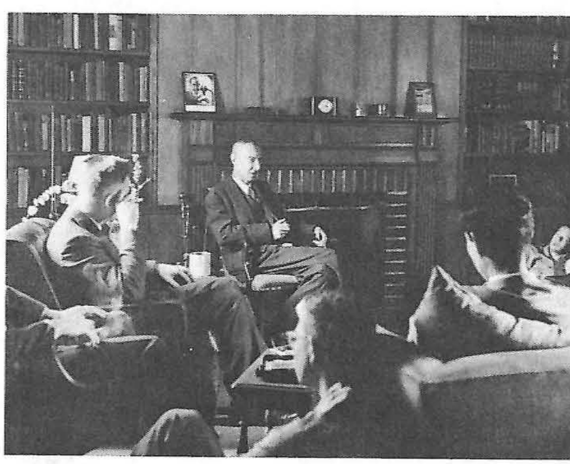


The Student Houses are pleasantly located in the east campus

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

"ASCIT." The undergraduate students are organized as the "Associated Students of the California Institute of Technology, Incorporated," (ASCIT). All students pay the student-body fees and are automatically members of this organization, which deals with affairs of general student concern and with such matters as may be delegated to it by the faculty. Membership in the corporation entitles each student to (a) admission to all regular athletic or forensic contests in which Institute teams participate, (b) one vote in each corporate election, and (c) the right to hold a corporate office. The executive body of the ASCIT corporation is the Board of Directors, which is elected by the members in accordance with the provisions of the By-Laws. The Board interprets the By-Laws, makes awards for athletic and extracurricular activities, authorizes expenditures from the corporation funds, and exercises all other powers in connection with the corporation not otherwise delegated.

Board of Control. The Honor System is the fundamental principle of conduct for all students. More than merely a code applying to conduct in examinations, it extends to all phases of campus life. It is the code of behavior governing all scholastic and extracurricular activities, all relations among students, and all relations between students and faculty. The Honor System is the outstanding tradition of the student body, which accepts full responsibility for its operation. The Board of Control, which is composed of elected representatives from each of the seven Houses, is charged with interpreting the Honor System. If any violations should occur, the Board of



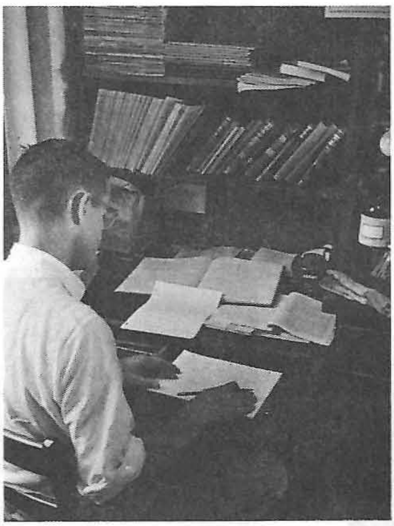
An informal discussion
with a distinguished visitor to the campus

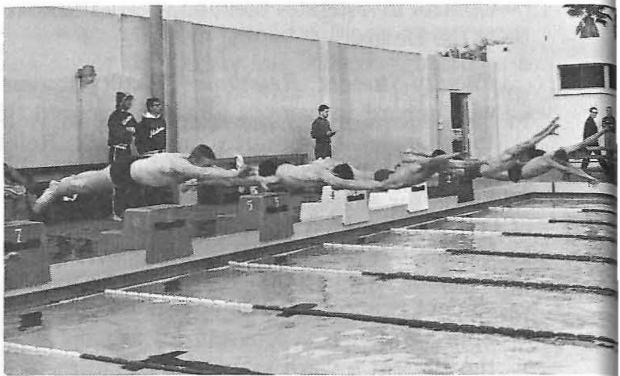
Control investigates them and recommends appropriate disciplinary measures to the Deans.

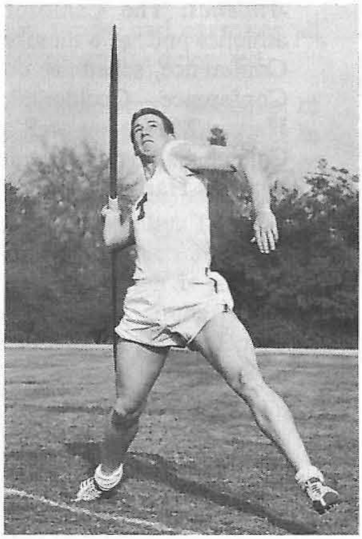
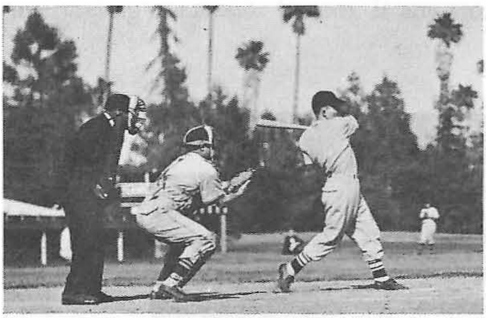
Faculty-Student Relations. Faculty-student coordination and cooperation with regard to campus affairs is secured through periodic joint meetings of the Faculty Committee on Student Relations and certain student body officers and elected representatives. These conferences serve as a clearing house for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

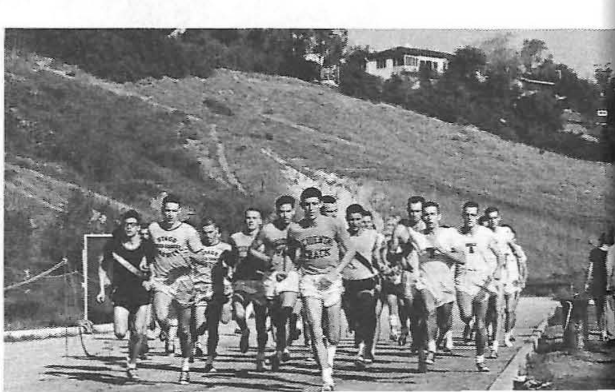
Option Advisors. Each member of the three undergraduate upper classes is assigned to an Option Advisor, a faculty member in the option in which the student is enrolled. The advisor interests himself in the student's selection of optional courses, progress toward his degree, and, eventually, in assisting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

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





The California Institute Athletic Field of approximately 23 acres includes a football field, a standard track, a baseball stadium, and championship tennis courts. The Scott Brown Gymnasium and the Alumni Swimming Pool, completed in 1954, provide attractive modern facilities for intercollegiate, intramural, or recreational competition in badminton, basketball, volleyball, swimming, and water polo. Funds for the pool were contributed by the alumni of the California Institute; construction of the gymnasium was made possible through a bequest of Scott Brown.

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

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

Musical Activities. The Institute provides qualified directors and facilities for a band and glee club. A series of chamber music concerts is given on Sunday evenings in the lounge of Dabney Hall. The Musicale is an organization which encourages interest in and appreciation for classical recordings. The extensive record library of the Institute provides opportunity for cultivation of this interest and for the presentation of public programs. From a special loan library, records may be borrowed for students' private use.

Student Societies and Clubs. There is at the Institute a range of undergraduate societies and clubs wide enough to satisfy the most varied interests. The American Institute of Electrical Engineers, the American Society of Civil Engineers, and the American Society of Mechanical Engineers all maintain active student branches.

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

The Institute also has a chapter of Pi Kappa Delta, the national forensic honor society. Members are elected annually from students who have represented the Institute in intercollegiate debate, or in oratorical or extempore speaking contests.

Special interests and hobbies are provided for by the Chemistry, Mathematics, and Physics Clubs, the Radio, Sailing, and Ski Clubs. The Christian Fellowship Group, Christian Science Group, Episcopal Group and the Newman Club are organized on the basis of religious interests. The Inter-Nations Association is composed of foreign students from various countries, as well as interested Americans. Its object is to make the students' stay at Caltech more valuable by introducing them to Americans, their customs and way of life. Conferences, weekly teas, and trips to points of interest in the vicinity are among the activities.

Student Shop. The Student Shop is housed in the new Winnett Student Center. It is equipped by the Institute, largely through donations, and is operated by the students under faculty supervision. It has no connection with regular Institute activities, and exists only as a place where qualified students may work on private projects that require tools and equipment not otherwise available. All students are eligible to apply for membership in the Student Shop; applications are acted on by a governing committee of students. Members who are not proficient in power tools are limited to hand tools and bench work; however, instruction in power tools will be given as needed. Yearly dues are collected to provide for maintenance and replacement.

Speech Activities. Practical training in public speaking is the keynote of the Institute's forensic program. A variety of experiences ranging from intercollegiate debate tournaments to local speech events can be had by all who wish to improve their abilities. Debaters take part in an average of six intercollegiate tournaments during the year. These tournaments, including extempore speaking, oratory, impromptu speaking and discussion, comprise such events as the Western Speech Association tournament, the regional Pi Kappa Delta speech tournament, and the annual Caltech invitational debate tournament held at the Institute. Bi-annually the Institute is represented at the national Pi Kappa Delta tournament.

YMCA. The California Institute YMCA is a service organization whose purpose is to supplement a technical and scientific education with a program emphasizing social and religious values. The "Y" is one of the most active student organizations on the campus and welcomes as members all students taking an active part in its regular program of activities. The program includes weekly luncheon clubs, discussion groups which bring speakers representing many interests to the campus, forums and lectures, student-faculty firesides, intercollegiate conferences, and work with local church groups. It also sponsors an annual freshman tea dance. The "Y" services to the student body include a used-textbook exchange, a loan fund, an all-year calendar of student events, and the use of the lounge and offices.

Bookstore. The student store serving students, faculty, and staff is located on the ground floor of the Winnett Center. The store, which is owned and operated by the Institute, carries a complete stock of required books and supplies, reference books, and such extracurricular items as athletic supplies, stationery, and fountain pens. There is, on open shelves, an extensive collection of paperbacks and other books of general interest.

DEPARTMENT OF AIR FORCE AEROSPACE STUDIES

THE California Institute of Technology unit of the Air Force Reserve Officers Training Corps (AFROTC) was established on campus at the beginning of the academic year 1951-52 as a four-year program. In the fall of 1964 an Act of Congress authorized the establishment of a two-year AFROTC program at the Institute. This program will be initiated in the fall of 1965. New enrollees in the four-year program will be limited to successful high school applicants for competitive four-year Air Force financial grants.

Students under the four-year program will take 4 units of AS 1 during each term of the freshman year and 4 units of AS 2 during each term of the sophomore year. The successful completion of these two years of Air Force Aerospace Studies will qualify the student for entry into the Professional Officer Course which consists of 7 units of AS 3 during each term of the junior year and 7 units of AS 4 during each term of the senior year.

Students under the two-year program are free to concentrate on general Institute requirements during the freshman and sophomore years. In the summer between the sophomore and junior years the applicants must attend a six-week summer course conducted at an Air Force base. The successful completion of this summer course will qualify the student for entry into the Professional Officer Course. In the Professional Officer Course studies are directed toward preparation of students for Junior Management positions in a rapidly changing and highly technical Air Force organization. Upon entry into the Professional Officer Course, the student must agree to faithfully pursue the Institute's established course of study leading to a degree, accept an Air Force Commission as a 2nd Lieutenant if tendered, and then serve an active duty tour of four years.

Ten hours during each term of the Professional Officer Course is devoted to a Leadership Laboratory which is, in effect, a proving ground for the training and evaluation of individual leadership and management abilities. Techniques of problem solving and use of gaming theories are proved in mock air defense and field exercises during the Leadership Laboratory periods. The Department of Air Force Aerospace Studies conducts a planned program of Air Force installation and aerospace industry visitations, orientation rides in jet aircraft, and other events which supplement and reinforce the AFROTC curriculum.

For interested students who qualify, an established Flight Instruction Program provides 30 hours of ground school, and 35 hours of actual flight training. Free flight training is conducted at a nearby civilian-contract flying school, which is approved by the Federal Aviation Authority.

Graduates of the Institute's AFROTC program are normally assigned to scientific, engineering, and technological positions within the Air Force organization. As a major portion of its primary mission, the USAF manages and operates a series of the world's most advanced development and test complexes. Here military scientists and engineers work in a professional, intellectual atmosphere in all areas of basic and applied research to advance the state of military and space hardware technology. Extensive physical laboratory facilities as well as the research environment and support are considered excellent in every respect, providing an extremely favorable opportunity for creative accomplishment.

Physically qualified graduates who have completed the Flight Instruction Program have the option to apply for a program of pilot or navigator flight training in the USAF. Air Force Distinguished Graduates may work toward advanced degrees as an initial military assignment with full tuition and other expenses paid by the Air Force, and they will receive the full pay and allowances of an officer during this graduate study period. In some instances other graduates may apply for advanced academic work as their first military assignment, provided they have a grade-point average of 2.5 or better. Also, all AFROTC graduates may elect to defer their active duty obligated tour for certain valid reasons such as that of pursuing graduate work on a personal basis.

Under the two-year program, the Air Force furnishes books and uniforms for its courses as well as $40 per month retainer pay for every month of participation in the program and approximately $180 plus travel pay for the six-week summer training. Students awarded Air Force financial grants receive full tuition, fees, books, and $50 per month retainer pay for every month of participation in this program. The government also offers to defer students participating in AFROTC from induction into the Armed Services, provided required academic and other standards are maintained.

Section III

INFORMATION AND REGULATIONS FOR THE GUIDANCE OF UNDERGRADUATE STUDENTS

Requirements for Admission to Undergraduate Standing

THE undergraduate school of the California Institute of Technology is not coeducational and applications are accepted from men students only. The academic year consists of one twelve-week term and two eleven-week terms extending from late September until the middle of June. There are no summer sessions, except that undergraduates and graduate students are permitted to register for summer research. Undergraduates are admitted only once a year—in September. All undergraduates at the California Institute are expected to carry the regular program leading to the degree of Bachelor of Science in the option of their choice. Special students who wish to take only certain subjects and are not seeking a degree cannot be accepted.

Admission to the Freshman Class

The freshman class of approximately 180 men is selected from the group of applicants on the basis of (a) high grades in certain required high school subjects, (b) results of the College Entrance Examination Board tests, and (c) recommendation forms, and a personal interview when this is feasible. The specific requirements in each of these groups are described below. An application fee of $10 is due at the time an application for admission is submitted. No application will be considered until this fee is paid. The fee is not refundable whether or not the applicant is admitted or cancels his application, but it is applied on the first-term bills of those who are admitted and who register in September.

APPLICATION FOR ADMISSION

Application for admission is made on a form which may be obtained by writing to the Office of Admissions, California Institute of Technology, Pasadena, California 91109. It is to be returned directly to the Institute together with an application fee of $10.

Completed admission application blanks and the $10 application fee must reach the Admissions Office not later than February 15, 1966. (Application to take entrance examinations must be made directly to the College Board at an earlier date, for which see page 171.

Applicants living outside of the United States must submit their credentials by November 1, 1965.

Transcripts of records covering three and a half years of high school should be submitted as soon as the grades of the first semester of the senior year are available, but not later than March 1, 1966. Those attending schools which operate on the quarter system should submit records covering the first three years and the first quarter of the senior year. They must also arrange for a supplementary transcript showing the grades for the second quarter to be sent as soon as possible. Applicants must be sure to list in space provided on the application blank all the subjects they will take throughout the senior year.

HIGH SCHOOL CREDITS

Each applicant must be thoroughly prepared in at least fifteen units of preparatory work, each unit representing one year's work in a given subject in an approved high school at the rate of five recitations weekly. Each applicant must offer all of the units in Group A and at least five units in Group B.

Group A:	English	3
	Mathematics	4
	Physics	1
	Chemistry	1
	United States History and Government	1
Group B:	Foreign Languages, Shop, additional English, Geology, Biology or other Laboratory Science, History, Drawing, Commercial subjects, etc.	5

The three units of English are a minimum and four units are strongly recommended.

The four-year program in mathematics should include the principal topics of algebra, geometry, analytic trigonometry, and the elementary concepts of analytic geometry and probability in a way which displays the underlying relationships between these branches of mathematics. The program should emphasize the principles of logical analysis and deductive reasoning and provide applications of mathematics to concrete problems.

The Admissions Committee recommends that the applicant's high school course include at least two years of foreign language, a year of geology or biology, and as much extra instruction in English grammar and composition as is available in the high school curriculum.

ENTRANCE EXAMINATIONS

In addition to the above credentials, all applicants for admission to the freshman class are required to take the following examinations given by the College Entrance Examination Board: the Scholastic Aptitude Test (morning program); the afternoon program consisting of the Level II Achievement Test in Mathematics and any two of the following: Physics, Chemistry, English Composition. The Level II Mathematics Test is designed for the students who have completed three and one-half years of a mathematics program of the type outlined above. The Level II test does not presuppose an advanced placement course in mathematics. Note that the Scholastic Aptitude and the Level II Mathematics tests must be taken,* and that the choice lies only among Physics, Chemistry, and English—of which two must be taken. No substitution of other tests can be permitted.

*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.

For admission in September 1966, the Scholastic Aptitude Test and achievement tests must be taken no later than the January 8 College Board test date. *It is important to note that no applicant can be considered in 1966 who has not taken the required tests by January 8, but tests taken on any prior date are acceptable.* No exception can be made to the rule that all applicants must take these tests.

Note that the Level II Mathematics Achievement Test *must* be taken on either May 1, 1965, or January 8, 1966. It is not offered at other administrations. Other tests may be taken on January 8, 1966, or on any prior date.

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 schools by writing to the appropriate address given below. The tests are given at a large number of centers, but should any applicant be located more than 65 miles from a test center, special arrangements will be made to enable him to take the tests nearer home.

Applicants who wish to take the examinations in any of the following states, territories, or foreign areas should address their inquiries by mail to College Entrance Examination Board, P.O. Box 1025, Berkeley, California 94701:

Alaska	Nevada	Province of British Columbia
Arizona	New Mexico	Province of Manitoba
California	Oregon	Province of Saskatchewan
Colorado	Utah	Republic of Mexico
Hawaii	Washington	Australia
Idaho	Wyoming	Pacific Islands, including
Montana	Province of Alberta	Japan and Formosa

Candidates applying for examination in any state or foreign area not given above should write to College Entrance Examination Board, P.O. Box 592, Princeton, New Jersey 08540.

Each examination application submitted for registration must be accompanied by the examination fee of $4.50 for the Scholastic Aptitude Test and $6.75 for the three Achievement Tests. Please note that the examination fee is *not* sent to the California Institute, but to the appropriate College Board office. The application fee of $10 is the only fee sent to the California Institute at the time an application is made.

All examination applications and fees should reach the appropriate office of the Board not later than the dates specified below.

	For examination centers located	
To take tests on	In the United States, Canada, the Canal Zone, Mexico, or the West Indies, applications must be received by	In Europe, Asia, Africa, Central and South America, and Australia, applications must be received by
December 4, 1965	November 6	October 16
January 8, 1966	December 14	November 13

Candidates are urged to send in their examination applications and fees to the Board as early as possible, preferably at least several weeks before the closing date, since early registration allows time to clear up possible irregularities which might otherwise delay the issue of reports. Under no circumstances will an examination application be accepted if it is received at a Board office later than one week prior to the date of examination. No candidate will be permitted to register with the supervisor of an examination center at any time. Only properly registered candidates, holding tickets of admission to the centers at which they present themselves, will be admitted to the tests. Requests for transfer of examination center cannot be considered unless these reach the Board office at least one week prior to the date of the examination.

Please note that requests to take the examinations and all questions referring exclusively to the examinations are to be sent to the College Entrance Examination Board at the appropriate address as given above, and not to the California Institute.

PERSONAL INTERVIEWS AND RECOMMENDATION FORMS

By March 1, recommendation forms will be sent out for each applicant who has an application on file. These forms are sent directly to the principal or headmaster of the school which the applicant is attending, with the request that they be filled out and returned directly to the California Institute. These recommendation forms provide valuable information on candidates. The College Board scores, the last of which will be received by about February15, provide further important data. Since, however, there are many more applicants to the California Institute than our facilities can accommodate, as much information as possible is desired on each candidate for admission. Wherever preliminary information shows that an applicant has a chance of gaining admission, an attempt is made to hold a personal interview with him at the school he is attending. It is not possible to visit all of the schools involved; but if a personal interview cannot be held, this in no way prejudices an applicant's chances of admission. The applicant has no responsibility with regard to the personal interview unless and until he receives a notice giving the time and date when a representative will visit his school. These visits occur between March 1 and April 6.

NOTIFICATION OF ADMISSION

Final selections will ordinarily be made and the applicants notified of their admission or rejection well before May 2. 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 of subsequent cancellation of application, the registration fee is *not* refundable unless cancellation is initiated by the Institute. Places in the entering class will not be held after May 2, if the applicant could reasonably be expected to have received notice at least ten days before this date. Otherwise, places will be held not more than ten days after notification. When the registration fee has been received, each accepted applicant will be sent a registration card which will entitle him to register, provided his physical examination is satisfactory. The registration card should be presented at Dabney Hall Lounge on the date of registration.

Checks or money orders should be made payable to the California Institute of Technology.

EARLY DECISION PLAN

The Institute will consider a few outstanding candidates who wish to make the California Institute their first choice under an early decision plan. Such candidates must have taken the required College Board tests by the end of their junior year or at the following July administration, must have an excellent school record, and must have the thorough backing of their high school.

An applicant for admission under the early decision plan must have his credentials on file by October 15 of his senior year. He will be notified by December 15 whether he has been accepted. An accepted applicant is then expected to withdraw all applications to other colleges. An applicant who is not accepted under the early decision plan will be considered without prejudice for admission at the regular time in April, unless he receives notice of final rejection in December.

ADVANCED PLACEMENT PROGRAM

A number of high schools and preparatory schools offer selected students the opportunity to accelerate and to take in the senior year one or more subjects which are taught at the college level and cover the material of a college course. The College Entrance Examination Board gives each year in May a set of Advanced Placement examinations covering this advanced work. The regulations governing Advanced Placement at the California Institute in the subjects concerned are as follows:

Chemistry. The freshman chemistry course at the Institute now contains much material formerly given in the sophomore year and not usually covered in advanced placement courses. For this reason all freshmen must take the first-term work (Chemistry 1 a). Those who took the College Board Advanced Placement examination in chemistry and received a score of 5 or 4 and who received a grade of B or better in Chemistry 1 a may be excused from the lecture portion of the last two terms if the advanced course they took in high school covered the substantial equivalent of the work given here in these terms. They may also be excused from the laboratory portion of Chemistry 1 bc if they have covered the substantial equivalent, but it is less likely that they will have done so. Anyone who feels that prior to entrance he has covered the equivalent of the freshman chemistry but who has not taken the College Board Advanced Placement examination may take the California Institute transfer examination in chemistry covering the work of the freshman year. Units from which a student has been excused by reason of advanced placement courses must be made up before graduation and may be taken in any subject offered in any division for which the student has the necessary prerequisites, except that those who wish to major in chemistry or chemical engineering may be required to make up the units by additional work in chemistry.

English and History. In view of the greatly altered character of freshman work in the fields of English and European history, beginning with 1965-66, the practice of granting advanced placement and credit has been suspended. The question will be reconsidered after the new freshman offerings in English and history have received a full trial. In the meantime, individual students who have received exceptionally high marks in college-level courses and in the

College Board Advanced Placement examinations in those same subjects may petition for special consideration.

Students who have received high marks in college-level courses in American history and government and high scores in the College Board Advanced Placement examination may be excused from sophomore history and government (H 2 abc: History and Government of the United States) in order to take advanced courses in that same subject.

NOTE: Because of a California state law requiring colleges to give instruction in the Constitutions of the United States and of the State of California, it will be necessary for students to do a small amount of supplementary reading if they are excused from H 2 abc.

Mathematics. An entering freshman who has achieved a sufficiently high score on the College Board Advanced Placement test in mathematics will be sent during the summer a questionnaire concerning the advanced work in mathematics which he has taken. If an entering freshman believes that he has covered the equivalent of the first-year mathematics but has not taken the College Board Advanced Placement test he may take the California Institute transfer mathematics examination covering the first-year work. On the basis of the College Board test or the transfer examination and of the information in the questionnaire he may be placed in a special mathematics section which will cover some topics of the freshman course not usually touched on in advanced placement courses and will cover substantially all the material of Mathematics 2 abc. In exceptional cases an entering freshman may be placed immediately in the sophomore course (Mathematics 2 abc). Students who receive advanced placement and who successfully complete either the special course or Mathematics 2 abc are given credit for Ma 1 abc and Ma 2 abc.

Physics. As currently organized, the required course in physics in the freshman year, Ph 1 abc, contains so little that might duplicate material in advanced placement work elsewhere that for the time being it is not contemplated that any advanced placement in physics will be given to entering freshmen.

NOTE: The Advanced Placement tests are in no way a substitute for the College Board Aptitude and Achievement Tests at the ordinary high school level required for admission. The latter are the only tests considered in granting freshman admission. After admission, those who offer advanced credits and examinations will be considered for credit and advanced placement in the subjects involved.

PHYSICAL EXAMINATION

Prior to final acceptance for admission, each applicant is required to submit a report of physical examination on a form which will be sent him at the time he is notified of admission. It is the applicant's responsibility to have this form filled out by a Doctor of Medicine (M.D.) of his own choosing. Admission is tentative pending such examination, and is subject to cancellation if the results of the examination are unsatisfactory (see page 189).

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

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

SCHOLARSHIPS AND LOANS

For information regarding scholarships for entering freshmen and deadline for application see pages 196-197. No one can be considered for a scholarship grant who has not sent in a scholarship form according to the instructions on page 196. In computing need the California Institute uses the figure $3250 as covering all expenses of an academic year for those who live on campus or wherever they must pay for board and lodging. This figure includes tuition, board and lodging, books and supplies, incidental fees and dues, and about $300 for personal expenses. To this figure is added an allowance for travel between Pasadena and the student's home. The travel allowance varies with the distance involved but in no case exceeds $450 for one academic year. The figure of $2425 is used for the expenses of those who live at home or with relatives or friends to whom they pay nothing for board and lodging. This figure includes the items listed above with the exception of board and lodging and with the addition of allowances for commuting expense and lunches. For further information on tuition and other costs, and on loans and the deferred plan see pages 192-195.

NEW STUDENT CAMP

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

A large number of faculty members and student leaders attend the camp. During the three-day program the new students hear what life at the Institute is like. They learn what is expected of them and what aids are available to them to help them live up to these expectations. Because of the comparatively small student body and the pressure of work once academic activity starts, it is important both to the student and to the Institute that new students become, at the very beginning, part of a homogeneous group sharing a common understanding of purpose and a common agreement on intellectual and moral standards. The three days at the camp afford the best possible opportunity for achieving this necessary unity.

STUDENTS' DAY

The California Institute holds an annual invitational Students' Day on the first Saturday in December. This popular event is conducted by invitation to allow a more intimate view of the work in the laboratories of science and engineering with the hope that this contact will assist the high school student in his choice of a future career. Science students and their teachers are invited, upon nomination by secondary schools throughout southern California, to view exhibits of the work in the various divisions of the Institute and to attend selected demonstration lectures given by students and faculty members. Student life on the campus is an important feature of Students' Day, with the undergraduate student body serving as host and responsible for the actual operation under the direction of a joint faculty-student committee. To avoid overcrowding at the exhibits and lectures it is necessary to limit attendance at this event to those who have been selected by their schools and whose names have been sent to the Students' Day Committee in advance.

Admission to Air Force ROTC

Applicants for admission to the United States Air Force Reserve Officers Training Corps curriculum must be citizens of the United States, and meet all other admission requirements and regulations as specified by the California Institute of Technology. Only those entering freshman students who have received an Air Force four-year Financial Grant will be accepted into the four-year AFROTC program. All other students who meet the requirements may apply for the two-year AFROTC program at the end of their sophomore year. Foreign students who will subsequently qualify for U.S. citizenship may be permitted to pursue the AFROTC program upon approval by the Professor of Air Force Aerospace Studies.

Admission to Upper Classes by Transfer from Other Institutions

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

A student who is admitted to the upper classes pursues a full course in engineering or in one of the options in science or humanities leading to the degree of Bachelor of Science. The Institute has no special students. Men are admitted either as freshmen in accordance with the regulations set forth on pages 169-172 or as upperclassmen in the manner described below. Those who have pursued college work elsewhere, but whose preparation is such that they have not had the substantial equivalent of the freshman courses in English, mathematics, and physics, will be classified as freshmen and should apply according to the instructions on pages 169-172. They may, however, receive credit for the subjects which have been completed in a satisfactory manner.

An applicant for admission as a transfer student must write to the Office of Admissions of the California Institute stating his desire to transfer, his choice of engineering or one of the options in science or humanities, and the number of years of college he will have completed by the date of transfer. At the same time he must present a transcript of his record to date, showing in detail the character of his previous training and the grades received both in high school and college. If the college transcript does not list subjects *and grades* for high school work, the applicant must see that his high school sends the Admissions Office a transcript of this work. After the transcripts have been evaluated by the Admissions Office, an application blank will be sent, provided the grades and subjects on the transcripts meet the transfer requirements.

Please note that an application blank is not sent until the transcripts have been received and evaluated, and that the applicant must write a letter giving the information outlined in the preceding paragraph. Transcripts are held in the files until such a letter is received.

Application blanks must be on file in this office by April 1. Transcripts should, therefore, be sent no later than March 15. Applicants living in foreign countries must have applications and transcripts on file by March 1 at the latest and should understand that no information with regard to acceptance or rejection can be sent before June 20.

Applicants who are enrolled in a college at the time applications are made do not ordinarily complete the academic year until May or June. Such applicants should make sure that a list of subjects being taken during the final semester is included in the transcript sent for evaluation and that a supplementary transcript showing the grades for the final semester is sent at the end of the academic year as soon as these grades are available. All transfer applicants must arrange to have sent in their scores on the Scholastic Aptitude Test (SAT) of the College Entrance Examination Board. If they have taken the SAT in previous years, these scores will be acceptable; but applicants must instruct the College Board (see address on page 171) to send the scores to the Institute. If the SAT has not been taken previously, it must be taken by the March 5 series at the latest. College Board Achievement Tests are not required of transfer applicants.

In addition, before their admission to the upper classes of the Institute, all students are required to take entrance examinations in mathematics, physics, and English composition covering the work for which they desire credit, except that in addition an examination in chemistry is required of those desiring to major in chemistry or chemical engineering. Students must offer courses, both professional and general, substantially the same as those required in the various years at the Institute (see pages 243-261) or make up their deficiencies as soon as possible after admission.

It is not possible to answer general questions regarding the acceptability of courses taken elsewhere. The nature of the work at the Institute is such as to demand that all courses offered for credit be scrutinized individually. Even when a transcript of record is submitted, it is not always possible to tell whether the courses taken are equivalent to the work at the Institute. In case the standard of the work taken elsewhere is uncertain, additional examinations may be required before the question of credit is finally determined.

Applicants are advised to read the descriptions of the freshman and sophomore courses, particularly those in physics, mathematics, and chemistry, and to note that the work in freshman mathematics includes differential and integral calculus, vector algebra, and infinite series. If an entering sophomore has not had the last two topics he will enroll in a special section of the sophomore mathematics course. Note also the references to freshman and sophomore chemistry on this page and 178.

The Institute has recently made a radical revision of its basic two-year course in physics which is required of all students. The new course is a course in classical and modern physics in which the emphasis is on modern ideas and applications, to be introduced to the student as early as possible. The revised first-year course covers kinematics, the Lorentz transformation, nonrelativistic and relativistic particle mechanics, electric and magnetic forces, Rutherford scattering, planetary motion, harmonic motion, geometrical optics, kinetic theory, thermodynamics, and black body radiation. Students wishing to transfer into the sophomore class, therefore, will be expected to have covered material not found in the ordinary freshman physics course. Unless a student can demonstrate proficiency in most of the areas covered by Physics 1 abc, he would probably do well to wait for another year and apply for admission as a junior. It is felt that the regular two-year program in physics at other colleges, although the sequence of topics may be different, will enable a good applicant to deal adequately with our physics test for admission to the junior level.

Two examinations of a comprehensive character are offered in each of the three subjects, mathematics, physics, and chemistry. One examination in each subject covers the work of the first year, the other examination that of the first and second years. Representative examination papers will be sent to approved applicants upon request. The English examination covers composition only and is the same, regardless of the level at which the applicant is seeking admission. The Institute courses for which those admitted will receive credit will be determined by the Committee on Admission to Upper Classes and the departments concerned, on the basis of the applicants' previous records and the results of their examinations.

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

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

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

The transfer examination in chemistry is required only of those wishing to major in chemistry or chemical engineering. For admission to the sophomore year this examination will cover general chemistry and qualitative analysis. The examination for admission to the third year is a comprehensive test covering general chemistry, qualitative and quantitative analysis. Transfer students entering the junior year in chemistry will be able to take the sophomore organic chemistry course during their first year at the Institute.

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

The schedule for the examinations for admission to upper classes, September 22, 1966, is as follows:

Chemistry	(3 hours)	1:00 P.M.	May 6, 1966
English	(1 hour)	9:00 A.M.	May 7, 1966
Mathematics	(2 hours)	10:30 A.M.	May 7, 1966
Physics	(3 hours)	2:00 P.M.	May 7, 1966

No other examinations for admission to upper classes will be given in 1966.

Applicants residing at a distance may take the examinations under the supervision of their local college authorities, provided definite arrangements are made well in advance. Arrangements for examinations in absentia should include a letter to the Dean of Admissions from the person directing the tests stating that the required supervision will be given.

The attention of students planning to transfer to junior standing is called to the fact that, until they have satisfactorily completed three full terms of residence at the Institute, they are subject to the same scholastic requirements as are freshmen and sophomores (see pages 183-188). In addition, they should note that to be permitted to register for any science, engineering, or humanities options during their junior and senior years they must meet the scholastic requirements of the divisions concerned (see page 185).

Physical examinations, vaccination, etc. are required as in the case of students entering the freshman class (see pages 174-175). Admission is conditional upon a satisfactory report on the physical examination.

Transfer students are required to pay a registration fee of $10 upon notification of admission to the Institute. In the event of subsequent cancellation of application, the registration fee is *not* refundable unless cancellation is initiated by the Institute. Transfer students are expected to attend the New Student Camp (see page 175).

Scholarship grants for transfer students are awarded on the same basis as are those for freshmen: namely, high standing on the entrance examinations and demonstrated financial need. To secure consideration for a scholarship, a transfer student must file a special form which will be sent on request and must be completely filled out by the parent or guardian responsible for the applicant's support. This form must reach the Admissions Office no later than April 15, and no applicant will be considered for a scholarship grant who does not have such a form on file here by that date.

THE 3-2 PLAN

Arrangements exist between the California Institute and certain liberal arts colleges whereby students enrolled in these liberal arts colleges may follow a certain prescribed course for the first three years and then transfer into the third year of the engineering option at the Institute without further formality, provided that they have the unqualified recommendation of the officials at the liberal arts college which they are attending. After satisfactorily completing in two years at the Institute all the remaining work required for a bachelor's degree in engineering, they will be awarded a Bachelor of Arts degree by the college from which they transferred and a Bachelor of Science degree by the California Institute. Application for admission at the freshman level under this plan should be made to the liberal arts college.

The list of colleges with which these arrangements exist is as follows:

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

REGISTRATION REGULATIONS

	Registration Dates	*Fees Payable*	*Instruction Begins*
Freshmen and Transfer Students	Sept. 23, 1965	Sept. 23, 1965	Sept. 28, 1965
Upperclassmen and Graduate Students	Sept. 27, 1965	Sept. 27, 1965	Sept. 28, 1965

For Second and Third Term dates refer to the Academic Calendar on page 4.

FEES FOR LATE REGISTRATION

Registration is not complete until the student has personally turned in the necessary registration and class assignment cards for a program approved by his registration officer and has paid his tuition and other fees. A penalty fee of four dollars is assessed for failure to register on the scheduled date, and a similar fee is assessed for failure to pay fees within the specified dates. These requirements apply to all three terms.

SPECIAL STUDENTS

Applicants who wish to take a special program without working toward a degree are not accepted for undergraduate admission. Registered undergraduates who register for programs which make it appear that they are no longer candidates for a B.S. degree may be refused further registration by the Undergraduate Academic Standards and Honors Committee.

CHANGES OF REGISTRATION

All changes in registration must be reported to the Registrar's Office by the student. Such changes are governed by the last dates for adding or dropping courses as shown on the Institute calendar. A grade of F will be given in any course for which a student registers and which he does not either complete satisfactorily or drop. A course is considered dropped only after the student has turned in to the Registrar's Office a drop card properly filled out and signed by the instructor concerned and any other required persons. A student may not at any time withdraw from a course which is required for graduation in his option without permission of one of the Deans. Senior students must also have the approval of the Registrar before dropping any course.

A student may not withdraw from a course after the last date for dropping courses without, in addition to his instructor's consent, the approval of the Undergraduate Academic Standards and Honors Committee. A student may, with the consent of the instructor concerned, add a course after he has completed his regular registration, provided the addition does not bring the total units for which he is registered above 55, plus Physical Education or ROTC. To carry excess units he must obtain the recommendation of his Departmental Advisor and the approval of the Undergraduate Academic Standards and Honors Committee (see page 187). A student may not add a course after the last date for adding courses without, in addition to his instructor's consent, the approval of the Undergraduate Academic Standards and Honors Committee. Registration for added courses is complete only after a student has turned in to the Registrar's Office an add card properly filled out and signed by the instructor concerned. No credit will be given for a course for which a student has not properly registered. The responsibility for seeing to it that drop cards and add cards are in the Registrar's office before the deadlines for dropping or adding courses each term rests entirely with the student. Failure to fulfill the responsibility because of oversight or ignorance is not sufficient grounds to petition for permission to drop or add courses after the deadline. It is the policy of the Undergraduate Academic Standards and Honors Committee that no petitions for the retroactive dropping or adding of courses will be considered except under very extenuating circumstances.

Summer Research

Qualified undergraduate students who are regular students in the Institute are permitted to engage in research during the whole or a part of the summer, but in order to receive academic credit the student must have the approval of his division and must file a registration card for such summer work in the Office of the Registrar during the week of May 16-20. Students who are registered for summer research will not be required to pay tuition for the research units.

General Regulations

Every student is expected to attend all classes and to satisfy the requirements in each of the courses in such ways as the instructor may determine.

Students are held responsible for any carelessness, willful destruction, or waste. At the close of the year, or upon the severance of their connection with any part of the work of the Institute, students are required to return immediately all locker keys and other Institute property.

It is taken for granted that students enter the Institute with serious purpose. The moral tone here is exceptionally good; the honor system prevails in examinations, and in all student affairs. A student who is known to be engaging in immoral conduct or exercising a harmful influence on the student life of the Institute may be summarily dismissed, whatever his scholastic standing.

Auditing of Courses

Persons not regularly enrolled in the Institute may, with the consent of the instructor in charge of the course and the chairman of the division concerned. be permitted to audit courses upon payment of a fee in the amount of $25.00 per term, per lecture hour. The cost of auditing courses by non-academic staff members may be covered through the Institute Tuition Support Plan. Registration cards for the auditing of courses 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 turned in to the Registrar's Office and no official record is kept of the work done.

Student Trainees

Non-registered students engaged in recognized and approved training programs at the Institute are required to pay the applicable health fee to be eligible for benefits as provided from the Emergency Health Fund. Such benefits are described under "Student Health Services" on page 189.

1. A $15 fee will be assessed each participant in such a program conducted during the academic year.
2. A health fee of $7.50 will be assessed each participant in such a program conducted during the summer period.

In addition, a charge of two dollars, plus cost of medicine and laboratory services, will be charged for each visit to the Health Center during the academic year and summer period.

SCHOLASTIC GRADING AND REQUIREMENTS

Scholastic Grading

For the 1965-66 academic year, grades in all freshman courses will be either "P," indicating passed, or "F," indicating failed. For other undergraduate courses, the following system of grades is used to indicate the character of the student's work in his various subjects of study: "A" excellent, "B" good, "C" satisfactory,* "D" poor, "E" conditioned, "F" failed, "Inc" incomplete.

In addition, Grades of A+ and A—, B+ and B—, C+ and C—, and D+ may, where appropriate, be used for undergraduates only.

In certain designated courses (see page 184), the grade of "P" indicating Pass may be given, but it is not counted in computing the grade-point average of an undergraduate student. The grade of "H" is given for satisfactory completion of freshman honor elective courses and is likewise not used in computing the grade-point average.

"Conditions" indicate deficiencies that may be made up without actually repeating the subject. A grade of "D" is given when the work is completed.

The grade *"incomplete"* is given only in case of sickness or other emergency which justifies non-completion of the work at the usual time. An incomplete will be recorded only if the reasons for giving it are stated by the instructor on a form which will be sent with each grade sheet and only if, in the opinion of the appropriate committee (Undergraduate Academic Standards and Honors Committee for undergraduates, and Graduate Study for graduate students), the reasons justify an incomplete. If, in the opinion of the committee, the incomplete is not justified, a condition will be recorded.

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

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

Scholastic Requirements

All undergraduates and Master of Science candidates are required to meet certain scholastic standards as outlined below. In addition, students who have been reinstated after having failed to make the required number of credits in the junior year are subject to these scholastic requirements in the senior year.

*Except that C — is considered poor.

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.* *Credits* are awarded on the basis of the number of units multiplied by four if the grade received is "A," three if "B," two if "C," and one if "D"; thus, a student receiving a grade of "B" in a twelve-unit course receives 36 credits for his course. For the assignment of credits to undergraduate grades with plus or minus designations, see the following table.

TABLE OF CREDITS CORRESPONDING TO GRADE AND NUMBER OF UNITS

No. of Units	A+	A	A−	B+	B	B−	C+	C	C−	D+	D	F
1	4	4	4	3	3	3	2	2	2	1	1	0
2	9	8	7	7	6	5	5	4	3	3	2	0
3	13	12	11	10	9	8	7	6	5	4	3	0
4	17	16	15	13	12	11	9	8	7	5	4	0
5	22	20	18	17	15	13	12	10	8	7	5	0
6	26	24	22	20	18	16	14	12	10	8	6	0
7	30	28	26	23	21	19	16	14	12	9	7	0
8	35	32	29	27	24	21	19	16	13	11	8	0
9	39	36	33	30	27	24	21	18	15	12	9	0
10	43	40	37	33	30	27	23	20	17	13	10	0
11	48	44	40	37	33	29	26	22	18	15	11	0
12	52	48	44	40	36	32	28	24	20	16	12	0
13	56	52	48	43	39	35	30	26	22	17	13	0
14	61	56	51	47	42	37	33	28	23	19	14	0
15	65	60	55	50	45	40	35	30	25	20	15	0

Grade-point average is computed by dividing the total number of credits earned in a term or an academic year by the total number of units taken in the corresponding period. Units for which a grade of "F" has been received are counted, even though the "F" may have subsequently been removed (see above). Units and credits in military subjects taken by Air Force ROTC students are counted in computing grade-point average. Physical education units and credits, and units for honor elective courses are not included in computing grade-point average. A grade of Pass may be given for courses bearing a number 200 or greater, for Ph 172, for research conferences and undergraduate research, and is not used in computing the grade-point average. Grade-point averages will not be computed for freshmen in the academic year 1965-66.

Ineligibility for registration. Freshmen who receive no "Fail" grades during the year are academically eligible to register for the sophomore year. Freshmen who have accumulated 48 or more units of "Fail" will automatically be evaluated by the Committee on Undergraduate Standards and Honors at the end of any term. Any freshman accumulating "Fail" grades in less than 48

*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.

units during the year may, at the end of the year, be referred to the Committee by the Dean of Freshmen and the student's adviser. If it is the opinion of the Committee on Undergraduate Academic Standards and Honors that any freshman referred to it is unprepared for the work of the sophomore year, he may be declared ineligible to register for academic reasons.

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

Any undergraduate student, except a freshman, is ineligible to register for another term:

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

(b) If he fails to obtain a grade-point average of at least 1.9 for the academic year. A student who has completed at least three full terms of residence at the Institute and has been registered for his senior or Master's year shall no longer be subject to the requirement that he make a grade-point average of at least 1.9 for the academic year. Seniors and Master's candidates are subject to the requirement, however, that they must receive a grade-point average of at least 1.4 each term to be eligible for subsequent registration. (Special note should be made of the graduation requirement described on page 186.)

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

(d) An undergraduate student who incurs a deficiency in one term of physical education in the freshman or sophomore year must make up the deficiency in the first term of the junior year. If he fails to do so, he is ineligible to register. An undergraduate student who incurs deficiencies in any two terms of physical education in the freshman and/or sophomore year is ineligible to register.

A student ineligible for registration because of failure to meet the requirements stated in the preceding paragraphs may, if he desires, submit immediately to the appropriate Dean a petition for reinstatement, giving any reasons that may exist for his previous unsatisfactory work and stating any new conditions that may lead to better results. Each such application will be considered on its merits. If this is the first such occurrence the Dean can, after consultation with the student and examination of his record, reinstate him. At the Dean's discretion, special cases may be referred to the Undergraduate Academic Standards and Honors Committee. A reinstated student who again fails to fulfill the scholastic requirements for registration must petition the Undergraduate Academic Standards and Honors Committee through the appropriate Dean. In any case the student may, if he wishes, appear before the committee or, at the discretion of the Dean, he may be required to appear. A second reinstatement will be granted only under very exceptional conditions.

Deficiency. Any upperclassman whose grade-point average during a term falls between 1.4 and 1.9 shall receive the usual letter of warning that his work is below the satisfactory minimum, but he shall not be required to obtain the approval of the Dean of Students before registering.

Leave of Absence. Leave of absence involving non-registration for one or more terms must be sought by written petition. A petition for a *medical* leave of absence must carry the endorsement of the Director of Health Services or his representative before being acted upon. Such leave up to one year can be granted by the appropriate Dean for a student whose grade-point average is 2.3 or more. Other petitions should be addressed to the Undergraduate Academic Standards and Honors Committee, and the student must indicate the length of time and the reasons for which absence is requested. In case of brief absences from any given exercise, arrangements must be made with the instructor in charge.

Departmental regulations. Any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed under his Division* may, at the discretion of his department, be refused permission to continue the work of that option. (See note at head of each option in schedule of undergraduate courses, for special departmental applications of this rule.) Such disbarment, however, does not prevent the student from continuing in some other option provided permission is obtained, or from repeating courses to raise his average in his original option.

Graduation requirement. To qualify for graduation a student must complete the prescribed work in one of the options with a passing grade in each required subject and with a grade-point average of 1.90. A grade of "F" in an elective course need not be made up, provided the student has received passing grades in enough other accepted units to satisfy the minimum total requirements of his option. In addition to the above requirement, a member of the Air Force ROTC unit must satisfactorily complete the basic course unless relieved of this obligation by the Air Force. If a member of the AFROTC has entered the advanced course or if he has at any time at the California Institute secured deferment under Selective Service by reason of his membership in the AFROTC, he must satisfactorily complete the AFROTC course and must accept a commission in the Air Force if one is offered unless excused from these obligations by action of the Air Force.

Graduation in the normally prescribed time. Any undergraduate student who fails to complete the requirements for graduation at the end of the normally prescribed time must petition the Undergraduate Academic Standards and Honors Committee for approval to register for further work.

Residence Requirement. All transfer students who are candidates for the Bachelor of Science degree must complete at least one full year of residence

*The curriculum of the Institute is organized under six divisions, as follows:
Division of Biology.
Division of Chemistry and Chemical Engineering.
Division of Engineering and Applied Science.
Division of Geological Sciences.
Division of Humanities.
Division of Physics, Mathematics and Astronomy.

in the undergraduate school at the Institute immediately preceding the completion of the requirements for graduation. At least ninety of the units taken must be in subjects in professional courses. A full year of residence is interpreted as meaning the equivalent of registration for three terms of not less than 49 units each.

Honor standing. At the close of each academic year the Committee on Undergraduate Academic Standards and Honors awards Honor Standing to twenty to thirty students in the sophomore and junior classes in residence.* These awards are based on the scholastic records of the students. A list of these students attaining Honor Standing on the basis of their academic records 1964-65 appears on page 365.

Graduation with honor. Graduation *with honor* will be granted a student who has achieved an over-all grade-point average of 3.2, including such an average in the senior year. In addition, a student may be graduated with honor under joint recommendation of his division and the Committee on Undergraduate Academic Standards and Honors, with the approval of the Faculty.

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

Excess or fewer than normal units. Undergraduates who wish to register in any term for more than 58 units inclusive of Physical Education or Air Science (55 academic units for Juniors and Seniors) must obtain the recommendation of the Option Advisor and the approval of the Undergraduate Academic Standards and Honors Committee. Master's candidates, see page 212. Petitions to carry excess units will not be accepted later than the last day of pre-registration.

Registration for fewer than 33 units must be approved by the Undergraduate Academic Standards and Honors Committee. See page 207 for graduate students.

Freshman honor electives. Honor Electives are available, on a voluntary basis, to all freshmen in the second and third terms of the freshman year. This Honors work is intended to maintain, or to rekindle, an interest the student brought with him to the Institute, or to develop an interest suggested by the work or the staff at the Institute. The Honor Electives are available campus-wide; any reasonable program of work, including critical reading, is acceptable. Upon satisfactory completion of a term of Honors work, a grade of "H" will be re-

*No honor standing will be granted for the freshman class since grades in all freshman courses are only "P," indicating passed, or "F," indicating failed.

corded for three units of credit; however, these units will not be included in computing the grade-point average.

Sophomore Honor Sections. Individual sophomore honor sections are organized in mathematics, physics, and history. An eligible student may register for only one, any two, or all three of these sections.

To be eligible, a student must have received grades of "P" in all courses in the freshman year, be recommended by the instructor in the prior course in the field of the particular honor section and have the permission of the instructor who is to teach the honor section.

Selection of option. In the middle of the third term freshmen must notify the Registrar's Office of their selection of an option in engineering, humanities, or science to be pursued in subsequent years. Upon the selection of an option, a freshman will be assigned an adviser in that option, whose approval must then be obtained for pre-registration for the following year.

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. After final approval for the change is obtained from the Chairman of the Curriculum Committee, the petition should be returned to the Registrar's Office.

Graduation in two different options. Students who wish to receive a second degree of Bachelor of Science in another option are required to have one additional year of residence (three terms of study involving at least 45 units per term) beyond the first Bachelor of Science degree.

Candidacy for the Bachelor's Degree

A student must file with the Registrar a declaration of his candidacy for the degree of Bachelor of Science on or before the first Monday of November preceding the date at which he expects to receive the degree. His record at the end of that term must show that he is not more than 21 units behind the requirement in the regular work of his course as of that date. All subjects required for graduation, with the exception of those for which the candidate is registered during the last term of his study, must be completed by the second Monday of May preceding commencement.

Transcripts of Records

At the request of a student, or former student, official transcripts of record bearing the seal of the Institute and signature of the Registrar will 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.

One transcript of a record will be furnished without charge. A charge of one dollar ($1.00) will be made for each transcript requested after the first.

STUDENT HEALTH AND PHYSICAL EDUCATION

Physical Education

Starting with the freshman year, all undergraduate students, except members of the Air Force ROTC, are required to participate in some form of physical training for at least one hour a day three days a week, until they can show credit for 6 terms of physical education at the college level. This requirement may be satisfied by engaging in organized sports, which include both intercollegiate and intramural athletics, or by regular attendance at physical education classes. Freshmen and sophomores who drop Air Force ROTC are required to register for Physical Education immediately.

Men may be excused from the requirement of physical education by petitioning the Physical Education and Athletics Committee for such excuse (1) because of physical disability, or (2) can show credit for 6 terms of physical education at the college level. It is the responsibility of students who wish to be excused and who are eligible under this ruling to make application for excuse at the Athletic Office. A transfer student accepted with junior standing will not be required to take Physical Education regardless of Physical Education credit from his previous institution or the lack of it.

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

Student Health

PRE-ADMISSION PHYSICAL EXAMINATION AND VACCINATION

All admissions, whether graduate or undergraduate, are conditional until a report of physical examination is received and approved by the Director of Student Health (see page 174). Required are: smallpox vaccination, tetanus immunization, and tuberculosis testing, all within six months of matriculation.

STUDENT HEALTH SERVICES

The Archibald Young Health Center is located at 1239 Arden Road, south of California Boulevard. Facilities include a dispensary and a ten-bed infirmary, with provision for expanding this to sixteen beds in an emergency. The Health Center provides general office medical care, minor emergency surgery, and certain psychological and psychiatric services. Complete laboratory facilities are available through the Pasadena Clinical Laboratory.

The services of the Health Center are available to undergraduate and graduate students. They are available for faculty on a limited basis, covering emergency care, on-the-job injuries, inoculations, and annual physical examinations under certain conditions. They are available for employees of the Institute for on-the-job injuries and inoculations.

The staff of the Health Center consists of attending physicians, retained consultants, a psychologist, nurses, and a receptionist. A medical consultant in radiological safety is on the consulting staff. Close cooperation is maintained with leading specialists in all fields within the Pasadena area. The services of these doctors are used freely in maintaining high standards of modern medical care.

The dispensary is open for all regular service from 9:00 a.m. to 5:00 p.m., Monday through Friday, and 9:00 a.m. to noon on Saturday, except during the vacation periods (Thanksgiving, Christmas, and spring recesses) and the summer months, when a slightly restricted schedule is observed. The Infirmary is operated (with a registered nurse available for emergency care, and a physician on call for emergencies) twenty-four hours a day, seven days a week, except during holidays and the summer period.

The Health Center is financed by the Institute and by a Health Fee. During the summer, a special health fee of $7.50 is charged to student trainees and to students who have not been enrolled during the preceding three school terms, except that those graduate students who pay regular tuition during the summer months are exempt from this special fee. Supplementary fees are charged for certain services during the summer months only.

STUDENT HEALTH PLAN

In addition to services available at the Health Center, year around coverage under California Physicians Service is provided. This integrated two-part plan includes basic hospital and surgical and major medical coverage for 80% of costs up to $10,000 after a $100 deductible. Details of coverage are contained in booklets available at the Personnel Office. All students are included, and benefits continue for twelve months, on campus and off campus, provided students remain enrolled through the school year. Students have available the following services:

1. Office consultations and treatment with a staff physician at prescribed hours.
2. Laboratory tests and radiographs as prescribed or ordered by the staff physician.
3. Inoculations and treatments administered by nurses.
4. Routine drugs and medicine which may be dispensed at the Health Center.
5. Infirmary and hospital care.
6. Emergency care, hospital benefits, physician visits while in the hospital, and surgical benefits outlined in the Student Health Plan brochure available at the Personnel Office and also distributed upon registration.
7. Funds are available to the Faculty Health Committee to assist students with the first $100 of expenses under the major medical coverage.
8. Psychological counseling and psychiatric service to the extent that these can be provided on a short-term basis. A staff psychiatrist and a staff psychologist are available at the Health Center. Cases requiring intensive or long-time care will be referred to outside physicians at the discretion of the Health Center staff and with the concurrence of the student or his family.
9. A charge of $5.00 is made for special physical examinations and the filling out of forms for insurance applications, transfer to other institutions, and similar personal services outside the purview of student care.
10. The Department of Physical Education maintains an insurance plan covering accidents in intercollegiate athletic participation.

COVERAGE OF DEPENDENTS

Besides the student coverage outlined above, a student's spouse and all unmarried dependent children over 14 days and under 19 years of age are eligible under the California Physicians Service contract. Dependent care is not administered at the Health Center except in case of severe emergency.

Application for dependent's insurance must be made at the time of registration or within 31 days of registration for any one school term. Rates applicable to dependent coverage are contained in the Student Health Plan brochure.

SERVICES NOT PROVIDED BY STUDENT HEALTH PLAN

1. Services provided to the student not authorized or requested by the Health Center staff (except during vacations or emergencies when the student is unable to utilize services of the Student Health Center).
2. Services for pregnancy or conditions arising therefrom, except for ectopic pregnancies.
3. Workmen's Compensation cases.
4. Services provided by federal or state governmental agencies or without cost to the student by any other governmental agency.
5. Services provided by any other medical or hospital service organization.
6. Eye refractions.
7. Hospitalization for tuberculosis after diagnosis, except when required for surgery.
8. Dental services, including oral surgery and hospitalization for such, except that up to $300 is provided for care of injury to the permanent teeth.

RESPONSIBILITY OF THE STUDENT

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

Any expenses incurred in securing advice and attention in any case are entirely the responsibility of the student, except as specified above. To secure payment and substantiate a claim for services rendered away from the Institute, the student is required to retain bills for such services and present them with appropriate documentation when major medical claim is made through the Personnel Office.

UNDERGRADUATE EXPENSES

For freshmen applying for admission, there is a $10.00 Application Fee, not refundable, but applicable upon registration to the Tuition Fee.

For freshmen and transfer students, there is a $10.00 Registration Fee payable upon notification of admission. Not refundable if admission cancelled by applicant.

ANNUAL EXPENSE SUMMARY

Tuition (3 terms)		$1,800.00	
General Deposit		25.00	
Health Fee		25.00	
Student Body Dues, including *California Tech*		22.00	
Assessment for *Big T*		6.00	$1,878.00
Books and Supplies (approx.)			80.00
Student House Living Expenses (21 meals per week)			
Board	$595.00		
Room[1]	405.00[1]	$1,000.00	
Dues		30.00	1,030.00
			$2,988.00

The following is a list of undergraduate student expenses at the California Institute of Technology for the Academic Year 1965-66, together with the dates on which the various fees are due. These charges are subject to change at the discretion of the Institute.

	First Term	*Fee*
Sept. 23, 1965 Freshmen and transfer students	General Breakage Deposit	$ 25.00
Sept. 27, 1965 All others	Tuition	600.00
	Board and Room	361.00
	Health Fee	25.00
	Incidental Fees:	
	Associated Student Body Dues	7.00
	Assessment for *Big T*	2.00
	Student House Dues	10.00
	Second Term	
January 3, 1966	Tuition	600.00
	Board and Room	326.00
	Incidental Fees:	
	Associated Student Body Dues	7.50
	Assessment for *Big T*	2.00
	Student House Dues	10.00
	Third Term	
March 28, 1966	Tuition	600.00
	Board and Room	313.00
	Incidental Fees:	
	Associated Student Body Dues	7.50
	Assessment for *Big T*	2.00
	Student House Dues	10.00

[1]There are a few large rooms available which will rent for $465.00 per year. Rates for room and board are subject to revision prior to beginning of any term upon notice to student.

Tuition Fees for fewer than normal number of units:

Over 35 units	Full Tuition[1]
Per unit per term	$17.00
Minimum per term	$180.00
Auditor's Fee (p. 182)	$25.00 per term, per lecture hour

Withdrawals. Students withdrawing from the Institute during the first three weeks of a term, for reasons deemed satisfactory to the Institute, are entitled to a refund of tuition fees paid, less a reduction of 20% and a pro rata charge for time in attendance.[2] No portion of the Student Body Dues, or subscription to *California Tech*, is refundable upon withdrawal at any time.

Associated Student Body Dues. Associated Student Body Dues of $22.00 are payable by all undergraduate students. These are used for the support of athletics and any other student activity that the Board of Directors of the Associated Students of the California Institute of Technology may deem necessary. The subscription to the student newspaper, *California Tech*, $3.00 per year, is included in the A.S.B. Dues. In addition, each undergraduate student is assessed $2.00 per term for the college annual, the *Big T*.

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

Winnett Student Center. Winnett Student Center facilities are reserved for the use of Caltech undergraduate and graduate students and their guests. A voluntary contribution of fifty cents a year is made by each student to help defray the expenses of the game room.

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

Application for rooms in the Student Houses may be made by addressing the Master of Student Houses (see page 160).

Special Fees. Students taking the Summer Field Geology course (Ge 123) should consult with the Division about travel and subsistence arrangements and costs.

Unpaid Bills. All bills owed the Institute must be paid when due. Any student whose bills are delinquent may be refused registration for the term following that in which the delinquency occurs. Students who have not made satisfactory arrangements regarding bills due and other indebtedness to the Institute by the date of graduation will be refused graduation.

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

[1]Although the Institute charges full tuition for over 35 units, the Veterans Admnistration allows the following subsistence percentages: 25% for 10 through 20 units per term; 50% for 21 through 29; 75% for 30 through 41; and 100% for 42 and over. See footnote page 243.

[2]Pro rata refunds are allowed students who are drafted (not volunteers) at any time in the term provided the period in attendance is insufficient to entitle student to receive final grades.

1. California Institute loan funds are available in amounts not to exceed \$750 in any one year and a maximum of \$3000 during undergraduate residence. No interest is charged and no repayment of principal is required during undergraduate residence as long as residence is continuous (the term "residence" includes the usual vacation periods). For those who do not go on to graduate school, repayment commences after the graduation of their class and is at the rate of \$50 per month including simple interest at 4 percent per annum on the unpaid balance. For those who go on to graduate school at Caltech or elsewhere no later than the fall following their class's graduation, interest is charged at the rate of 3 percent per annum, but no payment on principal is required until the final advanced degree is earned provided that the borrower remains in continuous residence. After the final degree has been earned, repayment commences at the rate of \$50 per month including interest at 4 percent on the unpaid balance. If the borrower withdraws from undergraduate or graduate registration at any time before receiving the last degree for which he has been working, the total amount owed the Institute becomes due and payable at once, unless the Scholarships and Financial Aid Committee agrees to some exception to this rule.

It is inadvisable for foreign students from countries with seriously adverse rates of exchange to borrow more than they can repay from savings (after taxes) out of salaries earned in the United States. The Federal Government grants a maximum extension of only 18 months on students' visas for holders who engage in full-time commercial employment after they take their degrees. For practical purposes, this means that total indebtedness may not exceed \$1000.

2. Federal loans under the National Defense Education Act are available to undergraduate students in amounts not to exceed \$1000 for any individual in a single year up to a total of \$5000. The borrower must demonstrate financial need, must be an above average student, and must be willing to sign a loyalty oath. No interest is charged on these loans nor is any repayment of principal required until one year after the final degree has been earned. At that time repayment commences and interest is charged at the rate of 3 percent per annum on the unpaid balance.

For loans to graduate students under the National Defense Education Act see page 242.

To the extent of available funds, students who wish to borrow and who meet the stipulated requirements will be given their choice of loan sources as stated on page 203.

Deferred Payment Plan. In addition to loans there is available a plan under which any student in good standing may defer up to \$1300 of his college bills each year to a total of \$5200 and may pay the deferred portion in installments after his graduation. The sum of \$50.70 a year is added to the deferred portion and represents the premiums on a life insurance policy in the amount of any balance due the Institute under this plan. The insurance policy covers the life of the student for the duration of the obligation, and during the four undergraduate years it covers in addition the life of the parent or guardian responsible for the student's support. Interest on the amount deferred is charged at the rate of 5½ percent per annum payable quarterly. The interest is the only payment made on this plan during the undergraduate years. On November 1 following his class's graduation the student commences repayment on the deferred portion at the rate of $65.00 a month including interest at 5½ percent on the unpaid balance. For those who go on to graduate school more favorable repayment arrangements may be made for the duration of graduate work. As in the case of loans, the total of any balance owed the Institute under this plan becomes due and payable at once if continuous residence is not maintained unless in the opinion of the Scholarships and Financial Aid Committee some exception to this rule should be made.

Loans and the Deferred Payment Plan may be used in combination, but the total that may be borrowed or deferred may not exceed $1300 in any year (maximum of $5200).

Entirely aside from loans and the Deferred Payment Plan a student may arrange with the business office to pay his college bills monthly rather than at the beginning of each term as is customary. No interest is charged on such monthly payments, but arrangements with the business office must be made in advance.

SCHOLARSHIPS, STUDENT AID AND PRIZES

1. Freshman Scholarship Grants

The recipients of scholarship grants are selected by the Freshman Admissions Committee from the candidates who have satisfied the entrance requirements of the Institute, and have submitted a *Parent's Confidential Statement* (see below).

Scholarship grants are awarded to the extent of available funds where financial need is demonstrated. Awards are made on the basis of all the information available in regard to the applicants—the results of their examinations, their high school records and recommendations, the statements submitted as to their student activities and outside interests, and the result of personal interviews where these are possible. A list of scholarship funds will be found on pages 198-202.

The California Institute uses the uniform scholarship grant application that has been adopted by many colleges in the United States. All applications for scholarship grants where financial need exists must be made on this form. The form, called a *Parent's Confidential Statement,* may be obtained in nearly all cases at the school where the applicant is attending. If his school does not have a supply, he should write to the College Scholarship Service at one of the College Entrance Examination Board offices, the addresses of which are given on page 171. The form is put out by the College Scholarship Service of the College Board and is to be returned directly to the appropriate office of the College Board (see page 171) and not to the California Institute. Space is provided on the form for the applicant to indicate that he wishes a copy sent to the California Institute and to such other colleges as he may desire. A fee of three dollars is charged by the service for sending a copy of the form to one college, and an additional two dollars each for copies sent to additional colleges. This fee must accompany the form when it is returned to the College Board office.

Parent's Confidential Statement forms must be sent to the appropriate College Board office not later than February 15 of the year in which admission is desired. All applicants who have submitted this form by the above date are considered for scholarship grants. It is not necessary to apply for any particular scholarship by name.

HONORARY SCHOLARSHIPS

In addition to the above, there are three honorary awards which carry stipends. The Sloan Scholarships, the General Motors Scholarships, and the California Institute National Prize Scholarships described on following pages are given without consideration of financial need. All applicants for admission are automatically considered for these scholarships. Only when need exists is it necessary to file a *Parent's Confidential Statement* in connection with these awards.

STATE AND NATIONAL SCHOLARSHIP AWARDS

Candidates for freshman scholarships are urged to make exhaustive inquiry of their school advisers and to watch their school bulletin boards for announcements of scholarship contests the winners of which may use the awards at the college of their choice. The State of California, for example, awards such scholarships annually to residents of the state who wish to attend a college within the state. Residents of the State of California who request financial aid will be penalized in consideration for scholarship grants if they do not apply for California State scholarships, provided their test scores indicate that they would have won a State award had they applied. Among the nationwide awards are the National Merit Scholarships, and the Westinghouse Talent Search Awards. Applicants in need of financial assistance should enter any such contest for which they are eligible, in addition to applying for California Institute Scholarship grants. While duplicate awards will not be given beyond the actual extent of need, the more sources to which a candidate applies the greater are his chances of receiving scholarship assistance.

REGULATIONS AND RENEWALS

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

2. Upperclass Scholarship Grants

Sophomores, juniors, and seniors are considered for scholarships if need is demonstrated and if throughout the preceding year they have carried at least the normal number of units required in their respective options, and if they have completed the preceding academic year with a grade-point average of at least 2.0. Awards are made in order of rank in class to the extent of the funds available. Most awards are for full or part tuition. When individual scholarships carry amounts in excess of full tuition, that fact is noted in the list of scholarships below. A student who ends the academic year with a grade-point average of 2.0 or higher and who wishes to apply for a scholarship grant for the next year should obtain a scholarship form from the Admissions Office in March. This form is to be filled out by the student and his parents (or guardian) and returned to the Admissions Office by May 1. No one will be considered for a scholarship grant unless a scholarship form completely filled out and signed by parents (or guardian) is submitted by the proper date. If a scholarship applicant feels that his parents should no longer be responsible for his support, he may attach an explanatory note to the form, but the form must be filled out.

It is expected that students to whom awards are made will maintain a high standard of scholarship and conduct. Failure to do so at any time during the school year may result in the termination of the award. The amount of a scholarship may be reduced if a student pays less than full tuition because of registration for less than a full academic load.

3. Scholarship Funds

Funds for freshman and upperclass scholarships are provided in large part from the special scholarship funds named below. Where the amount of a grant is not specified, there is a certain total sum available each year to be distributed among several scholarship holders in any proportion. Grants from these funds are usually for full tuition, or less if the need of the recipient is less. It is not necessary to apply for any particular scholarship by name. Applicants for admission who have a *Parent's Confidential Statement* on file will be considered for the best award to which their relative need and standing on the entrance examinations entitle them. For Honorary Scholarships see above.

Alcoa Scholarships: The Alcoa Foundation of the Aluminum Company of America has given funds for two undergraduate scholarships.

Alumni Scholarships: The Alumni Association of the California Institute provides scholarships covering full tuition to be awarded to entering freshmen. The recipients of these scholarships can expect to receive this amount for four years provided their conduct and grades continue to be satisfactory.

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

ARCS Foundation (Achievement Rewards for College Scientists) of Los Angeles: The ARCS Foundation has established a fund for the award of several undergraduate and graduate scholarships.

R. C. Baker Foundation Scholarship: The R. C. Baker Foundation of Los Angeles has established a fund for undergraduate engineering scholarships.

Edward C. Barrett Scholarship: Friends of Edward C. Barrett, who for forty-one years was Secretary of the California Institute, established in his name a scholarship to be awarded annually to an undergraduate student.

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

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

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

California Institute National Prize Scholarships: Seven National Prize

Scholarships not related to need and amounting to $1000 for the freshman year may be awarded at the discretion of the Admissions Committee.

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

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

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

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

Crown Zellerbach Foundation Scholarships: The Crown Zellerbach Foundation of San Francisco provides two scholarships of $1200 each for juniors or seniors majoring in a science option.

Cyprus Mines Corporation Scholarships: The Cyprus Mines Corporation of Los Angeles gave $1000 to be used for undergraduate scholarships.

Dabney Scholarships: Mrs. Joseph B. Dabney made provision for annual scholarships to be awarded at the discretion of the Institute to members of the undergraduate student body. The recipients are designated Dabney Scholars.

Douglas Aircraft Company Scholarship: The Douglas Aircraft Company of Los Angeles made provision for a $1500 scholarship to be awarded to a junior or senior in engineering or physics, in that order of preference.

Douglas Oil Company of California: The Douglas Oil Company of California gave $500 to be made available to a senior who has interest in the field of industrial relations.

Drake Scholarships: Mr. and Mrs. A. M. Drake of Pasadena made provision for an annual scholarship available for a graduate of the high schools of St. Paul, Minnesota, and a similar annual scholarship available for a graduate of the high school of Bend, Oregon. If there are no such candidates, the Institute may award the scholarships elsewhere. Mr. and Mrs. Drake, by a Trust Agreement of July 23, 1927, also established the Alexander McClurg Drake and Florence W. Drake Fellowship and Scholarship Fund, the income of which may be used for fellowships and scholarships as determined by the Board of Trustees of the Institute.

Robert S. and Nellie V. H. Dutton: Mrs. Robert S. Dutton established a fund, the interest from which is used for undergraduate scholarships.

General Motor Corporation Scholarships: The General Motors Corporation established three scholarships at the California Institute to be awarded to entering freshmen. The award may range from a prize scholarship of $200 for a student not in need of financial assistance to an amount as high as $2000 a year depending on need. A holder of this scholarship may expect it to be renewed in each of the three upperclass years provided the holder's grades and conduct remain satisfactory.

The Gnome Club Scholarship: The alumni of the Gnome Club established a scholarship usually awarded to a student in the senior class.

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

Robert E. Gross—Lockheed Aircraft Corporation: These scholarships are part of an award program to perpetuate the memory of Robert E. Gross, who founded Lockheed and served as its principal officer until his death in 1961.

Harriet Harvey and Walter Humphry Scholarships: Miss Harriet Harvey and Mrs. Emily A. Humphry made provision for two scholarships. The first of these, the Harriet Harvey Scholarship, is to be awarded preferably to a well-qualified candidate from the state of Wisconsin. If there is no such candidate the Institute may award the scholarship elsewhere. The second, the Walter Humphry Scholarship, is to be awarded preferably to a well-qualified candidate from the state of Iowa. If there is no such candidate, the Institute may award the scholarship elsewhere.

Robert Haufe Memorial Scholarship: This scholarship is supported by a fund established in 1950 by Mr. and Mrs. J. H. Haufe as a memorial to their son, Robert Haufe.

Hewlett-Packard Scholarship: The Neely Sales Division of Hewlett-Packard gave $2000 for undergraduate scholarships with preference to be given to sophomores.

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

The International Nickel Company Scholarship: The International Nickel Company of New York established a four-year scholarship of $1900 a year for a student entering the freshman year in 1962.

J. W. and Ida M. Jameson Foundation: The Jameson Foundation has made possible the award of three scholarships.

Earle M. Jorgensen Scholarship: Mr. Earle M. Jorgensen has made possible the award of two scholarships.

J. B. Keating Scholarships: Mr. John B. Keating has made possible the award of two scholarships for undergraduate juniors or seniors.

Kennecott Copper Corporation Scholarship: The Kennecott Copper Corporation has given a $1000 scholarship for a junior or senior student majoring in chemical engineering.

Lockheed National Engineering Scholarship: The Lockheed Aircraft Corporation of Burbank, California, established a scholarship covering tuition and certain other expenses. This scholarship is to be awarded to an entering freshman who indicates that he intends to pursue a course in engineering. The recipient of this scholarship may expect to continue to receive this award during each of the three upperclass years, provided that his grades and conduct remain satisfactory.

Management Club of California Institute of Technology Scholarship: The Management Club at the Institute gives two tuition scholarships to be awarded to undergraduate students in any of the three upper classes.

Mayr Foundation Scholarships: The George H. Mayr Foundation of Beverly Hills granted funds for a number of undergraduate scholarships. Not open to freshmen.

William C. McDuffie Scholarship: Friends of Mr. William C. McDuffie, for many years a Trustee of the California Institute, have given a fund, the income from which is used for undergraduate scholarships.

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

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

Frances W. Noble Scholarship: This scholarship has been established from funds given to the Institute by Mrs. Frances W. Noble.

La Verne Noyes Scholarship: Under the will of La Verne Noyes of Chicago, funds are provided for paying the tuition, in part or in full, for deserving students needing this assistance to enable them to procure a university or college training. This is to be done without regard to differences of race, religion or political party, but only for those who shall be citizens of the United States of America and either: first, shall themselves have served in the army or navy of the United States of America in the war into which our country entered on the 6th of April, 1917, and were honorably discharged from such service, or second, shall be descended by blood from someone who has served in the army or navy of the United States in said war, and who either is still in said service or whose said service in the army or navy was terminated by death or an honorable discharge. The recipients are designated La Verne Noyes Scholars.

Pasadena Optimists Club Scholarship Endowment Fund: The Pasadena Optimists Club gave a fund the interest from which is to be used for undergraduate scholarships.

Edgar H. Pflager Scholarship Fund: Mr. Edgar H. Pflager established, by gift and bequest, a fund the income from which is to be used for undergraduate scholarships.

Phillips Foundation Scholarship: The Charlotte Palmer Phillips Foundation of New York established a four-year scholarship to be awarded to an entering freshman, with no restriction as to major field of study.

Procter and Gamble Scholarship: The Procter and Gamble Fund provides a four-year undergraduate scholarship covering tuition and certain other expenses. This four-year award is open to entering freshmen only.

Radio Corporation of America Scholarship: The Radio Corporation of America provided funds for an undergraduate scholarship in the amount of $800.

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

Alfred P. Sloan National Scholarships: The Alfred P. Sloan Foundation of New York established at the California Institute a minimum of six scholarships to be awarded to entering freshmen without restriction as to the field of study to be pursued. Original selection of the holders of these scholarships is made without regard to financial need. Once selection has been made, awards will range from a prize scholarship of $200 per year for students not in need of financial assistance to amounts as high as $2400 per year to those whose need warrants such consideration. Holders of these scholarships may expect them to be renewed in each of the three upperclass years provided the holder's grades and conduct remain satisfactory.

Standard Oil Company of California Scholarships: The Standard Oil Company of California provided two scholarships for undergraduates majoring in engineering.

Elizabeth Thompson Stone Scholarship: Miss Elizabeth Thompson Stone of Pasadena established, in her will, a scholarship known as the Elizabeth Thompson Stone Scholarship.

William W. Stout Scholarship Endowment Fund: Mr. William W. Stout established a scholarship fund the interest from which is to be used for undergraduate scholarships.

Superior Oil Company Scholarship: The Superior Oil Company of Los Angeles established a four-year scholarship covering tuition and certain other expenses. Preference is given to a student interested in geology, chemical engineering, or physics.

Systems Technology Scholarship: Systems Technology, Inc. has provided money for an undergraduate scholarship.

Texaco Scholarships: Texaco Inc. is providing for one or more scholarships to be awarded to juniors or seniors majoring in a field of engineering or science that would prepare them for a career in the petroleum industry.

Waltmar Foundation: The Waltmar Foundation of Garden Grove, California, has given $2000 for scholarships with preference to be given to students from Garden Grove High School or from Orange County.

Western Electronic Manufacturers Association Scholarship: Western Electronic Manufacturers Association of Los Angeles provided for one or more scholarships for junior and senior students in engineering. The purpose of these scholarships is to promote interest in the electronics field.

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

Brayton Wilbur–Thomas G. Franck Scholarship: Mr. Brayton Wilbur and Mr. Thomas G. Franck of Los Angeles established the Brayton Wilbur-Thomas G. Franck Scholarship Fund, the income to be used for a scholarship for a deserving student at the Institute.

In addition to the foregoing named scholarships, there is a Scholarship Endowment Fund made up of gifts from various donors.

Of the scholarship donors listed above the following include with their scholarship gifts an unrestricted grant to the Institute's general funds to help defray educational costs in excess of that portion covered by tuition.

Alcoa Foundation
The R. C. Baker Foundation
Crown Zellerbach Foundation
Cyprus Mines Corporation
Douglas Aircraft Company, Inc.
Douglas Oil Company
General Motors Corporation
Goodyear Foundation, Inc.
International Nickel Co., Inc.
Kennecott Copper Corporation
Lockheed Leadership Fund
The Procter & Gamble Fund
Radio Corporation of America
Alfred P. Sloan Foundation
Texaco Inc.

INSTITUTE LOAN FUNDS

4. Student Aid Loan Funds

(See page 194)

Thanks to funds presented by a number of generous donors, the Institute is enabled to lend money to many students who, without aid, could not complete their education. Each fund is administered according to the wishes of the donor, but in general, as outlined on pages 194-195. Borrowers must be making satisfactory progress toward their degrees; and, in general, preference is given to students who have earned part of their expenses. The Institute Loan Funds are named as follows:

The Gustavus A. Axelson Loan Fund
The Olive Cleveland Fund
The Hosea Lewis Dudey Loan Fund
The Dudley Foundation Loan Fund
The Claire Dunlap Loan Fund
Ford Foundation Loan Fund
Susan Baker Geddes Loan Fund
Thomas-Lain Gordon Memorial Loan Fund
The Roy W. Gray Fund
The Raphael Herman Loan Fund
The Vaino A. Hoover Student Aid Fund
The Howard R. Hughes Student Loan Fund
The Thomas Jackson Memorial Fund
The Ruth Wydman Jarmie Loan Fund
Eugene Kirkeby Loan Fund
The Gustav D. Koehler Loan Fund
The Frank W. Lehan Loan Fund
The John McMorris Memorial Loan Fund
The James K. Nason Memorial Loan Fund
The Noble Loan and Scholarship Fund
The James R. Page Loan Fund
The Sloan Foundation Loan Fund
The Albert H. Stone Educational Fund
Scholarship and Loan Fund—Sundry Donors

NATIONAL DEFENSE STUDENT LOAN PROGRAM

(See page 194)

All students are eligible to apply for loans from these limited funds provided they are: citizens or permanent residents of the United States; meeting the Institute's academic standards and standards of conduct; and are recommended by the Scholarships and Financial Aid Committee. Students with superior grades take precedence over others.

A student may apply for a maximum of $1000 a year for five years. Beginning one year after he has completed his education, he pays 3 percent interest per year on the unpaid balance of his loan. He pays no interest as long as he is a full-time student, nor if he is serving in the armed forces (maximum three years).

Applicants must show evidence of need (statement of family income and resources, personal resources, and an estimated annual budget); sign an oath of allegiance; and (if applicant is under 21) obtain signature of parent or guardian to the effect that he has read the application.

DEFERRED PAYMENT PLANS FOR TUITION

See detailed information on pages 194-195.

STUDENT EMPLOYMENT

The Institute tries to help students to find suitable employment when they cannot continue their education without thus supplementing their incomes. The requirements of the courses at the Institute are so exacting, however, that under ordinary circumstances students who are entirely or largely self-supporting should not expect to complete a regular course program satisfactorily in the usual time. It is highly inadvisable for freshman students to attempt to earn their expenses. Students wishing employment are advised to write, before coming to the Institute, to the Director of Placements.

PLACEMENT SERVICE

The Institute maintains a Placement Office under the direction of a member of the Faculty. With the services of a full-time staff, this office assists graduates and undergraduates to find employment.

Interviews with candidates for the Ph.D. degree are arranged during any term. Interviews with candidates for other degrees are arranged during the second and third terms. Students, both graduate and undergraduate, wanting part-time employment during the school year or during vacations, should register at the Placement Office. Assistance will be given whenever possible in securing employment for summer vacations. Alumni who are unemployed or desire improvement in their positions should register at the Placement Office.

A large number of brochures published by industrial organizations and government agencies are available. These show placement opportunities in the fields of science and engineering. The Director of Placements is always available for consultation and guidance on placement problems.

The Placement Office maintains information on fellowships and scholarships offered by universities, foundations, and industry.

It should be understood that the Institute assumes no responsibility in obtaining employment for its graduates, although the Placement Office will make every effort to find employment for those who wish to make use of this service.

5. PRIZES

THE FREDERIC W. HINRICHS, JR., MEMORIAL AWARD

The Board of Trustees of the California Institute of Technology established the Frederic W. Hinrichs, Jr., Memorial Award in memory of the man who served for more than twenty years as Dean and Professor at the Institute. In remembrance of his honor, courage, and kindness, the award bearing his name is made annually to the senior who, in the judgment of the undergraduate Deans, throughout his undergraduate years at the Institute has made the greatest contribution to the welfare of the student body and whose qualities of character, leadership, and responsibility have been outstanding. At the discretion of the Deans, more than one award or none may be made in any year. The award, presented at commencement without prior notification, consists of $100 in cash, a certificate, and a suitable memento.

THE CONGER PEACE PRIZE

The Conger Peace Prize was established in 1912 by the Reverend Everett L. Conger, D.D., for the promotion of interest in the movement toward universal peace, and for the furtherance of public speaking. The annual income from $1000 provides for a first and second prize to be awarded at a public contest. The contest is under the direction of representatives of the Division of the Humanities.

THE MARY A. EARLE MCKINNEY PRIZE IN ENGLISH

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

THE DON SHEPARD AWARD

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

THE DAVID JOSEPH MACPHERSON PRIZE IN ENGINEERING

The David Joseph Macpherson Prize in Engineering was established in 1957 by Margaret V. Macpherson in memory of her father, a graduate of Cornell University in civil engineering, class of 1878. A prize of $100 is awarded annually to the graduating senior in engineering who best exemplifies excellence in scholarship. The winning student is selected by a faculty committee of three, appointed annually by the chairman of the Division of Engineering.

TRAVEL PRIZE

Each year those juniors who are in the top 15-20% of their class, scholastically, are eligible to compete for a Travel Prize. This prize provides funds for the winners (about three annually) to travel during the summer between their junior and senior years almost anywhere to pursue individual vocational or avocational interests.

THE ERIC TEMPLE BELL UNDERGRADUATE MATHEMATICS RESEARCH PRIZE

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

THE GEORGE W. GREEN MEMORIAL PRIZE

The George W. Green Memorial Prize was established in 1963 based on contributions given in memory of George W. Green, who for fifteen years served on the staff of the Caltech business office and was from 1956-1962 Vice President for Business Affairs. The prize of $400 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 SCAAPT PRIZE

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

Section IV

INFORMATION AND REGULATIONS FOR THE GUIDANCE OF GRADUATE STUDENTS

A. General Regulations

I. REQUIREMENTS FOR ADMISSION TO GRADUATE STANDING

1. The Institute offers graduate work leading to the following degrees: Master of Science, after a minimum of one year of graduate work; Aeronautical Engineer, Civil Engineer, Electrical Engineer, Geological Engineer, Geophysical Engineer, and Mechanical Engineer, after a minimum of two years of graduate work; and Doctor of Philosophy after a minimum of three years of graduate work.

2. To be admitted to graduate standing an applicant must in general have received a bachelor's degree representing the completion of an undergraduate course in science or engineering substantially equivalent to one of the options offered by the Institute. He must, moreover, have attained such a scholastic record and, if from another institution, must present such recommendations as to indicate that he is fitted to pursue with distinction advanced study and research. In some cases examinations may be required.

3. Application for admission to graduate standing should be made to the Dean of Graduate Studies, on a form obtained from his office. Admission to graduate standing will be granted *only to a limited number of students of superior ability,* and application should be made as early as possible. Women students are admitted only in exceptional cases. In general, admission to graduate standing is effective for enrollment only at the beginning of the next academic year. If the applicant's preliminary training has not been substantially that given by the four-year undergraduate options at the Institute, he may be admitted subject to satisfactory completion of such undergraduate subjects as may be assigned. Admission sometimes may have to be refused solely on the basis of limited facilities in the department concerned. Students applying for assistantships or fellowships (see page 236) need not make separate application for admission to graduate standing, but should submit their applications before February 15. For requirements in regard to physical examination, see pages 174 and 189.

4. Admission to graduate standing does not of itself admit to candidacy for a degree. Application for admission to candidacy for the degree desired must be made as provided in the regulations governing work for the degree.

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

II. GRADUATE RESIDENCE

1. 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 larger number of units in any one term will not be regarded as increasing the residence. See pages 203, 204, 207 for special requirements for residence.

2. Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Except by specific action of the Committee on Graduate Study, graduate students will be required to register for at least 36 units during each of their first three terms of attendance at the Institute. A graduate student who is registered for 36 or more units is classed as a full-time graduate student.

3. Graduate students expecting to receive a degree will be required to maintain their admission status until the degree is obtained, either by continuity of registration or on the basis of approved leave of absence. In case of lapse in graduate standing, readmission must be sought before academic work may be resumed or the degree may be conferred.

4. Graduate students are encouraged to continue their research during the whole or a part of the summer, but in order that such work may count in fulfillment of the residence requirements, the student must file a registration card for such summer work in the office of the Registrar by May 16. A minimum of 10 units must be taken. Students who are registered for summer research must pay the Summer Insurance Accident fee. They will not in general be required to pay tuition for the research units, but will be required to pay minimum tuition of $170 if Ph.D. or engineer's degree thesis requirements are completed during the summer.

III. REGISTRATION

1. Students are required to register and file a program card in the Registrar's Office at the beginning of each term of residence, whether they are attending a regular course of study, carrying on research or independent reading only, writing a thesis or other dissertation, or utilizing any other academic service.

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

3. The number of units allowed for a course of study or for research is so chosen that one unit corresponds roughly to one hour a week of work throughout the term for a student of superior ability.

4. A student will not receive credit for a course unless he is properly registered. At the first meeting of each class he should furnish the instructor with a regular assignment card for the course, obtained on registration. *The student himself is charged with the responsibility of making certain that all grades to which he is entitled have been recorded.*

5. All changes in registration must be reported, on drop or add cards, to the Registrar's Office by the student. Such changes are governed by the last dates for adding or dropping courses as shown on the academic calendar on pages 4 and 5. A student may not withdraw from or add a course after the last date for dropping or adding courses without, in addition to his department's consent, the approval of the Dean of Graduate Studies.

6. 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 the research does not justify the full number originally registered for.

7. A graduate student who undertakes activities related to the Institute (studies, research, and assisting or other employment) aggregating more than 62 hours per week must receive prior approval therefor from the Dean of Graduate Studies. Petition forms for this purpose may be obtained from the Graduate Office, and must carry the recommendation of the student's major department before submission to the Graduate Office.

8. Registration, with at least minimum tuition (see page 192), 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 thesis. Registration with minimum tuition will be allowed for at most one term.

9. A graduate student doing unsatisfactory work may be declared ineligible to register at the beginning of any term.

10. A graduate student will be considered to be ineligible for registration at the beginning of his second term at the Institute unless his photograph for the Registrar's record card is affixed thereto, or a certification from the photographer is obtained to show that such photograph is in course of preparation on the date of registration. The Registrar provides the opportunity to have these photographs made, without cost to the student, on the registration days of the first and second terms of each year. Photographs taken for this purpose at other times are provided by the student at his own expense.

IV. GRADES IN GRADUATE COURSES

1. Term examinations are held in all graduate courses unless the instructor, after consultation with the Chairman of the Division, shall arrange otherwise. No student taking a course for credit shall be exempt from these examinations when they are held.

2. Grades for all graduate work are reported to the Registrar's office at the close of each term.

3. The following system of grades is used to indicate class standing in graduate courses: "A" excellent, "B" good, "C" satisfactory, "D" poor, "E" conditioned, "F" failed, "Inc" incomplete. In addition to these grades, which are to be interpreted as having the same significance as for undergraduate courses (see page 183), the grade "P," which denotes passed, may be used at the discretion of the instructor, for all or some of the students, in the case of seminar or other work which does not lend itself to more specific grading. In graduate research, only the grades of "P" and "F" are given.

V. TUITION AND OTHER FEES

The tuition charge for all students registering for graduate work is currently $1800 per academic year, payable in three installments at the beginning of each term. Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Students desiring permission to register for fewer than 36 units should petition therefor on a blank obtained from the Registrar. If reduced registration is permitted, the tuition for each term is at the rate of $17 a unit for fewer than 36 units with a minimum of $170 a term. Additional tuition will be charged to students registering for special courses made available to them which are not part of the normal educational facilities of the Institute.

The payment of tuition by graduate students is required (a) without reference to the character of the work of the student, which may consist in the prosecution of research, in independent reading, or in the writing of a thesis or other dissertation, as well as in attendance at regular classes; (b) without reference to the number of terms in which the student has already been in residence; and (c) without reference to the status of the student as an appointee of the Institute, except that members of the academic staff of rank of Instructor or higher are not required to pay tuition.

A yearly health fee of $25 is charged to every student. This fee is applied to provide medical services; for details, see page 189. A summer fee of $7.50 must be paid by students who register for summer work, and who have not paid the $25 health fee during the preceding academic year.

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

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

In regard to *fellowships and assistantships,* see page 236 of this catalog. In addition, to students of high scholastic attainments there may be awarded *graduate scholarships* covering the whole or a part of the tuition fee. For such students *loans* also may be arranged, for which application should be made to the Scholarships and Financial Aid Committee.

Graduate students are eligible to borrow from certain funds under the jurisdiction of the Committee on Student Aid (see page 242).

GRADUATE EXPENSES

Tuition (3 terms)		$1,800.00	
General Deposit		25.00	
Health Fee		25.00	$1,850.00
Books and Supplies (approx.)			80.00
Graduate House Living Expenses (see page 235 for details)			
Room—$382.50 to $450.00 per academic year			
Meals—Available at the Chandler Dining Hall or the Athenaeum (members only)			
	First Term		
September 27, 1965	Tuition	600.00	
	General Deposit (see page 189)	25.00	
	Health Fee	25.00	
	Second Term		
January 3, 1966	Tuition	600.00	
	Third Term		
March 28, 1966	Tuition	600.00	
*Summer Accident Insurance Fee		7.50	
Tuition fees for fewer than normal number of units:			
	Over 35 units	Full Tuition[1]	
	Per unit per term	$ 17.00	
	Minimum per term	170.00	
Auditor's Fee (p. 182)		$25.00 per term, per lecture hour	

A voluntary contribution of fifty cents a year is made by each student to help defray the expenses of the Winnett Student Center game room.

Withdrawals. Students withdrawing from the Institute during the first three weeks of a term, for reasons deemed satisfactory to the Institute, are entitled to a refund of tuition fees paid, less a reduction of 20% and a pro rata charge for time in attendance.

B. Regulations Concerning Work for the Degree of Master of Science

1. 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. Regulations governing registration will be found on page 207.

2. *Residence.* At least one academic year of residence (as defined on page 207) and 135 units of graduate work subsequent to the baccalaureate degree are required for the master's degree. Included in these are at least 27 units of

*An Accident Insurance Fee of $7.50 will be charged to all students taking summer research who were not enrolled during the previous academic year.

[1] Although the Institute charges full tuition for 36 units, the Veterans Administration allows the following subsistence percentages: 25% for 10 through 20 units per term; 50% for 21 through 29; 75% for 30 through 41; and 100% for 42 and over.

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. A student will not, in general, be admitted to graduate standing until he has completed work equivalent to that required for the bachelor's degree.

To qualify for a master's degree, a student must complete the work indicated in the schedule of first-year graduate courses (see pages 262-274) with a grade-point average of at least 1.90, considering the grade of P as being equivalent to C, and excluding grades for research.

3. *Admission to Candidacy*. Before the end of the sixth week of the academic year in which the student expects to receive the degree, he must file in the office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. On the candidacy form, the student will submit his proposed plan of study, which must have the approval of his department. This plan of study, if approved, shall then constitute the requirements for the degree, and changes in the schedule will not be recognized unless initialed by the proper authority. 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.

4. *Special Requirements for the Master's Degree*

(a) Students admitted to work toward the master's degree in the Division of Chemistry and Chemical Engineering are required to take placement examinations. See page 265.

(b) Students admitted to work toward the degree of Master of Science in Electrical Engineering must take placement examinations prior to initial registration to be used as a guide in selecting the proper course of study. These examinations are given on Friday of the week preceding registration. The examinations will be concerned with the content of the undergraduate engineering courses on electromagnetic fields and waves (EE 151 abc), and engineering mathematics and complex variables (AM 95 abc). The results of these examinations have no bearing on a student's admission to graduate school, but in the event that preparation in one of these subject areas is inadequate, the student will be required to enroll in the corresponding undergraduate course. In cases where there is a clear basis for ascertaining the student's preparation, the examinations may be waived. Students with deficiencies in more than one of these areas may not be able to fulfill the M.S. requirements in one academic year. Notices of the placement examinations are sent well in advance of the examination date.

(c) A written placement examination is required of incoming graduate students in the Division of Geological Sciences. For details see page 227. Candidates for the master's degree in the Division of Geological Sciences should familiarize themselves with, and are expected to meet, certain special requirements concerning basic sciences and field geology. Detailed information on these requirements may be obtained from the Division Secretary.

(d) Students admitted to work toward the master's degree in the Division of Physics, Mathematics and Astronomy are required to take placement examinations to be used as a guide in selecting the proper course of study. See page 231.

(e) In the case of a required thesis two final copies must be filed with the Division concerned ten days before the degree is to be conferred. Instructions for the preparation of theses may be obtained from the respective departments.

C. REGULATIONS CONCERNING WORK FOR THE ENGINEER'S DEGREE

1. The work for an engineer's degree must consist of advanced studies and research in the field appropriate to the degree desired. It must conform to the special requirements established for the degree desired and should be planned in consultation with the members of the faculty concerned. Advanced studies are defined on page 207. Regulations governing registration will be found on page 208. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a new application to continue graduate work toward the desired degree. Students who have received an engineer's degree will not in general be admitted for the doctor's degree.

2. *Residence.* At least six terms of graduate residence (as defined on page 207) subsequent to a baccalaureate degree equivalent to that given by the California Institute are required for an engineer's degree. Of these, at least the last three terms must be at the California Institute. It must be understood that these are minimum requirements, and students must often count on spending a somewhat longer time in graduate work.

To qualify for an engineer's degree, a student must complete the work prescribed by his supervising committee with a grade-point average of at least 1.90, considering the grade of P as being equivalent to C and excluding grades for research. Work upon research and the preparation of a thesis must constitute no fewer than 55 units. More than 55 units may be required by certain departments and the student should determine the particular requirements of his department when establishing his program.

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

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

which appears on the approved schedule and for which the applicant is registered may be removed after the last date for dropping courses as listed in the catalog.

The student will be admitted to candidacy for the degree when his supervising committee certifies: (a) that all the special requirements for the desired degree have been met, with the exception that certain courses of not more than two terms in length may be taken after admission to candidacy; (b) that the thesis research has been satisfactorily started and probably can be finished at the expected time.

Such admission to candidacy must be obtained by mid-term of the term in which the degree is to be granted.

4. *Thesis*. At least two weeks before the degree is to be conferred, each student is required to submit to the Dean of Graduate Studies two copies of his thesis in accordance with the regulations governing the preparation of doctoral dissertations, obtained from the Graduate Office.

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

Before submitting his thesis, the candidate must obtain written approval of it by the chairman of the division and the members of his supervising committee, on a form obtained from the office of the Dean of Graduate Studies.

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

Special Requirements for the Degree of Electrical Engineer. To be recommended for the degree of Electrical Engineer the applicant must pass the same subject requirements as listed for the doctor's degree on page 224.

Special Requirements for the Degree of Mechanical Engineer. Each student admitted to work for the degree of Mechanical Engineer shall meet with a committee before registration for the purpose of planning the student's work.

Not less than a total of 55 units of this work shall be for research and thesis, the exact number of units to be left to the discretion of the supervising committee appointed by the Dean of Graduate Studies. The courses shall be closely related to mechanical engineering, and the specific courses to be taken and passed with a grade of C or better by each candidate shall be determined by the supervising committee, but must include an advanced course in mathematics or applied mathematics, such as AM 125 abc or Ph 129 abc, acceptable to the faculty in mechanical engineering.

A list of possible courses from which a program of study may be organized will be found on page 270.

D. Regulations Concerning Work for the Degree of Doctor of Philosophy

I. GENERAL REGULATIONS

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

Subject to the general supervision of the Committee on Graduate Study, the student's work for the degree of Doctor of Philosophy is specifically directed by the department in which he has chosen his major subject. Each student should consult his department concerning special divisional and departmental requirements. See pages 218-237.

With the approval of the Committee on Graduate Study, any student studying for the doctor's degree whose work is not satisfactory may be refused registration at the beginning of any term by the department in which the student is doing his major work.

II. REQUIREMENTS FOR ADMISSION TO WORK FOR DOCTOR'S DEGREE

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

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

III. GENERAL REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

1. *Major and minor program of study.* The work for the doctor's degree must consist of scientific research and advanced studies in some branch of science and engineering, called the major program of study; and of additional advanced work outside of this branch, called the minor program of study. The minor program of study will be at the option of the student, either a general minor or a subject minor.

Advanced studies include courses with numbers of 100 or over. However, only in approved cases is graduate residence credit given for such courses when they are required in the undergraduate option corresponding to the student's major field. No residence credit is given for courses with numbers under 100 when they constitute prerequisites to the student's minor subject courses. Credit in the amount to be determined by the Committee on Graduate Study may be allowed for other courses with numbers under 100 when they are outside the student's major field.

(a) *General minor*. The work will consist of at least 45 units of advanced work in one or more disciplines in the humanities or science or engineering other than that of the major subject. The choice and scope of this work must be approved by the division in charge of the major subject, on a form obtainable from the Graduate Office.

(b) *Subject minor*. The work is concentrated in one discipline, including at least 45 units of advanced work in this discipline, and must be comprehensive enough to give the student a fundamental knowledge of it. The minor subject may be in the humanities or in any discipline listed on pages 218-238, under special requirements adopted by the various divisions of the Institute. The program must be approved by both major and minor divisions on a form obtainable from the Graduate Office. The candidate will be examined on this work (see item 5, page 217). A student who has satisfied the requirements for such a minor program of study will be given recognition for this work by explicit mention on his Ph.D. diploma of the minor subject or minor subjects if the requirements have been satisfied in more than one discipline.

2. *Residence*. At least three academic years of residence subsequent to a baccalaureate degree equivalent to that given by the Institute are required for the doctor's degree. Of this at least one year must be in residence at the Institute. It should be understood that these are minimum requirements, and students must usually count on spending a somewhat longer time in residence. However, no student will be allowed to continue work toward the doctor's degree for more than 15 terms of graduate residence, nor more than 18 registrations for full- or part-time academic work except by special action of the Committee on Graduate Study. In either case graduate study taken elsewhere will be counted when residence credit at the Institute has been allowed. (See page 208 regarding summer registration for research.)

Graduate students will be permitted only by special arrangement made in advance to conduct all or a portion of their research in the field, in government laboratories, or elsewhere off the campus. In order that such research be counted in fulfillment of residence requirements, the graduate student must file in advance a registration card for this work. The work must be carried out under the direct supervision of a member of the Institute staff. The number of units to be credited for such work shall be determined by the Dean of Graduate Studies in consultation with the chairman of the division in which the student is carrying his major work; and a recommendation as to the proportion of the full tuition to be paid for such work shall be made by the Dean to the Vice President in charge of Business Affairs.

A student whose undergraduate work has been insufficient in amount or too narrowly specialized, or whose preparation in his special field is inadequate, must count upon spending increased time in work for the degree.

3. *Admission to Candidacy.* On recommendation of the chairman of the division concerned, the Committee on Graduate Study will admit a student to candidacy for the degree of Doctor of Philosophy after he has been admitted to work toward the doctor's degree and been in residence at least one term thereafter; has satisfied the several departments concerned by written or oral examination or otherwise that he has a comprehensive grasp of his major and minor subjects as well as of subjects fundamental to them; has fulfilled the language requirements; has shown ability in carrying on research with a research subject approved by the chairman of the division concerned; and has intiated a program of study approved by his major department and, if needed, by his minor department. For special departmental regulations concerning admissions to candidacy, see pages 218-238. Members of the Institute staff of rank higher than that of assistant professor are not admitted to candidacy for a higher degree.

A regular form, to be obtained from the Dean of Graduate Studies, is provided for making application for admission to candidacy. Such admission to candidacy must be obtained before the beginning of the fourth academic year after admission to graduate standing at the Institute. A student not admitted to candidacy at that time must petition through his division to the Dean of Graduate Studies for permission to register for further work.

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

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

(b) To pass with a grade of B– or better one of the following courses: L 1 abc in French, L 32 abc in German, or L 51 a in Russian.

(c) With the approval of the department of languages, to complete a translation project. A knowledge of the fundamentals of the language is presupposed in such a case. (At the discretion of the department of languages, graduate students may be required to pass an elementary examination before becoming eligible to undertake a translation project.)

5. *Examination.* During his course of study every doctoral candidate shall be examined broadly and orally on his major subject, the scope of his thesis and its significance in relation to his major subject, and, if the candidate has a subject minor, on the subject of that program. These examinations, subject to the approval of the Committee on Graduate Study, may be taken at such time after admission to candidacy as the candidate is prepared, except that they must take place at least two weeks before the degree is to be conferred.

The examinations may be written in part, and may be subdivided into parts or given all at one time at the discretion of the departments concerned. The examination relating to the subject minor need not be included in the final examination. It may be given at a time to be determined by agreement between the minor and the major departments. The student must petition for these examinations on a form obtained from the Dean of Graduate Studies. For special departmental regulations concerning candidacy and final examinations, see pages 218-238.

6. *Thesis*. Two weeks before the degree is to be conferred, the candidate is required to submit to the Dean of Graduate Studies two copies of his thesis in accordance with the regulations governing the preparation of doctoral dissertations obtainable from the Graduate Office. For special departmental regulations concerning theses, see pages 218-238.

With the approval of the department concerned, a portion of the thesis may consist of one or more articles published jointly by the candidate and members of the Institute staff or others. In any case, however, a substantial portion of the thesis must be the candidate's own exposition of his work. For regulations regarding use of "classified" material, see page 214.

Regulations and directions for the preparation of theses may be obtained from the office of the Dean of Graduate Studies, and should be followed carefully by the candidate.

Before submitting his thesis to the Dean of Graduate Studies, the candidate must obtain approval of it by the chairman of his division and the members of his examining committee. This approval must be obtained in writing on a form which will be furnished at the office of the Dean. *The candidate himself is responsible for allowing sufficient time for the members of his committee to examine his thesis.*

IV. SPECIAL REQUIREMENTS FOR THE DOCTOR'S DEGREE

In agreement with the general requirements for the doctor's degree adopted by the Committee on Graduate study, as set forth in III; page 215, the various divisions of the Institute have adopted the following supplementary regulations.

DIVISION OF BIOLOGY

1. *Aims and Scope of Graduate Study in Biology*. Graduate students in Biology come with very diverse undergraduate preparation—majors in physics, chemistry, and mathematics, as well as in biology and its various branches. The aims of the graduate program are to provide, for each student, depth of experience and competence in his particular chosen major specialty; perception of the nature and values of biology as a whole; sufficient strength in the basic sciences to allow him to continue self-education after his formal training has been completed and keep in the forefront of his changing field; and the motivation and training to serve that field productively through a long career. In accordance with these aims the graduate study program in biology leading to the doctor's degree includes the following parts: (a) *The major program* which is to provide the student with early and intense original research experience in a discipline of biology of his own choice, supplemented with

advanced course work and independent study in this discipline; (b) *the minor program,* designed to provide him with professional insight into a discipline outside his major one and consisting of specialized course work, or course work and a special research program; and as a rule (c) a *program of course work in advanced subjects,* designed to provide him with a well-rounded and integrated training in biology and the appropriate basic sciences, and adjusted to his special interests and needs. (b) and (c) may include supervised, independent study. An individual program will be recommended to each student when he meets with his advisory committee (see section 4).

2. *Admission.* Applicants are expected to meet the following minimal requirements: mathematics through calculus, general physics, organic chemistry, physical chemistry, and biology approximately equaling the content of two of the following courses: Bi 3 (Plant Biology), Bi 10 (Animal Biology) and Bi 9 (Cell Biology). Students with deficient preparation in one or more of these categories may be admitted but required to remedy their deficiencies in the first years of graduate training, no graduate credit being granted for such remedial study. This will usually involve taking the courses in the categories in which the student has deficiencies. In certain instances, however, deficiencies may be corrected by examinations following independent or supervised study apart from formal courses. Graduate Record Examinations are required of applicants for graduate admission intending to major in the Biology Division.

Furthermore, the program of the Biology Division is diverse, and in particular fields such as psychobiology or in interdisciplinary programs such as neurophysiology-electrical engineering, other kinds of undergraduate preparation may be substituted for the general requirements listed above.

3. *Placement Examinations.* All students admitted to graduate work towards the Ph.D. in the Division of Biology are required either to take placement examinations in two of the following areas: cell biology, plant biology, animal biology; or to pass or have passed two of the equivalent courses (Bi 3, Bi 10, Bi 9), with a grade of B– or better. These examinations or courses must be taken before the end of the first year of graduate study.

4. *Advisory Committee.* During the week preceding registration for the first term, each entering student confers with his Advisory Committee. The committee consists of a chairman and three other members of the faculty representing diverse fields of biology. The committee will advise the student of deficiencies in his training; will design a remedial study program where necessary; and will recommend an individual study program of advanced course work in accordance with item (c), section 1. The committee will also be available for consultation and advice throughout his graduate study. Its chairmanship and constitution may, however, change as the student ascertains the subject of his specialization or changes it. Such changes are readily made.

5. *Teaching Requirements for Graduate Fellows.* A graduate student who holds a national fellowship to do graduate work in the Division of Biology may be assigned to give limited assistance in teaching undergraduate courses if his advisory committee considers it to be of value for him to gain teaching experience.

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

Biochemistry	Genetics
Biophysics	Neurophysiology
Cell Biology	Plant Physiology
Developmental Biology	Psychobiology

7. *Minor Subjects.* A student majoring in one of the above disciplines may elect to take a minor in any of the following ways, subject to the approval of his advisory committee: (a) a subject minor in another discipline of biology, which must be markedly different in content and techniques from the major; (b) a subject minor in another division of the Institute, or (c) a general minor consisting of not less than 45 units of advanced course work in one or more disciplines in the humanities, sciences (other than biology), or engineering. When a student takes a subject minor, his degree designates the disciplines of his major and minor (e.g., Biophysics and Psychobiology or Cell Biology and Chemistry). When he takes a general minor, his degree designates only his major discipline (e.g., Biochemistry or Neurophysiology).

A student majoring in another division of the Institute may, with the approval of the Biology Division and his major division, elect a subject minor in any one of the disciplines listed in section 6. The requirements for such a minor consist of (a) passing the placement examination in plant biology, cell biology, or animal biology, and (b) passing the qualifying examination in the discipline elected. There is no program for a minor in General Biology, but advanced courses in the Biology Division can, of course, be included in a general minor under the supervision of the student's major division. A student majoring in another division who elects a subject minor in one of the disciplines of Biology may arrange to have his minor designated as Biology rather than with the name for his minor discipline. The Institute's general requirements for major and minor programs of study are noted on pages 215-216.

8. *Admission to Candidacy.* To be recommended by the Division of Biology for admission to candidacy for the doctor's degree, the student must have demonstrated his ability to carry out original research and have passed, with a grade of B or better, the candidacy examination in his major. With regard to his minor: (a) A student who elects to take a subject minor in the Biology Division is required to pass a candidacy examination in the minor field with a grade of B or better; (b) in case the minor is taken outside the Biology Division, the student is required to fulfill the minor requirements of the outside division and of the Institute.

Students majoring in other divisions and electing a subject minor in the Biology Division see paragraph 2 of section 7 above.

9. *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 corrections, 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. The examining committee will consist of such individuals as may be recommended by the Chairman of the Division and approved by the Dean of Graduate Studies.

Division of Chemistry and Chemical Engineering

1A. *Chemistry*. During the week preceding General Registration for the first term of graduate study, graduate students admitted to work for the Ph.D. degree will be required to take three written placement examinations, one each in the fields of inorganic chemistry and organic chemistry (on Monday), and physical chemistry (on Tuesday). These examinations will cover their respective subjects to the extent that these subjects are treated in the undergraduate chemistry option offered at this Institute. In general they will be designed to test whether the student possesses an understanding of general principles and a power to apply these to specific problems, rather than a detailed informational knowledge. Graduate students are expected to demonstrate a proficiency in the above subjects not less than that acquired by abler undergraduates. Students who have demonstrated this proficiency in earlier residence at this Institute may be excused from these examinations.

In the event that a student fails to show satisfactory performance in one or more of the placement examinations he may be required to register for a prescribed course, or courses, in order to correct the deficiency promptly. In general no graduate credit will be allowed for prescribed undergraduate courses. If the student's performance in the required course or courses is not satisfactory, he will not be allowed to continue his graduate studies except by special action of the Division of Chemistry and Chemical Engineering on receipt of his petition to be allowed to continue.

To be recommended for candidacy for the doctor's degree in chemistry the applicant, in addition to demonstrating his understanding and knowledge of the fundamentals of chemistry, must give satisfactory evidence of his proficiency at a higher level in that field of chemistry elected as his primary field of interest and approved by the Division of Chemistry and Chemical Engineering. In general the applicant will be required to pass an oral examination and to submit to his examining committee one week prior to his examination (1) a written progress report giving evidence of his industry and ability in research and of his power to present his results in clear, concise language and with discrimination as to what is essential in scientific reports, and (2) three propositions (as described under 5 below) which the applicant is prepared to defend during his oral examination.

In the event that any of the candidate's propositions is found to be unsatisfactory he will not be recommended for candidacy at that time, but will be required to submit and defend a set of new or revised propositions at an examination to be taken at least three terms prior to his final examination.

A student admitted to work for the Ph.D. degree in chemistry who fails to satisfy the Division's requirements for candidacy by the end of his fifth term of graduate residence at the Institute will not be allowed to register in a subsequent academic year except by special permission of the Division of Chemistry and Chemical Engineering.

1B. *Chemical Physics.* Students working for the Ph.D. degree in chemistry may elect to do research in chemical physics. Except for the differences mentioned below, all of the requirements regarding graduate students in chemistry are applicable to students who wish to work in the field of chemical physics.

On Tuesday of the week preceding General Registration, but at a different time than the physical chemistry examination, there will be a placement examination in chemical physics. It will be designed specifically to test the preparation of students who wish to carry on research in this area, and will require a knowledge of physics and mathematics beyond the corresponding courses normally required for the undergraduate chemistry option at this Institute. These students must also take the placement examinations in inorganic, organic, and physical chemistry.

Students taking the chemical physics examination may substitute demonstration of proficiency in that field for establishment of proficiency in one or more of the other fields. Students who choose chemical physics as their primary field of interest will, in general, take a larger fraction of their graduate courses in mathematics and physics than students in other fields of chemistry.

1C. *Chemical Engineering.* During the week preceding General Registration for the first term of graduate study, students admitted to work for the Ph.D. degree will be required to take three written placement examinations in the fields of industrial and general chemistry (on Monday), transport phenomena and the unit operations of chemical engineering (on Tuesday), and engineering thermodynamics of one-component systems (on Wednesday). These examinations will cover their respective subjects to the extent that they are treated in the undergraduate chemical engineering option at this Institute. In general they will be designed to test whether the student possesses an understanding of general principles and a power to apply these to specific problems, rather than a detailed informational knowledge. Students who have demonstrated proficiency in earlier residence at this Institute may be excused from these examinations. Any remedial work prescribed as a result of unsatisfactory performance in one or more of these placement examinations must be satisfactorily completed prior to the candidacy examination.

To be recommended for candidacy the student must demonstrate proficiency at a graduate level in chemical engineering. This will be done in chemical engineering courses and in the Divisional oral candidacy examination which is to be taken before the end of the second term of the student's second year of graduate residence at the Institute. At least one week before the examination the student will submit three propositions and a written progress report on his research to his examining committee. The examination will cover the progress report and propositions. Questions on applied physical chemistry, thermodynamics, applied chemical kinetics, transport phenomena, and the joint application of these and related subjects to practical problems will also be included, with emphasis at the discretion of the committee. A student who fails to satisfy the division's candidacy requirements by the end of the third term of his second year of graduate residence at the Institute will not be allowed to register in a subsequent academic year except by special permission of the Division of Chemistry and Chemical Engineering.

2. 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 in the student's field of interest. In case the applicant's training is not equivalent to this, the Division may prescribe additional work in these subjects before recommending him as a candidate.

3. The units of study offered to satisfy a minor requirement are to consist in general of graduate courses other than research; however, the Division of Chemistry and Chemical Engineering may, by special action, permit up to one-half of these units to consist of appropriate research. If a student elects a minor program of study of the general type, 45 units or more of advanced work are required and must represent an integrated program approved by the Division; for students in chemistry it must consist of courses other than chemistry; for students in chemical engineering it must consist of courses other than chemical engineering. A grade of C or better is required in these courses.

4. The candidate must submit a copy of his thesis to the chairman and to each member of his examining committee two weeks prior to his final examination, which according to the Institute regulation must be held at least two weeks before the degree is conferred. After his examination the original (ribbon) and two reproduced copies are to be submitted to the office of the Dean of Graduate Studies to be proofread, after which one reproduced copy is returned for the Division library. All reproduced copies may be either an electrostatic bond copy (Xerox or similar) or an electrostatic vellum (Xerox or similar). All copies except those retained by the Institute will be returned to the student.

5. The final examination will consist in part of the candidate's oral presentation and defense of a brief résumé of his research and in part of the defense of a set of propositions prepared by the candidate.

Five propositions are required. In order to obtain diversity with respect to subject matter not more than two shall be related to the immediate area of the candidate's thesis research. Each proposition shall be stated explicitly and the argument presented in writing with adequate documentation. Propositions of exceptional quality presented at the time of the candidacy examination may be included among the five submitted at the time of the final examination.

The propositions, prepared by the candidate himself, should display his originality, breadth of interest, and soundness of training; the candidate will be judged on his selection and formulation of the propositions as well as on his defense of them. It is recommended that the candidate begin the formulation of his set of propositions early in his course of graduate study.

A copy of the set of propositions in final form must be submitted as part of each copy of the thesis to the chairman and members of his examining committee at least two weeks before the date set for the examination.

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

Ch 148-149 and one or more graduate courses in chemistry so selected as to provide an understanding of at least one area of chemistry. The total number of units shall not be less than 45, and a grade of C or better in each course included in the program will be required.

Division of Engineering and Applied Science

1. *Aeronautics*. In general, a graduate student is not admitted to work for the doctor's degree in aeronautics until he has completed at least 20 units of research in his chosen field. Thus, upon completion of his fifth year's work, he will be admitted to work towards the engineer's degree. If his course work and research during the sixth year show that he is capable of carrying on work at the doctoral level and if he satisfactorily passes a qualifying oral examination, he may then be admitted to work towards the doctor's degree. Upon being admitted to work towards the doctor's degree, his admission to work for the engineer's degree will be cancelled.

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

AMa 101 abc	Methods of Applied Mathematics
AM 125 abc	Engineering Mathematical Principles
Ma 108 abc	Advanced Calculus
Ph 129 abc	Methods of Mathematical Physics

and both of the following subjects:

Ae 210 abc	Fundamentals of Solid Mechanics
Ae 201 abc	Fundamentals of Fluid Mechanics

If any of the above subjects were taken elsewhere than at the Institute, the candidate may be required to pass special examinations indicating an equivalent knowledge of the subject.

2. *Applied Mechanics, Engineering Science, Materials Science, and Mechanical Engineering*. To be recommended for candidacy for the Ph.D. degree in Applied Mechanics, Engineering Science, Materials Science, or Mechanical Engineering, the student must, in addition to the general Institute requirements (including languages):

a. complete 12 units of research.

b. complete at least 50 units of advanced courses arranged by the student in conference with his adviser and approved by the relevant faculty in applied mechanics, engineering science, materials science or mechanical engineering. If any course submitted for candidacy was taken elsewhere than at the Institute, the student may be required to pass special examinations indicating a satisfactory knowledge of the subject.

c. pass with a grade of at least C an advanced course in mathematics or applied mathematics, such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the relevant faculty in applied mechanics, engineering science, materials science, or mechanical engineering. Such courses shall be in addition to requirement (b) above.

d. complete at least 45 units of advanced courses as a minor as arranged by the student in conference with his advisor and approved by the relevant faculty in applied mechanics, engineering science, materials science or mechanical engineering, and if a subject minor is specified, with the approval of the faculty concerned with the subject minor. The minor requirement may be satisfied in any one of the following ways: (i) a subject minor in another division of the Institute; (ii) a subject minor in another discipline of engineering, which must differ markedly in content from the major; (iii) a general minor consisting of courses listed as *Advanced Subjects* in the catalog, in one or more disciplines in the sciences, engineering, or the humanities.

   A portion of the courses in a general minor should preferably be outside the Division of Engineering; the course used to satisfy the mathematics requirement (c) above may not be included. Courses for either a subject minor or a general minor may be included only if they differ from the field of the student's thesis research. The diploma designates the disciplines of both the major and the minor if the requirements for a subject minor have been satisfied. If a general minor is selected and approved, the diploma designates only the major discipline.

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

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

A student majoring in another branch of engineering, or another division of the Institute, may, with the approval of the relevant faculty in applied mechanics, engineering science, materials science, or mechanical engineering, elect a discipline in one of these fields as a minor subject, consisting of a group of courses that differ markedly from the major subject of study or research.

3. *Civil Engineering*. Before the end of the second year of graduate residence the student must pass a Ph.D. qualifying oral examination, demonstrating his knowledge of the field of civil engineering. The examination will include, but will not be limited to, presentation and defense of one or more propositions which should be controversial or unresolved topics in civil engineering for which there is more than one point of view. At least eight weeks before the examination the student must submit his propositions for approval. Furthermore, ten days before the examination the student must present (a) a brief exposition of the arguments for each of his propositions, and (b) a brief statement of his proposed thesis research.

To be recommended for admission to candidacy for the Ph.D. degree, the student must, in addition to general Institute requirements (including languages):

a. pass the qualifying examination described above.

b. pass a candidacy oral examination on the major subject, and minor subject (if the student has elected a subject minor).

c. submit a satisfactory written progress report on his thesis research.

d. pass the courses required for the M.S. degree, and other advanced courses as required by the staff.

e. pass at least 27 units of course work in advanced mathematics such as AM 125, Ph 129, or satisfactory substitution. For a student whose program is more closely related to the sciences of biology or chemistry than physics, AM 113 and AM 116 or Ma 112 will be an acceptable substitution for the mathematics requirement.

Minor. The purpose of the minor program of study is to broaden the student's outlook by acquainting him with subject matter outside his major field. The minor requirement is completion of at least 45 units of advanced courses arranged by the student in conference with his advisor, and approved by the faculty in civil engineering, in one of the three following ways:

(i) a subject minor in another division of the Institute;

(ii) a subject minor in another discipline of engineering, which must differ markedly in content from the major subject; or

(iii) a general minor consisting of courses listed as *Advanced Subjects* in the catalog in one or more disciplines; a portion of such courses should preferably be outside the Division of Engineering and Applied Science.

Furthermore, the minor program (subject or general) may not include (a) the courses used to satisfy the mathematics requirement (including prerequisites); nor (b) any course in the specialized field of the student's thesis research.

4. *Electrical Engineering*. In general, a graduate student is not admitted to work for the doctor's degree in Electrical Engineering until he has received a degree of Master of Science or equivalent.

Admission to graduate work beyond the M.S. degree is by recommendation of the EE faculty, based upon their evaluation of the student's academic record, future research potential, and performance in a preliminary oral examination normally taken in the January before he obtains his M.S. degree.

To be recommended for candidacy for the doctor's degree the applicant must satisfy the requirements listed below.

a. Complete 18 units of research in his field of interest.

b. Complete at least 45 units of advanced courses in a minor field. Courses for either a subject or a general minor may be offered only if their content is primarily in a field other than that of the student's thesis research. Preferably some of the courses in a general minor should be outside the Division of Engineering.

c. Pass with a grade of C or better one of the following subjects:

AMa 101 abc	Methods of Applied Mathematics
AM 125 abc	Engineering Mathematical Principles
Ma 108 abc	Advanced Calculus
Ph 129 abc	Methods of Mathematical Physics

An applicant may also satisfy any of the above course requirements by taking an examination in the subject with the instructor in charge. Every examination of this type will cover the whole of the course specified, and the student will not be permitted to take it either in parts (e.g. term by term) or more than twice.

d. Pass a qualifying oral examination covering broadly his major field and minor program of study. This examination is normally taken in the third term of the student's first post-M.S. year.

The candidate is required to take a final oral examination covering his doctoral thesis and its significance in and its relation to his major field. This final examination will be given not less than one month after the doctoral thesis has been presented in final form, and prior to its approval.

Division of Geological Sciences

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

1. *Placement Examinations.* Applications for admission to graduate study in the Division of Geological Sciences should be supported by a report of the student's score on both the aptitude test and the advanced test in geology of the Graduate Record Examination. This is not an absolute requirement, but compliance is strongly urged. On Wednesday, Thursday, and Friday of the week preceding registration for his first term of graduate work, the student will be required to map a small field area and to take written placement examinations covering basic aspects of the earth sciences and including elementary physics, mathematics, chemistry, and biology. These examinations will be used to determine the student's understanding of basic scientific principles and his ability to apply these principles to specific problems. It is not expected that he possess detailed informational knowledge, but it is expected that he demonstrate a degree of proficiency not less than that attained by abler undergraduate students at the California Institute. A student who has demonstrated proficiency in earlier residence at the Institute may be excused from these examinations.

The student's past record and his performance in the placement examinations will be used to determine whether he should register for certain undergraduate courses. Any deficiencies must be corrected at the earliest possible date. All students who do not demonstrate adequate proficiency in mathematics will be required to register for Ge 108 in their first year of graduate residence.

Each member of the Division faculty serves as an advisor to a small number of graduate students. Each graduate student will be notified, prior to his arrival, who his advisor will be, and prior to registration day the student should seek the counsel of his advisor in planning his program for each term. If the student has, or develops an interest in a particular field, he should also consult with staff members in that field concerning his program of study and research.

Well-qualified graduate students are encouraged to apply for National Science Foundation Fellowships, but each student should consult with his advisor prior to making application for, seeking a renewal of, or terminating such a fellowship.

It is the wish of the Division that its graduate students become productively research-minded as early as possible. To that end it is strongly recommended that each student register for not less than 10 units of research in two out of the first four terms of residence. Each of these terms of research shall be under the direction of *different* staff members. Guidance in arranging for research should be sought from that student's advisor and from individual members of the staff. The primary objective is to communicate to the students the excitement of discovery based on original investigations. An important by-product can be the formulation of propositions for the Ph.D. oral examination or even an orientation toward Ph.D. thesis research.

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

Students who exhibit exceptional ability in physics and mathematics and whose program of study and research is devoted strictly to problems unrelated to surface or subsurface geology or to the characteristics of rocks and geological relations as they can be observed in the field may be excused from the minimal program of study in field geology. Individual decisions on these matters are made by a special committee appointed by the Division Chairman upon request of the student's advisor.

3. *Major Subject.* The work for the doctorate in the Division of the Geological Sciences shall consist of advanced studies and of research in some discipline in the geological sciences which will be termed the "major subject" of the candidate. The Division will accept as major subjects any of the disciplines listed herewith, provided that the number of students working under the staff members in that discipline does not exceed the limit of efficient supervision.

Geology　　Geochemistry
Geobiology　　Geophysics
Planetary Science

4. *Minor Requirement.* The purpose of the minor requirement is to give diversification of training and a broadening of outlook. It should involve basic approaches, techniques, and knowledge distinct from those of the major subject. The Division prefers to have its students satisfy the minor requirement by work in other divisions of the Institute as prescribed on pages 215-216 of this catalog. However, the student may propose a subject minor in one of the five fields listed in section 3 above, that is different from the major subject, or he may include Geology Division courses within a minor program of general type, if they are pertinent to an intelligently integrated

program. However, Ch 124 ab will ordinarily not be acceptable toward the 45 units of minor work. Students from other divisions can obtain a subject minor in geology by offering a suitable combination of graduate-level Geology Division courses which can be, but need not be, concentrated solely in one of the five fields specified in section 3. All proposed minor programs are subject to review and approval by the Division and the Dean of Graduate Studies.

A proposed minor program for the Ph.D. must be submitted to the staff for preliminary evaluation before the end of the 6th term of residence, and preferably earlier.

5. *Additional Requirements for Ph.D.*

In Geochemistry: In addition to the general Institute and Division requirements, the candidate for the Ph.D. in Geochemistry must have as a minimum the equivalent of the courses that are required for the undergraduate curriculum in geochemistry. The candidate will be expected to take a minimum of 45 units of advanced courses in chemistry and geochemistry. These same courses cannot be presented to satisfy the requirements for a minor or for a distributed minor.

Substitution for courses equivalent to the undergraduate requirement may be permitted by the Division upon petition. The natures of the substitutions that are permitted will depend upon the abilities and interests of the student.

In Geophysics: Students entering work for a Ph.D. in Geophysics should have completed the following courses or their equivalents: Ph 106 abc, and either Ma 108 abc or AM 113 ab, plus AM 116. If a student is not qualified in these courses, or their equivalents, he may have to spend extra time in residence to acquire this training. In addition, Ph.D. candidates in geophysics are required to take Ph 129 abc and 18 units of advanced (200 level) geophysics courses, plus at least 100 units of advanced course work elected from the following disciplines: Electromagnetic Theory, Advanced Mechanics, Geophysics (200 level), Solid Mechanics—Elasticity, Quantum and Solid State Physics, Statistical Physics—Communication Theory, Applied Mathematics—Numerical Analysis, Thermodynamics, Linear Systems—Signal Analysis, Geology (100 and 200 level courses) including the field geology courses specified in the field requirement above (item 2). The study program is subject to approval by the student's advisor and faculty members supervising his work.

In Planetary Science: In addition to the general Institute and Divisional requirements, the candidate for a Ph.D. degree in planetary science is required to demonstrate special competence in the geological, geophysical, or geochemical aspects of the moon and planets. This requirement may be satisfied by successful completion of 60 hours of advanced work pertinent to planetary science approved by the Division, including one of the following course combinations:

Geological emphasis—Ge 220 ab, Ge 221, Ge 222, Ge 225
Geophysical emphasis—Ge 265 ab, Ph 129 abc, Ge 225
Geochemical emphasis—Ge 220 ab, Ge 222, Ge 225

All candidates for the Ph. D. degree in planetary science are stongly urged to take a minor in astronomy; however, a distributed minor with a strong emphasis on astronomy may be permitted with Division approval. The candidate's

Divisional advisor will take particular care to see that the study program is constituted to develop a high level of competence in some specific aspect of planetary science.

6. *Admission to Candidacy*. An otherwise qualified student is eligible for admission to candidacy for the doctorate in the Division of the Geological Sciences as soon as he has passed his qualifying oral examination. This examination will consist of: (1) the oral defense of a proposition prepared by the student and supported by a paper of not more than 5 to 10 pages developing the concept of the proposition and (2) the oral defense of two additional propositions which can be represented by a succinct one-paragraph statement of the basic problem and of the candidate's specific approach to or evaluation of it. The student has the privilege of consultation and discussion with various staff members concerning his ideas on propositions, but the paper submitted must represent the work of the student and not a distillation of comments and suggestions from the staff. Candidates in geology should realize that propositions based on field investigations are just as acceptable as those arising from laboratory work or theoretical deductions. If the student does not choose to submit two additional propositions, he will be examined orally in 3 or 4 fields or areas of the earth sciences or related sciences. The student will submit a brief paragraph identifying areas and fields in which he has interest and competence. It is expected that the combination of propositions or the statement of interest and competence will demonstrate that the candidate has both depth and breadth in terms of his basic training and interests. In general, the examination is designed to evaluate a student's basic background in the earth sciences and allied fields and to determine his capabilities in applying fundamental scientific principles to the solution of specific problems. The ideal candidate will display originality and imagination as well as scholarship.

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

Three copies of the proposition and the supporting paper, and of the additional propositions or statement of competence and interest, should be filed in the office of the Division of the Geological Sciences not later than midterm of the fifth term of graduate residence for evaluation by the core members of the Qualifying Examination Committee in consultation with other members of the staff (see page 218). An examining committee will then be appointed and a date which is mutually agreeable to those concerned will be set for the examination. The propositions and statements, as approved by the core committee, must be filed by the candidate in the Division office at least two weeks in advance of the date set for the examination.

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

A student admitted to work for the Ph.D. degree who fails to satisfy the Division's requirements for candidacy by the end of his fifth term of residence will not be allowed to register in a subsequent academic year except by special permission of the Division of Geological Sciences. Successful completion of the qualifying examination is a necessary step in admission to candidacy. The remaining steps are outlined on page 217, item 3.

Before the end of the ninth term of residence the student will be required to file with the Division the regular form for application for admission to candidacy with specification of major field, the Ph.D. work, and a minor program. This will be accorded formal staff consideration even though all other requirements for admission to candidacy, such as the language examination, may not have been met.

7. *Thesis and Paper for Publication.* The doctoral candidate must complete his thesis and submit it in final form by May 10 of the year in which the degree is to be conferred. A first draft of the thesis must be submitted by March 1 of the year in which it is proposed to take the degree. The candidate must also prepare a paper for publication embodying the results of his thesis work in whole or in part. He should consult with the member of the staff supervising the major research on the choice of subject and on the scope of the paper.

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

Division of Physics, Mathematics and Astronomy

The disciplines offered by the Division in which major or minor work may be undertaken, as specified on page 215, are Astronomy, Mathematics, and Physics.

1. Physics

a. *Placement Examinations.* On Thursday and Friday preceding the begining of instruction for his first term of graduate study, a student admitted to work for an advanced degree in physics is required to take placement examinations to be used as a guide in selecting the proper course of study. These examinations will cover material in Mechanics and Electromagnetism, Atomic and Nuclear Physics, Quantum Mechanics, and Advanced Calculus, approximately as covered in Ph 106, Ph 112, Ph 125, and Ma 108. In general, they will be designed to test whether the student possesses an understanding of general principles and a power to apply these to concrete problems, rather than detailed informational knowledge. In cases in which there is a clear basis for ascertaining the status of the entering graduate student, the placement examinations may be waived.

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

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

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

	Group II, Elective Courses
Ph 201	Analytical Mechanics
Ph 203	Nuclear Physics
Ph 204	Low Temperature Physics
Ph 213	Nuclear Astrophysics
Ph 216	Introduction to Plasma Physics
Ph 217	Spectroscopy
Ph 220	Introduction to Solid State Physics
Ph 227	Thermodynamics, Statistical Mechanics and Kinetic Theory
Ph 230	Elementary Particle Theory
Ph 231	High Energy Physics
Ph 234	Topics in Theoretical Physics
Ph 236	Relativity Theory
Ph 240	Current Theoretical Problems in Particle Physics
Ay 131	Astrophysics I
or	
Ay 132	Astrophysics II
Ay 133	Radio Astronomy

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

The student is expected to obtain a grade of C or better in each of his courses. If he obtains grades below C in the courses of Group I and those courses he elects from Group II, or in the courses presented to fulfill the requirements for 45 units in a discipline other than physics, or in the oral candidacy examination, the Physics Department Graduate Committee will review the student's entire record, and if it is unsatisfactory, will refuse permission for him to continue work for the Ph.D.

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

Candidates who have selected a minor subject must pass a special oral examination in their minor subject. It is the responsibility of the candidate to make arrangements for this examination. It should be held as soon as possible after completion of the required course work in the minor.

d. *Admission to Candidacy.* To be recommended for candidacy for the Ph.D. degree in physics, a student must, in addition to the general Institute requirements, pass (or pass the written candidacy examinations in) all 54 units of Group I and 36 units of Group II, pass the physics oral candidacy examination, and be accepted for thesis research by a staff member.

A student, admitted to work toward the Ph.D. degree, who does not satisfy the Division requirements for 54 units of Group I, 36 units of Group II, and the Physics oral candidacy examination by the end of the second year of graduate study at the Institute will not be allowed to register in a subsequent academic year without special permission of the Physics Department Graduate Committee. When a student is required to take courses prerequisite to those listed in section b, this committee ordinarily will grant at that time a suitable extension of the time allowed to complete the candidacy requirements.

e. *Further Requirements for the Ph.D. Degree.* In order to be recommended for the Ph.D. degree, each candidate must, in addition to the requirements for candidacy and the general Institute requirements for a Ph.D. degree, pass satisfactorily the 54 units from Group I and a total of 54 units from Group II. In addition to these requirements, the student will normally take other advanced courses, particularly in his field of specialization. In general a student will find it desirable to continue his graduate study and research for two years after admission to candidacy.

A final examination will be given not less than one month after the thesis has been presented in final form. *This examination will cover the thesis topic and its relation to the general body of knowledge of physics.*

The candidate himself is responsible for completing his thesis early enough to allow the fulfillment of all Division and Institute requirements, having due regard for the impossibility of scheduling by the Division of more than one final oral examination per day.

f. *Subject Minor.* A subject minor program in physics (see page 215) will be approved by the minor division if it includes at least 18 units of Physics courses from Groups I and II, excluding Ph 129, Ay 131, Ay 132, Ay 133, and any specified course in physics required for the major. Physics courses with numbers over 100 but for which reduced units are given to graduate students in physics will be allowed for the subject minor, but will count at the same reduced rate toward the required total of 45 units. The required oral examination in the subject minor will normally be a separate examination but may be part of one of the oral examinations in the major subject if sufficient time is made available. It is the responsibility of the candidate to arrange for this examination.

2. MATHEMATICS

a. Each new graduate student admitted to work for an advanced degree in mathematics will be given an informal interview on Thursday or Friday of the week preceding the beginning of instruction in the fall term. The purpose of this interview is to ascertain the preparation of the student and assist him in mapping out a course of study. The work of the student during the first year will include independent reading and/or research.

b. To be recommended for candidacy for the degree of Doctor of Philosophy in Mathematics the applicant must satisfy the general requirements and pass an oral candidacy examination.

This examination will usually be held at the end of the first term of the second year of graduate study, but in special cases the department may change the date. The purpose of this examination is to evaluate the work of the student up to date, including independent work done by the candidate during his first year. On the basis of the performance, the examining committee will map out the further program of study of the student and specify the course and research requirements which he will have to satisfy to be admitted to candidacy. At the discretion of the department the examination may be supplemented by a written examination.

Students are urged to satisfy the requirements for admission to candidacy as early as possible. Under any circumstances they must have been admitted to candidacy before the beginning of the spring term of the year in which the degree will be conferred.

c. On or before the first Monday in April of the year in which the degree is to be conferred, a candidate for the degree of Doctor of Philosophy must deliver a typewritten or reproduced copy of his thesis to his supervisor. This copy must be complete and in the exact form in which it will be presented to the members of the examining committee. The candidate is also responsible for supplying the members of his examining committee, at the same time or shortly thereafter, with reproduced copies of his thesis. The department will assign to the candidate, immediately after the submission of his thesis, a topic of study outside his field of specialization. During the next four weeks the candidate is expected to assimilate the basic methods and the main results of the assigned topic with the aim of recognizing the direction of further research in this field.

d. The final oral examination in mathematics will be held as closely as possible four weeks after the date the thesis has been handed in. It will cover the thesis and fields related to it and the assigned topic of study.

e. Candidates who have selected a subject minor must pass a special examination in their minor subject. It is the responsibility of the candidate to make arrangements for this examination. It should be held as soon as possible after admission to candidacy and completion of the course work in his minor subject.

f. Subject minor in Mathematics. Students majoring in other fields may take a subject minor in mathematics (see page 215) provided their program consists of 45 units or more units of advanced work in mathematics and is approved by the Mathematics Committee on Minors. The required oral examination in the subject minor will normally be a separate examination but may be a part of one of the oral examinations in the major subject. It is the responsibility of the candidate to submit the proposed program for approval and to arrange for the examination.

3. APPLIED MATHEMATICS

a. *Placement examinations.* Each new graduate student admitted to work for the Ph.D. in Applied Mathematics will be given an informal interview on Thursday or Friday of the week preceding the beginning of instruction for the fall term. The purpose of this interview is to ascertain the preparation of the student and assist him in mapping out a course of study. The work of the student during the first year will include some independent reading and/or research.

b. *Categories of courses.* Courses which are expected to form a large part of the student's program are divided into three categories as follows:

Group A. Courses in mathematics and mathematical methods. Examples of these would include:

AMa 101	Methods of Applied Mathematics I
AMa 201	Methods of Applied Mathematics II
AMa 104	Matrix Algebra
AMa 105	Introduction to Numerical Analysis
Ma 109	Delta Functions and Generalized Functions
Ma 137	Introduction to Lebesgue Integrals
Ma 143	Functional Analysis and Integral Equations
Ma 144	Probability

Group B. Courses of a general nature in which common mathematical concepts and techniques are applied to problems occurring in various scientific disciplines. Examples of these include:

AMa 151	Perturbation Methods
AMa 152	Linear and Non-Linear Wave Propagation
AMa 153	Stochastic Processes
AMa 251	Applications of Group Theory
IS 181	Linear Programming

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.

c. *The Oral Candidacy Examination.* In order to be recommended for candidacy the student must, in addition to satisfying the general Institute requirements, pass an oral candidacy examination. This examination will normally be given during the first term of the second graduate year. It will be based upon one year's work in courses of the type described in Group A above, and upon one year's work in courses of the type described in Groups B and C. The examination will also cover the independent study carried out by the student during his first graduate year.

d. *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.

e. *Submission of Thesis and Assigned Study Topic.* On or before the first Monday in April of the year in which the degree is to be conferred, a candidate for the degree of Ph.D. in Applied Mathematics must deliver a typewritten or printed copy of his completed thesis to his research supervisor. The candidate will then be assigned a short topic of study outside his immediate field of specialization. This requirement is to ensure sufficient breadth of study.

f. *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, and also the assigned topic of study.

g. *The Minor.* The minor requirement for students majoring in Applied Mathematics will be satisfied by 45 units of study in a field or fields sufficiently far removed from the candidate's major field of study. In accordance with Institute requirements, candidates who elect a subject minor must pass a special examination in this subject. It is the responsibility of the candidate to arrange for this examination. It should be held as soon as possible after completion of course work in the minor subject.

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 Committee.

4. ASTRONOMY

The Placement Examinations in Physics, page 231, Section 2a, covering material equivalent to Ph 106, Ph 112 and Ph 125, and an additional oral examination in astronomy, covering the material in Ay 112, will be required of first-year students. Their goal is to ascertain whether the student's background of atomic and nuclear physics, mathematical physics, and astronomy is sufficiently strong to permit advanced study in these subjects.

To be recommended for candidacy for the doctor's degree in astronomy the applicant must (a) complete satisfactorily 18 units of research, Ay 142, (b) pass with a grade of C or better, or by special examination, Ay 131 ab, Ay 132 ab, Ay 133 ab, Ay 210, and Ay 211, and (c) select a satisfactory program, approved by the Department, in fields which will depend on the student's specialty. Students in radio astronomy may substitute 18 units of Ay 133 ab and Ay 134 for the required course Ay 132 ab. Students in space science may omit Ay 132 ab, Ay 210 and Ay 211, substituting Ay 136, Ge 220 ab or Ge 265 ab, after prior consultation with the instructors.

The student's program during the first two years of graduate study should include a minimum of 63 units of advanced subjects in physics; for those students specializing in radio astronomy or in applied astronomical electronics, advanced courses in electrical engineering and applied mechanics can be substituted. Students in space science should substitute advanced courses in geophysics and geochemistry. This program of study must be planned, and approved by the Department during the first year. Fields in which subject minors are usually taken include physics, geology, or engineering, dependent on the student's field of specialization. See page 233 for the physics subject minor.

For admission to candidacy an oral examination will be given covering the entire field of study. This examination must be taken before the end of the second term of the second year. Special permission will be required for further registration if the candidacy course requirements and the oral examination are not satisfactorily completed by the end of the second year of graduate work.

A final draft of the thesis must be submitted at least six weeks before the commencement at which the degree is to be conferred. At least two weeks after submission of the thesis the student will be examined orally on the scope of his thesis and its relation to current research in astronomy.

E. Living Accommodations for Graduate Students

Housing Facilities. The Institute has four resident houses providing single rooms for 166 male graduate students. These handsome and comfortable residences, located on the campus, were donated by William M. Keck, Jr., Samuel B. Mosher and Earle M. Jorgensen, David X. Marks Foundations, and the family of Carl F. Braun. The rates per academic year vary from $382.50 to $450.00, depending upon the accommodations and services provided. During the summer only, rooms may be rented on a month-to-month basis. Complete information may be obtained and reservations made by writing to the Office of Residence and Dining Halls, California Institute of Technology.

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

There are no facilities available on the campus at present for married graduate students. They should write to the Off-Campus Housing Office, California Institute of Technology, for assistance in finding suitable accommodations in the community.

Dining Facilities. Graduate students are privileged to join the Athenaeum (Faculty Club), which affords the possibility of contact not only with fellow graduate students but also with others using the Athenaeum, including the Associates of the Institute, distinguished visitors, and members of the professional staffs of the Mount Wilson Observatory, the Huntington Library, and the California Institute.

The *Chandler Dining Hall,* located on the campus, is open Monday through Friday from 7 a.m. to 4 p.m. and 5:30 p.m. to 7:30 p.m.; Saturday and Sunday from 9 a.m. to 1 p.m. and 5:30 p.m. to 7:30 p.m.; serving breakfast, lunch, dinner, and snacks, cafeteria style.

F. Financial Assistance

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

Forms for making application for fellowships, scholarships, or assistantships may be obtained on request from the Dean of Graduate Studies. In using these forms it is not necessary to make separate application for admission to graduate standing. These applications should reach the Institute by February 15. Appointments to fellowships, scholarships, and assistantships are for one year only; and a new application must be filed each year by all who desire appointments for the following year, whether or not they are already holders of such appointments.

In addition, loans are available to graduate students who need such aid to continue their education. They are made upon application, subject to the approval of the Scholarships and Financial Aid Committee, and the extent of the available funds (see page 242).

In addition to loans, the Deferred Payment Plan is also available to graduate students (see page 242).

I. GRADUATE ASSISTANTSHIPS

Graduate Assistants devote during the school year not more than fifteen hours a week to teaching, laboratory assistance, or research of a character that affords them useful experience. This time includes that required in preparation and in marking notebooks and papers, as well as that spent in classroom and laboratory. The usual assistantship assignment calls for fifteen hours per week at most and ordinarily permits the holder to carry a full graduate residence schedule as well.

II. GRADUATE SCHOLARSHIPS AND FELLOWSHIPS*

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

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

ARCS Foundation (Achievement Rewards for College Scientists) of Los Angeles: The ARCS Foundation has established a fund for the award of several graduate and undergraduate scholarships.

Meridan Hunt Bennett Scholarships: The scholarships for graduate students are granted from the Meridan Hunt Bennett Fund as stated on page 198.

Blacker Scholarships: The Robert Roe Blacker and Nellie Canfield Blacker Scholarship Endowment Fund, established by the late Mr. R. R. Blacker and Mrs. Blacker, provides in part for the support of graduate men engaged in research work. The recipients are designated as Blacker Scholars.

Bridge Fellowship: The late Dr. Norman Bridge provided a fund, the income of which is used to support a research fellowship in physics. The recipient is designated as the Bridge Fellow.

Edith Newell Brown Scholarships: The income from the Edith Newell Brown Fund is used to maintain scholarships for graduate students. The recipients are designated as Edith Newell Brown Scholars.

Theodore S. Brown Scholarships: The income from the Theodore S. Brown Fund is used to maintain scholarships for graduate students. The recipients are designated as Theodore S. Brown Scholars.

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

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

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

Ray G. Coates Scholarship: Provided by the income from a bequest made by the late Mrs. Alice Raymond Scudder Coates, to maintain a scholarship for a student of physics. The graduate student recipient is designated as the Ray G. Coates Scholar.

Cole Fellowships: The income from the Cole Trust, established by the will of the late Mary V. Cole in memory of her husband, Francis J. Cole, is used to provide three scholarships annually, one in each of the following fields: electrical engineering, mechanical engineering, and physics. The recipients are designated as Cole Fellows.

Caroline W. Dobbins Scholarships: The income from the Caroline W. Dobbins Scholarship Fund, provided by the late Mrs. Caroline W. Dobbins, is used to maintain scholarships at the Institute. Graduate student recipients are designated as Caroline W. Dobbins Scholars.

Drake Scholarships: The income from the Drake Fund, provided by the late Mr. and Mrs. Alexander M. Drake, is used to maintain scholarships in such numbers and amounts as the Board of Trustees determines. Graduate students who are recipients from this fund are designated as Drake Scholars.

Lawrence A. Hanson Foundation: The gifts made by this Foundation are to be used for student aid.

Clarence J. Hicks Memorial Fellowship in Industrial Relations: This fellowship is supported by a fund made available by Industrial Relations Counselors, Inc., and other contributors. The fellowship is granted to a graduate student who undertakes some studies in industrial relations, as approved by the Director of the Industrial Relations Center.

Henry Laws Scholarships: The income from a fund given by the late Mr. Henry Laws is used to provide scholarships for research in pure science, preferably in physics, chemistry, and mathematics. The recipients are designated as Henry Laws Scholars.

Robert L. Leonard: A fund contributed by Mrs. Robert L. Leonard, income from which is for graduate scholarships.

Joseph F. Manildi: A fund contributed as a memorial to Dr. Joseph F. Manildi. The income may be used for graduate or undergraduate scholarships.

Blanche A. Mowrer: A bequest from Blanche A. Mowrer, income from which is for the benefit of graduate students in the pursuance of post-graduate work in the study of chemistry.

David Lindley Murray Scholarships: The income from the David Lindley Murray Educational Fund is used in part to provide scholarships for graduate students. The recipients are designated as Murray Scholars.

May McManus Oberholtz Scholarship Endowment Fund: The income from this fund is to be used for scholarships.

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

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

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

Ralph L. Smith Scholarship: This scholarship is supported by yearly grants.

Royal W. Sorensen Fellowship: The income from a fund created in honor of Royal W. Sorensen is used to provide a fellowship or a scholarship for a student in electrical engineering.

Keith Spalding Memorial Scholarship Fund: A fund contributed in memory of Mr. Keith Spalding, the income to be used for either graduate or undergraduate scholarships.

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

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

III. SPECIAL FELLOWSHIPS AND RESEARCH FUNDS

In addition to the National Science Foundation, the Department of Health, Education and Welfare, the National Aeronautics and Space Administration, the Woodrow Wilson Foundation, and the Ford Foundation, the following corporations, foundations and individuals contribute funds for the support of Graduate Fellowships which are administered by the Institute:

R. C. Baker Foundation
The Boeing Company
Consolidated Electrodynamics Corporation
Del Mar Science Foundation
Douglas Aircraft Company
E. I. du Pont de Nemours Company
Eastman Kodak Company
Fluor Foundation
General Dynamics Corporation
General Electric Foundation
Gillette Paper-Mate Manufacturing Company
Fannie and John Hertz Foundation
Hughes Aircraft Company
Inland Steel-Ryerson Foundation
International Business Machines Corporation
Kennecott Copper Corporation
Paul E. Lloyd
Lockheed Leadership Fund
Arthur McCallum Fund
Radio Corporation of America
Rand Corporation
Richfield Oil Corporation
Schlumberger Foundation
Shell Companies Foundation
Sinclair Oil Corporation
Alfred P. Sloan Foundation
Standard Oil Company of California
John Stauffer
Stauffer Chemical Company
Tektronix Foundation
Title Insurance and Trust Company Foundation
TRW Systems
Union Carbide Corporation
United States Steel Foundation
Xerox Corporation Electro-Optical Systems, Inc.

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

Daniel and Florence Guggenheim Fellowships in Jet Propulsion: These are fellowships established with the Guggenheim Jet Propulsion Center by the Daniel and Florence Guggenheim Foundation for graduate study in jet propulsion.

AEC Special Fellowships in Nuclear Science and Engineering: These fellowships are made available and are administered by the Atomic Energy Commission to support study in the general field of nuclear energy technology. The California Institute is a participating school at which AEC Fellows may pursue graduate study. See Nuclear Energy Option in Mechanical Engineering, page 272, and note under Engineering Science, page 153.

IV. POST DOCTORAL FELLOWSHIPS

A number of government agencies, foundations, societies, and companies support fellowships for the encouragement of further research by men who hold the doctor's degree. These grants usually permit choice of the institution at which the work will be done, and include, among others, those administered by the National Research Council, Rockefeller Foundation, John Simon Guggenheim Memorial Foundation, Commonwealth Fund, American Chemical Society, Bell Telephone Laboratories, E. I. du Pont de Nemours and Company, Merck and Company, Inc., American Cancer Society, the Atomic Energy Commission, the U. S. Public Health Service, the National Science Foundation, the National Foundation, and other government agencies, as well as various foreign governments. Applications for such fellowships should in general be directed to the agency concerned.

Institute Research Fellowships: The Institute each year appoints as Research Fellows a number of men holding the degree of Doctor of Philosophy who desire to pursue further research. Application for these appointments, as well as for other special fellowships listed below, should be made on forms provided by the Institute. These forms may be obtained from the Chairman of the Division in which the applicant wishes to work.

Gosney Fellowships: In 1929 Mr. E. S. Gosney established and endowed the Human Betterment Foundation. Following the death of Mr. Gosney in 1942, the Trustees of this Foundation transmitted the fund to the California Institute for the study of biological bases of human characteristics. The Trustees of the Institute have, for the present, set the income aside for the establishment of Gosney Fellowships. These are post doctoral research fellowships, the conditions being similar to those of Guggenheim Fellowships. The stipend varies with the experience of the Fellow.

Harry Bateman Research Fellowship: In honor of Professor Harry Bateman, the Institute offers a research fellowship in pure mathematics to a candidate holding the doctorate. The recipient will devote the major part of his time to research, but will be expected to teach one course in mathematics. The appointment is normally made for one year, but may be renewed for a second year.

Arthur Amos Noyes Fellowships: Dr. Arthur Amos Noyes, for many years Professor of Chemistry and Director of the Gates and Crellin Laboratories of Chemistry, left most of his estate to the Institute to constitute a fund to be known as the "Noyes Chemical Research Fund." The purpose of this fund, as stated in his will, is to provide for the payment of salaries or grants to competent persons who shall have the status of members of the staff of the Institute, and shall devote their time and attention mainly to the execution at the Institute of experimental and theoretical researches upon the problems of pure science (as distinct from those of applied science) in the field of chemistry. Dr. Noyes further provided that "no portion of the income of said fund shall be used for the payment of tuition fees, nor for scholarships or fellowship grants to persons still registered as students, or in general for the education of persons as to existing knowledge; but on the contrary the whole thereof shall be used for promoting, in the manner aforesaid in the field aforesaid, the search for new or more exact knowledge by persons who have completed their period of formal study and are devoting at least one-half of their working time to scientific investigations."

Millikan Fellowship: Established by Dr. Robert A. and Greta B. Millikan. Post-doctoral fellowship in the field of physical sciences, the recipients to be known as Millikan Fellows.

Richard Chace Tolman Fellowship: A fellowship in theoretical physics established in honor of Dr. Tolman, late Professor of Physical Chemistry and Mathematical Physics.

V. LOANS AND DEFERRED PAYMENTS

There are two sources of loans available to graduate students: Federal loans under the NDEA and loans from special funds of the California Institute of Technology. The terms and conditions for these loans are the same as those outlined for undergraduate students on pages 193 and 203, except that the maximum amount which may be borrowed under the NDEA by a qualified graduate student is $2500. The total of loans made to such a student from this source for all years, including any loans made to him as an undergraduate, may not exceed $10,000. Loans and the deferred payment plan may also be used in combination, but the total amount from all sources may not exceed $2500 in any one year of graduate study. Loans from Institute funds for graduate students will be subject to interest charges from the time the loan is made.

The Deferred Payment Plan is also available to graduate students and the conditions for this plan are as outlined on page 194.

VI. INSTITUTE GUESTS

Members of the faculties of other educational institutions, including research appointees already holding the doctor's degree, who desire to carry on special investigations, may be invited to make use of the facilities of the Institute provided the work they wish to do can be integrated with the over-all research program of the Institute and does not overcrowd its facilities. Arrangement should be made in advance with the chairman of the division of the Institute concerned. Such guests are given official appointment as Research Fellows, Senior Research Fellows, Research Associates, Visiting Associates, or Visiting Professors, and thus have faculty status during their stay at the Institute.

Section V

SCHEDULES OF THE COURSES

The school year is divided into three terms. The number of units assigned in any term to any subject represents the number of hours spent in class, laboratory, and preparation per week. In the following schedules, figures in parentheses denote hours in class (first figure), hours in laboratory (second figure), and hours of outside preparation (third figure).[1]

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

KEY TO ABBREVIATIONS

Aeronautics	Ae
Air Force-Aerospace Studies	AS
Anthropology	An
Applied Mathematics	AMa
Applied Mechanics	AM
Astronomy	Ay
Biology	Bi
Chemical Engineering	ChE
Chemistry	Ch
Civil Engineering	CE
Economics	Ec
Electrical Engineering	EE
Engineering	E
Engineering Graphics	Gr
Engineering Science	ES
English	En
Geology	Ge
Government and International Affairs	Gt
History	H
Hydraulics	Hy
Information Sciences	IS
Jet Propulsion	JP
Languages	L
Materials Science	MS
Mathematics	Ma
Mechanical Engineering	ME
Philosophy and Psychology	Pl
Physical Education	PE
Physics	Ph

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

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

[2]See page 189 for rule regarding excuses from physical education.

SCHEDULES OF UNDERGRADUATE COURSES

FIRST YEAR, ALL OPTIONS

The subjects listed below are taken by all students during their first year.[1] Differentiation into the various options begins in the second year.

		Units per Term 1st	2nd	3rd
Ma 1 abc	Calculus, Vector Algebra, Analytic Geometry (4-0-8)	12	12	12
Ph 1 abc	Kinematics, Particle Mechanics, and Electric Forces (4-3-5)	12	12	12
Ch 1 abc	General and Quantitative Chemistry (3-6-3)	12	12	12
En 1 a	English Literature (3-0-3)	6	.	.
H 1 a	History of European Civilization (2-0-3)	5	.	.
En 1 bc or H 1 bc	Nineteenth and Twentieth Century Literature (3-0-8) or Nineteenth and Twentieth Century Europe (3-0-8)	.	11	11
Gr 1	Basic Graphics (0-3-0)	3	.	.
PE 1 abc[2]	Physical Education (0-3-0)	3	3	3
		53	50	50

SENIOR HUMANITIES ELECTIVES

An 1	Race, Language and Culture
An 2	Social and Cultural Anthropology
An 3	Theories of Social Change
Ec 48	Introduction to Industrial Relations
Ec 104	Government Regulation
Ec 120	International Economic Relations
Ec 121	Price Theory
Ec 122	Econometrics
Ec 123	The Russian Economy
Ec 125	Technical Cooperation Seminar
Ec 126	Money, Income and Growth
En 8	Contemporary English and European Literature
En 9	American Literature
En 10	Modern Drama
En 11	Literature of the Bible
En 18	Modern Poetry
En 21	Introduction to the Visual Arts
En 125	Sixteenth and Seventeenth Centuries
En 126	Eighteenth Century
En 127	Earlier English Novel
En 128	Victorian Novel
En 130	American Renaissance
H 105	The Middle Ages
H 112	Europe Since 1914
H 116	Modern and Contemporary Germany
H 117	Modern and Contemporary Russia
H 118	Modern Britain
H 120	The British Empire and the Commonwealth
H 121	Modern India and Pakistan
H 130	History of War
H 147	The Far West and the Great Plains
H 151	Industrial Change in America 1865-1917
H 152	The 1920s and New Deal
H 153	Modern America
H 154	American Foreign Relations
H 157	Science in America since 1865
Gt 115	National Security
Gt 130	Comparative Politics
Gt 140	Seminar in Foreign Area Problems
Gt 141	African Studies
Gt 142	Southeast Asia
L 5	French Literature
L 40	German Literature
Pl 1	Introduction to Philosophy
Pl 2	Symbolic Logic
Pl 3	Contemporary European Philosophy
Pl 4	Human Nature and Ethics
Pl 6 a	The Psychology of Behavioral Processes
Pl 6 b	The Psychology of Personality Development
Pl 100	Philosophy of Science
Pl 102	Philosophy and Literature

[1]Honor electives (3 units) to be given second and third terms. See page 187.
[2]AFROTC students will substitute AS 1 abc (1-1-2) for PE 1 abc.

ASTRONOMY OPTION

(For First Year see page 244)

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 his division may, at the discretion of his department, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 185.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ph 2 abc	Electricity, Fields and Atomic Structure (4-3-5)	12	12	12
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
Ay 1	Introduction to Astronomy (3-1-5)	.	.	9
	Electives (see below)	15-18	15-18	6-9
PE 2 abc[1]	Physical Education (0-3-0)	3	3	3
		48-51	48-51	48-51

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

THIRD YEAR

En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (3-0-6)	9	9	9
Ay 112 abc	General Astronomy (3-3-3)	9	9	9
	Electives (see below) to total	44-49	44-49	44-49

FOURTH YEAR

	Humanities Electives[2] (3-0-6)	9	9	9
Ec 4 ab	Economic Principles and Problems (3-0-3)	6 and	6 or	6
H 5 abc	Public Affairs (1-0-1)	2	2	2
	Astronomy or Physics electives (see below)	18	18	18
	Electives to total	44-49	44-49	44-49

Suggested Electives

The student may elect any course that is offered in any division in a given term, provided that he has the necessary prerequisites for that course. The following list contains some of the courses that are useful to work in various fields of astronomy.

Ge 1	Physical Geology (4-2-3)	9	.	.
Bi 1	Elementary Biology (3-3-3)	.	9	.
EE 5	Introductory Electronics (3-0-6)	.	.	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
AM 98 abc	Analytical Dynamics (3-0-6)	9	9	9

[1]AFROTC students will substitute AS 2 abc (1-1-2) for PE 2 abc.
[2]For list of Humanities electives see page 244.

AM 95 abc[3]	Engineering Mathematics(4-0-8)	12	12	12
AM 116 abc	Complex Variables (4-0-8)	12	12	12
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
Ma 112	Elementary Statistics (3-0-6)	9 or	9	.
Ge 2	Geophysics	.	.	9
EE 13 abc	Linear Network Theory (3-0-6)	9	9	9
EE 90 abc	Laboratory in Electronics (0-3-0)	3	3	3
EE14 abc	Electronic Circuits (3-0-6)	9	9	9
Ph 77 ab	Experimental Physics Laboratory	6	6	.
Ph 112 abc[3]	Atomic and Nuclear Physics (3-0-6)	9	9	9
Ph 115 ab	Geometrical and Physical Optics (3-0-6)	9	9	.
Ay 108 ab[3]	Astronomical Instruments and Radiation Measurement (3-1-5), (3-2-4)	9	9	.
Ay 133 ab	Radio Astronomy (3-0-6)	9	9	.
Ay 131 ab[3]	Stellar Atmospheres (3-0-6)	9	9	.
Ay 132 ab[3]	Stellar Interiors (3-0-6)	.	9	9
Ay 136[3]	Planetary Physics (3-0-6)	9	.	.
Ay 141 abc	Research Conference in Astronomy (1-0-1)	2	2	2

[3]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 advisors.

BIOLOGY OPTION

(For First Year see page 244)

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 his division may, at the discretion of his department, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 185.

SECOND YEAR

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

Electives

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

Ch 41 abc	Chemistry of Covalent Compounds (2-0-2)	4	4	4
Ch 46 abc	Experimental Methods of Covalent Chemistry (1-5-0)	6	6	6
Bi 1	Elementary Biology (3-3-3)	.	9	.
Bi 9	Cell Biology (3-3-3)	.	.	9
	Non-Biology elective	9	.	.

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

THIRD YEAR

Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
En 7 abc	Advanced Literature (3-0-5)	8	8	8
Bi 107 abc	Biochemistry (3-0-7; 3-0-7; 0-8-2)	10	10	10
Bi 3	Plant Biology (3-6-3)	.	12	.
Bi 10	Animal Biology (3-6-3)	12	.	.
	Electives	7-12	7-12	19-24
		46-51	46-51	46-51

Electives

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

Bi 114	Immunology (2-4-3)	9	.	.
Bi 122	Genetics (3-3-4)	10	.	.
Bi 119	Advanced Cell Biology (3-4-5)	.	12	.
Bi 126	Genetics of Microorganisms (2-4-4)	.	10	.
Bi 127	Biochemical Genetics (2-4-4)	.	.	10
Bi 128	Advanced Microtechnique (1-4-1)	.	.	6
Bi 106	Introductory Developmental Biology of Animals (2-6-4)	.	.	12
Bi 20	Mammalian Anatomy and Histology (2-6-4)	.	.	12
L 32 abc	Elementary German (4-0-6)	10	10	10
L 50 abc	Elementary Russian (4-0-6)	10	10	10

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

FOURTH YEAR

		Units per Term 1st	2nd	3rd
	Humanities Electives[2]	15	15	9
H 5 abc	Public Affairs (1-0-1)	2	2	2
Bi 118	General Physiology (3-3-4)	10	.	.
Bi 122	Genetics (3-3-4)	10	.	.
	Electives	9-14	29-34	35-40
		46-51	46-51	46-51

Electives

In addition to those listed for the third year:

		1st	2nd	3rd
Bi 117	Psychobiology 1 (2-4-3)	.	.	9
Bi 129 ab	Biophysics (2-0-4)	6	6	.
Bi 132 ab	Biophysics of Macromolecules (3-0-6)	9	9	.
Bi 133	Biophysics of Macromolecules Laboratory (0-10-4)	.	14	.
Bi 214 abc	Chemistry of Bioorganic Substances (1-0-2)	3	3	3
Bi 218	Virology (2-3-4)	.	9	.
Bi 220 abc	Developmental Biology of Animals (2-0-4)	6	6	6
Bi 221	Developmental Biology Laboratory (units to be arranged)	x or	x or	x
Bi 230	Psychobiology 2 (units to be arranged)	x or	x or	x
Bi 240 abc	Plant Physiology 2-0-4)	6	6	6
Bi 241 abc	Advanced Biochemistry (2-0-4)	6	6	6
Bi 260	Advanced Physiology (units to be arranged)	.	x	.
Bi 109	Advanced Genetics Laboratory (units to be arranged)	.	x	.
Bi 22	Special Problems (units to be arranged)	x or	x or	x
Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Ch 144	Advanced Organic Chemistry (3-0-6)	9	9	9
Ch 244	Molecular Biochemistry (3-0-3)	6	6	.
	Any advanced course offered by other Divisions subject to approval by the student's advisor.			

[2]For list of Humanities electives, see page 244.

CHEMICAL ENGINEERING OPTION

(For First Year see page 244)

Any student of the Chemical Engineering Option whose grade-point average in the required chemistry and chemical engineering subjects of any year is less than 1.9 will be admitted to the required chemistry and chemical engineering subjects of the following year only with the special permission of the Division of Chemistry and Chemical Engineering.

SECOND YEAR

(Identical with the Chemistry Option)

		Units per Term 1st	2nd	3rd
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
Ph 2 abc	Electricity, Fields, and Atomic Structure (4-3-5)	12	12	12
Ch 41 abc	Chemistry of Covalent Compounds (2-0-2)	4	4	4
Ch 46 abc	Experimental Methods of Covalent Chemistry (1-5-0)	6	6	6
	Electives in Science and/or Engineering[1,2]	9	9	9
PE 2 abc	Physical Education (0-3-0)[3]	3	3	3
		52	52	52

THIRD YEAR

		1st	2nd	3rd
En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ec 4 ab	Economic Principles and Problems (3-0-3)	.	6	6
Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ch 26 ab	Physical Chemistry Laboratory (0-6-2)	.	8	8
ChE 63 ab	Chemical Engineering Thermodynamics (3-0-6; 2-0-4)	9	6	.
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
		48	49	43

FOURTH YEAR

		1st	2nd	3rd
	Humanities Electives (3-0-6)[4]	9	9	9
H 5 abc	Public Affairs (1-0-1)	2	2	2
ME 55	Adaptive Design (3-0-6)	9	.	.
ChE 61 ab	Industrial Chemistry (3-0-6)	9	9	.
ChE 64	Applied Chemical Thermodynamics (3-0-6)	.	.	9
ChE 66 ab	Transport Phenomena (3-0-9)	12	12	.
ChE 67 ab	Chemical Engineering Laboratory (0-7-2)	.	9	9
ChE 73	Unit Operations (3-0-9)	.	.	12
	Electives [2,5]	6-10	6-10	6-10
		47-51	47-51	47-51

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

[2]If ChE 80 units are to be used 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.

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

[4]For list of humanities electives, see page 244.

[5]These electives must be approved by the advisor. A student entering the chemical engineering option after the sophomore year who has not taken Ch 41 abc and Ch 46 abc must take these courses instead of an equal number of elective units. Electives may include, but are not limited to, the following graduate chemical engineering courses: ChE 101 ab, ChE 102, ChE 104 ab, ChE 170, and ChE 171 ab. If EE 5 has not been taken previously, it is strongly recommended as a senior elective.

CHEMISTRY OPTION

(For First Year see page 244)

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

SECOND YEAR

(Identical with the Chemical Engineering Option)

		Units per Term 1st	2nd	3rd
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
Ph 2 abc	Electricity, Fields, and Atomic Structure (4-3-5)	12	12	12
Ch 41 abc	Chemistry of Covalent Compounds (2-0-2)	4	4	4
Ch 46 abc	Experimental Methods of Covalent Chemistry (1-5-0)	6	6	6
	Electives in Science and/or Engineering[1,2]	9	9	9
PE 2 abc	Physical Education (0-3-0)[3]	3	3	3
		52	52	52

THIRD YEAR

En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ec 4 ab	Economic Principles and Problems (3-0-3)	.	6	6
L 32 abc	Elementary German[4] (4-0-6)	10	10	10
Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ch 26 ab	Physical Chemistry Laboratory (0-6-2)	.	8	8
Ch 90	Oral Presentation (1-0-1)	2	.	.
	Electives[2,5]	8-12	6-10	6-10
		47-51	47-51	47-51

FOURTH YEAR

	Humanities Electives (3-0-6)[6]	9	9	9
H 5 abc	Public Affairs (1-0-1)	2	2	2
	Electives[2,7]	36-40	36-40	36-40
		47-51	47-51	47-51

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

[2]If Ch 80 units are to be used as electives in the Chemistry Option, a thesis describing the research or a portion of it and approved by the research director must be submitted in duplicate before May 10 of the year of graduation. No more than 60 units of undergraduate research may be used as chemistry electives without special permission.

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

[4]May be taken in either third or fourth year. L 33 abc or L 50 abc may be substituted for L 32 abc.

[5]In addition to approved elective courses listed on page 249 any science and engineering course will be accepted if approved by the advisor. A student entering the chemistry option after the sophomore year who has not taken Ch 41 abc and CH 46 abc must take these courses instead of an equal number of elective units.

[6]For list of humanities electives see page 244.

[7]Approved elective courses listed on page 251.

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

The choice of electives must include courses which require a total of 18 units of laboratory work (for example, Ch 16, Chemical Instrumentation (0-6-2) requires 6 units of laboratory) or a total of 36 units of research (Ch 80). These elective laboratory units can be accumulated throughout the undergraduate years. No more than 60 units of undergraduate research may be used as chemistry electives without special permission. Other courses may be taken as electives provided they are in science or engineering subjects and are approved by the advisor. Students must meet any prerequisites required by a course.

		Units per Term		
		1st	2nd	3rd
Ch 16	Chemical Instrumentation (0-6-2)	8	.	.
Ch 24 c	Elements of Physical Chemistry (4-0-6)	.	.	10
Ch 80	Chemical Research (units to be arranged)	.	.	.
Ch 81	Special Topics in Chemistry (units to be arranged)	.	.	.
Ch 113	Advanced Inorganic Chemistry (3-0-6)	.	.	9
Ch 117	Electroanalytical Chemistry (2-0-2)	.	4	.
Ch 118 ab	Electroanalytical Chemistry Laboratory (0-6-0)	.	6	6
Ch 125 abc	Introduction to Chemical Physics (3-0-6)	9	9	9
Ch 127 ab	Nuclear Chemistry (2-0-4)	6	6	.
Ch 129 abc	Structure of Crystals (3-0-6)	9	9	9
Ch 130	Photochemistry (2-0-4)	6	.	.
Ch 132 ab	Biophysics of Macromolecules (3-0-6)	9	9	.
Ch 133	Biophysics of Macromolecules Laboratory (0-10-4)	.	14	.
Ch 144 abc	Advanced Organic Chemistry (3-0-6)	9	9	9
Ch 145	Advanced Organic Chemistry Laboratory (1-5-1)	7	.	.
Ch 148 ab	Characterization of Organic Compounds (2-0-2)	4	4	.
Ch 149 ab	Laboratory in Characterization of Organic Compounds (0-6-0)	6	6	.
ChE 61 ab	Industrial Chemistry (3-0-6)	9	9	.
ChE 63 ab	Introduction to Thermodynamics (3-0-6; 2-0-4)	9	6	.
ChE 64	Applied Chemical Thermodynamics (3-0-6)	.	.	9
ChE 66 ab	Transport Phenomena (3-0-9)	12	12	.
ChE 73	Unit Operations (3-0-9)	.	.	12
ChE 80	Undergraduate Research (units to be arranged)	.	.	.
ChE 101 ab	Applied Chemical Kinetics (2-0-7)	.	9	9
ChE 102	Applied Physical Chemistry (2-0-7)	9	.	.
ChE 170	Chemical Process Control (3-0-6)	.	.	9
EE 5	Introductory Electronics (3-0-6)	.	.	6
EE 90 abc	Laboratory in Electronics (0-3-0)	3	3	3
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ph 112 abc	Atomic and Nuclear Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (4-0-5)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
AM 102 abc	Applied Nuclear Physics (2-0-4)	6	6	6
Bi 107 abc	Biochemistry (3-0-7; 3-0-7; 0-8-2)	10	10	10
Bi 119	Advanced Cell Biology (3-4-5)	.	12	.
Bi 127	Biochemical Genetics (2-4-4)	.	.	10
Ge 3	Mineralogy (3-3-3)	.	9	.
Ge 130 ab	Introduction to Geochemistry (2-0-4)	6	6	.
Ge 151	Laboratory Techniques in the Earth Sciences (0-5-0)	.	5	.
L 35	Scientific German (0-0-10)	10	.	.

ECONOMICS OPTION

(For First Year see page 244)

SECOND YEAR

Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
Ph 2 abc	Electricity, Fields, and Atomic Structure (4-3-5)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
	Science-Engineering Electives	9	9	9
Ec 4 ab	Economic Principles and Problems (3-0-3)	6	6	.
	Electives	.	.	6
PE 2 abc	Physical Education (0-3-0)[1]	3	3	3
		48	48	48

THIRD YEAR

En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ec 126 ab	Money, Income, and Growth (3-0-6)	9	9	.
Ec 120	International Economic Relations (3-0-6)			9
	Electives[2]	27	27	27
		44	44	44

FOURTH YEAR

H 5 abc	Public Affairs (1-0-1)	2	2	2
Ec 121	Price Theory (3-0-6)	9	.	.
Ec 122	Econometrics (3-0-6)	.	9	.
	Economics Electives[3]	9	9	18
	Electives[2]	27	27	27
		47	47	47

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

[2]60 units of science, mathematics or engineering electives are to be taken beyond the sophomore year. For students in the economics option, this should include 21 units in mathematics.

[3]Chosen from:

Ec 111	Business Cycles and Governmental Policy
Ec 112	Modern Schools of Economic Thought
Ec 104	Government Regulation
Ec 123	The Russian Economy
Ec 125	Technical Cooperation (Seminar)
Ec 127 abc	Problems in Economic Theory (Seminar)

ENGINEERING OPTION

(For First Year see page 244)

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 his division may, at the discretion of the faculty in Engineering, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 185.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
Ph 2 abc	Electricity, Fields, and Atomic Structure (4-3-5)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
PE 2 abc[1]	Physical Education (0-3-0)	3	3	3
	Science or Engineering Electives	9	9	9
	Electives[2]	6-12	6-12	6-12
		48-54	48-54	48-54

THIRD YEAR

		1st	2nd	3rd
En 7 abc	Advanced Literature (3-0-5)	8	8	8
AM 95 abc or Ma 108 abc	Engineering Mathematics or Introduction to Real & Complex Analysis (4-0-8)	12	12	12
	Electives[2]	25-31	25-31	25-31
		45-51	45-51	45-51

FOURTH YEAR

		1st	2nd	3rd
	Humanities Elective[3] (3-0-6)	9	9	9
H 5 abc	Public Affairs (1-0-1)	2	2	2
E 10 ab or E 11 ab	Technical Presentations (1-0-1)	2	2	.
	Electives[2]	32-38	32-38	32-38
		45-51	45-51	43-49

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

[2]The electives must include Ec 4 ab and at least 99 units of Engineering Division courses (Ae, AM, CE, EE, Gr, Hy, JP, MS, ME) in which a passing grade is obtained. Of these 99 units, at least 9 units must be chosen from among available engineering laboratory courses such as AM 103, AM 111, ME 126, EE 91, etc. Electives must be approved by the student's advisor. A passing grade must be obtained in courses aggregating at least 565 units for graduation in the Engineering Option.

[3]For list of Humanities electives, see page 244.

Note: A student who plans to apply for graduate study at the Institute in some field of Engineering should, before choosing his electives, consult Sections IV and V of this catalog for specific requirements for admission to graduate study in this field.

ENGLISH OPTION

(For First Year see page 244)

Attention is called to the requirement that all students in the English option demonstrate competence in one foreign language.

	SECOND YEAR			
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
Ph 2 abc	Electricity, Fields, and Atomic Structure (4-3-5)	12	12	12
H 2 abc	History and Government of United States (2-0-4)	6	6	6
	Science or Engineering Electives	9	9	9
PE 2 abc	Physical Education (0-3-0)[1]	3	3	3
En 7 abc	Advanced Literature (3-0-5)	8	8	8
		50	50	50
	THIRD YEAR			
Ec 4 ab	Economic Principles and Problems (3-0-3)	6	6	.
En 125 abc (new course)	Sixteenth and Seventeenth Centuries (3-0-6)	9	9	9
	Electives[2] not less than	30	30	36
		45	45	45
	FOURTH YEAR			
H 5 abc	Public Affairs (1-0-1)	2	2	2
	English Electives[3]	9	9	9
En 122 abc	Senior Seminar (2-0-7)	9	9	9
	Electives[2]	27	27	27
		48	48	48

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

[2] 60 units of science, mathematics or engineering electives are to be taken beyond the sophomore year.

[3] Chosen from

- En 8 Contemporary English and European Literature
- En 9 American Literature
- En 10 Modern Drama
- En 11 Literature of the Bible
- En 18 Modern Poetry
- En 100 Seminar in Literature
- En 124 Medieval Literature
- En 126 Eighteenth Century
- En 127 Earlier English Novel
- En 128 Victorian Novel
- En 130 American Renaissance

GEOLOGICAL SCIENCES OPTION

(For First Year see page 244)

Attention is called to the fact that any student whose grade-point average in freshman and sophomore physics, chemistry, and mathematics is less than 1.9 at the end of an academic year may, at the discretion of the Division of Geological Sciences, be refused permission to register in the Geological Sciences Option. Furthermore, any student whose grade-point average is less than 1.9 in the subjects in the Division of Geological Sciences for the academic year, may, at the discretion of the Division, be refused permission to continue in the Geological Sciences Option.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
Ph 2 abc	Electricity, Fields, and Atomic Structure (4-3-5)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
Ge 1	Physical Geology (4-2-3)	9	.	.
Ge 3	Mineralogy (3-3-3)	.	9	.
PE 2 abc[1]	Physical Education (0-3-0)	3	3	3
	Electives (see suggested Electives listed below)*	10	9	18
		52	51	51

*The following courses are suggested as being especially suitable for a balanced program of study. Different courses may be elected with the advice and consent of the student's advisor, but at least 18 units of electives must be taken outside of the Division. Please note that En 7, which is required of all students in the option in the Junior year, may be elected.

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

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

Geochemistry Option

(Students in the Geochemistry option are strongly urged to elect Ch 41 abc and Ch 46 ab.)

Ch 41 abc	Chemistry of Covalent Compounds (2-0-2)	4	4	4
Ch 46 abc	Experimental Methods of Covalent Chemistry (1-5-0)	6	6	6
		52	52	52

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

THIRD YEAR

Common to All Options in the Division

En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ge 120 abc	Field Geology (4-5-1; 0-8-2; 2-6-2)	10	10	10

Geology Option

Ge 114	Mineralogy II (Optical Mineralogy) (3-8-1)	12	.	.
Ge 115 a	Igneous Petrology and Petrography (3-6-3)	.	12	.
Ge 115 b	Sedimentary Petrology and Petrography (3-4-3)	.	.	10
Ch 24 ab	Elements of Physical Chemistry (4-0-6)	10	10	.
	Electives (select from Electives listed below)	9	9	9
		49	49	37

Geochemistry Option

Ge 114	Mineralogy II (Optical Mineralogy) (3-8-1)	12	.	.
Ge 115 a	Igneous Petrology and Petrography (3-6-3)	.	12	.
Ge 115 b	Sedimentary Petrology and Petrography (3-4-3)	.	.	10
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
	Recommended Electives:			
Ge 130 ab	Introduction to Geochemistry (2-0-4)	6	6	.
	Other Electives (select from Electives listed below)	4	4	10
		49	49	47

Add electives with advice and consent of advisor to bring load up to a minimum of 49 units but not to exceed the allowable limit. Ec 4 ab must be included in the electives by or before the fourth year. Special attention is called to the opportunity to take L 32 abc or L 50 abc. Other desirable elective subjects include Ay 1, Bi 2 (for paleontologists), Ma 112, Ch 14, Ch 24c, ChE 50, Hy 134, Hy 210 ab, AM 97 abc, AM 98 abc, AM 110 a, CE 155 among others, provided student has proper prerequisites.

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

Geophysics Option

Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Am 95 ab	Engineering Mathematics (4-0-8)	12	12	12
	Electives	*	*	*
		50	50	50

*Add electives to bring unit load up to a minimum of 50 units, but not to exceed the allowable limit, selected with the advice and consent of the advisor. Suggested electives: (The elective list is intended to indicate a minimal level of advancement and is not complete.) Any Ge course, Ay 1, Am 130 abc, Phy 125, Ms 5, Ma 108, Ma 109, Ma 112, AMa 105, Ch 21 abc, EE 13 abc. Special attention is called to the opportunity to take L 32 abc or L 50 abc. Ec 4 ab must be taken by or before the fourth year.

FOURTH YEAR

Common to All Options in the Division

L 32 abc or L 50 abc	Elementary German (4-0-6) Elementary Russian	10	10	10
H 5 abc	Public Affairs (1-0-1)	2	2	2
Ge 102	Oral Presentation (1-0-1)	2	.	.
Ge 100	Geology Club (1-0-0)	1	1	1
	Humanities Elective (3-0-6) (Elect from section listed on page 244)	9	9	9

Geology Option

Ge 121 abc	Advanced Field Geology (4-8-2; 0-8-2; 0-5-6)	14	10	11
	Electives	9-11	12-15	11-14
	Electives to be selected from any advanced courses in the Division of Geological Sciences or courses in other Science or Engineering Divisions. (See list under third year.) The elective courses must be approved by the student's advisor.			
		47-49	44-47	44-47

Geochemistry Option

Ge 115 c	Metamorphic Petrology and Petrography (3-4-3)	10	.	.
Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Ch 26 ab	Physical Chemistry Laboratory (0-6-2)	.	8	8
	Electives (see statement immediately below)	4	18	18
	A suitable program will be worked out by the student and his advisor. This program will include courses from the Chemistry and Geology options. For example: Ch 113, Ch 127 ab, Ch 129, and Ge 151 a.			
		48	48	48

Geophysics Option

Physics or Mathematics Electives	18-27	18-27	18-27
Geology or Geophysics Electives	7-10	7-10	7-10
General Electives	*	*	*
	49-61	47-59	47-59

*Electives to be selected from advanced courses in Geology, Physics, Mathematics, Chemistry, Astronomy or Engineering. Suggested list of Physics, Mathematics, and Electrical Engineering electives: (The elective list is intended to indicate a minimal level of advancement and is not complete.) Ph 125, Ph 129, Ph 115, Ph 205, AMa 101, AMa 104, AMa 152, Ma 205, AM 125, AMa 205, EE 161 abc. Ec 4 ab must be elected if not already taken.

HISTORY OPTION

(For First Year see page 244)

Attention is called to the requirement that all students in the History option demonstrate competence in one foreign language.

SECOND YEAR

Ph 2 abc	Electricity, Fields, and Atomic Structure (4-3-5)	12	12	12
Ma 2 abc	Sophomore Mathematics (4-0-8)	12	12	12
H 2 abc	History and Government of the United States (2-0-4)	6	6	6
	Science or Engineering Electives	9	9	9
	Electives[2]	9	9	9
PE 2 abc	Physical Education (0-3-0)[1]	3	3	3
		51	51	51

THIRD YEAR

En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ec 4-ab	Economic Principles and Problems (3-0-3)	6	6	.
	Electives, not less than[3]	30	30	36
		44	44	44

FOURTH YEAR

H 5 abc	Public Affairs (1-0-1)	2	2	2
H 101	Tutorial	9	9	9
	Electives, not less than[3]	36	36	36
		47	47	47

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

[2]At least 9 units are to be chosen from the courses in History listed as "Advanced Subjects."

[3]A total of at least 81 units of history are to be selected from among the courses listed as "Advanced Subjects." The courses so chosen must include at least 9 units in each of three major areas of historical study: early European, modern European, and American History. The 9 units specified for the Sophomore year may count as part of the total of 81 units. Note also that a total of 60 units of science, mathematics, or engineering electives are to be taken beyond the sophomore year.

MATHEMATICS OPTION

(For First Year see page 244)

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 may, at the option of his department, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 185.

SECOND YEAR

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

THIRD YEAR

		1st	2nd	3rd
En 7 abc	Advanced Literature (3-0-5)	8	8	8
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
	Selected courses in Mathematics ....Minimum	9	9	9
	Selected courses in the Humanities[2] or Ec 4 ab ....Minimum	6	6	.
	Non-Mathematics Electives ....Minimum	9	9	9
	For each term the total number of units is required to fall within range	44-49	44-49	44-49

FOURTH YEAR

		1st	2nd	3rd
H 5 abc	Public Affairs (1-0-1)	2	2	2
	Selected course in Mathematics	9	9	9
	Selected courses in the Humanities[2]	9	9	9
	Electives (Mathematics or Non-Mathematics) Minimum	18	18	18
	For each term the total number of units is required to fall within range	38-48	38-48	38-48

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

[1]AFROTC students will substitute AS 2 abc (1-1-2) for PE 2 abc.
[2]For list of Humanities electives, see page 244.

PHYSICS OPTION

(For First Year see page 244)

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 his division may, at the discretion of his department, be refused permission to continue the work of that option. A more complete statement of this regulation will be found on page 185.

SECOND YEAR

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

Suggested Electives

The student may elect any course that is offered in any term, provided only that he has the necessary prerequisites for that course. The following subjects are suggested as being especially suitable for a well-rounded course of study.

		1st		2nd		3rd
AM 95 abc	Engineering Mathematics (4-0-8)	12		12		12
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9		9		9
Ge 1	Physical Geology (4-2-3)	9		.		.
Bi 1	Elementary Biology (3-3-3)	.		9		.
Ay 1	Introduction to Astronomy (3-1-5)	.		.		9
ME 1	Introduction to Design (0-9-0)	9	or	9	or	9
ME 3	Materials and Processes (3-3-3)	9	or	9	or	9
ME 17 ab	Thermodynamics (3-0-6)	9		9		.
EE 5	Introductory Electronics (3-0-6)	.		.		9
Ch 41 abc	Chemistry of Covalent Compounds (2-0-2)	4		4		4
Ch 46 abc	Experimental Methods of Covalent Chemistry (1-5-0)	6		6		6
ChE 50	Applications of Chemistry (3-0-6)	.		9		.
L 32 abc	Introductory Scientific German (3-1-6) (3-1-6) (4-0-6)	10		10		10

THIRD YEAR

		1st	2nd	3rd
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (4-0-5)	9	9	9
En 7 abc	Advanced Literature (3-0-5)	8	8	8
	Electives[3] not less than	15	15	15
		41	41	41

Suggested Electives

		1st	2nd	3rd
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
Ge 165	General Geophysics (3-0-3)	.	.	6
Ge 171	Applied Geophysics (4-0-6)	.	10	.
Bi 9	Cell Biology (3-3-3)	.	.	9
Ay 2 abc	General Astronomy (3-3-3)	9	9	9

[1]At least 27 units of sophomore electives shall be chosen from science and engineering courses of which at least 18 units shall be in science and engineering courses other than mathematics or physics.

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

[3]Students should note that EE 13 abc is prerequisite to most advanced electrical engineering courses, and that Ma 108 abc is prerequisite to most advanced mathematical courses.

EE 13 abc	Linear Network Theory (3-0-6)	9	9	9
EE 14 abc	Electronic Circuits (3-0-6)	9	9	9
EE 20 abc	Physics of Electronic Devices (3-0-6)	9	9	9
EE 90 abc	Laboratory in Electronics (0-3-0)	3	3	3
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ch 26 ab	Physical Chemistry Laboratory (0-6-2)	.	8	8
Ph 115 ab	Geometrical and Physical Optics (3-0-6)	9	9	.
L 35	Scientific German (4-0-6)	10	.	.
L 50 abc	Elementary Russian (4-0-6)	10	10	10
L 1 ab	Elementary French (4-0-6)	.	10	10

FOURTH YEAR

Ph 77 ab	Experimental Laboratory[1]	6	6	.
Ec 4 ab	Economic Principles and Problems (3-0-3)	.	6	6
H 5 abc	Public Affairs (1-0-1)	2	2	2
	Senior Physics Electives	18	18	18
	Humanities Elective[2]	9	9	9
	Electives	9	9	9
		44	50	44

Senior Physics Electives

Ph 112 abc	Atomic and Nuclear Physics (3-0-6)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9
Ph 203 abc	Nuclear Physics (3-0-6)	9	9	9
Ph 205 abc	Principles of Quantum Mechanics (3-0-6)	9	9	9
Ph 209 abc	Electromagnetism and Electron Theory (3-0-6)	9	9	9
Ph 213 ab	Nuclear Astrophysics (3-0-6)	9	9	.
Ph 216 abc	Introduction to Plasma Physics (3-0-6)	9	9	9
Ph 217 a	Spectroscopy (3-0-6)	.	.	9
Ph 220 a	Introduction to Solid State Physics (3-0-6)	.	.	9
Ph 231 abc	High Energy Physics (3-0-6)	9	9	9
Ph 236 ab	Relativity Theory (3-0-6)	9	9	.
Ay 131 ab	Stellar Atmospheres (3-0-6)	9	9	.
Ay 132 ab	Stellar Interiors (3-0-6)	9	9	.

[1]The laboratory requirement may also be satisfied by an equal number of units in experimental research.

[2]For list of Humanities electives, see page 244.

SCHEDULES OF GRADUATE COURSES

GRADUATE HUMANITIES ELECTIVES

Any Humanities course numbered 100 or higher may be used as a Graduate Humanities Elective. See listings under Advanced Subjects in Economics, English, History, Languages, and Philosophy.

AERONAUTICS

Program for degree of Master of Science in Aeronautics

		Units per Term 1st	2nd	3rd
	Humanities	9-10	9-10	9-10
Ae 101 abc	Elements of Gasdynamics	9	9	9
Ae 102 abc	Static and Dynamic Elasticity	9	9	9
Ae 103 abc	Performance and Flight Dynamics of Aircraft and Spacecraft	9	9	9
Ae 150 abc	Aeronautical Seminar	1	1	1
	Electives (not fewer than)*	9	9	9
		46-47	46-47	46-47

Program for degree of Aeronautical Engineer

Prerequisite, one year of graduate study covering the equivalent of the M.S. degree program above.

		Units per Term 1st	2nd	3rd
Ae 200 abc	Research in Aeronautics	20	20	20
	Mathematics[1]	9	9	9
	Seminar [2]	1	1	1
	Electives [3] (not fewer than)*	18	18	18
		48	48	48

*Courses AM 95 abc (Engineering Mathematics) and Ae 104 abc (Experimental Methods in Aeronautics) or Ae 104 a plus Ae 105 abc (Research Laboratory in Fluid Mechanics) are required undergraduate subjects. If these, or their equivalents, have not been taken previously they should be taken as electives. Otherwise, more than one year of residence will be required for the M.S. degree in Aeronautics. Graduate students should take AM 113 ab (Engineering Mathematics) and AM 116 (Complex Variables and Applications) instead of AM 95 abc.

[1]Any of the courses listed as acceptable for Ph.D. candidacy on page 220 are acceptable. These are AMa 101 abc (Methods of Applied Mathematics); AM 125 abc (Engineering Mathematical Principles; Ma 108 abc (Advanced Calculus); or Ph 129 abc (Methods of Mathematical Physics).

[2]Any advanced seminar as Ae 208 (Fluid Mechanics), Ae 209 (Solid Mechanics) or JP 290 (Jet Propulsion).

[3]Not fewer than 9 units of electives should be taken in the following Aeronautics subjects: Ae 201 abc (Fundamentals of Fluid Mechanics); Ae 203 (Flight Mechanics and Applied Aerodynamics); Ae 210 (Fundamentals in Solid Mechanics); Ae 211 (Applied Solid Mechanics).

AERONAUTICS (JET PROPULSION OPTION)

Program for degree of Aeronautical Engineer (Jet Propulsion Option)

JP 208	Research in Jet Propulsion	20	20	20
Ae 201 abc or Ae 210 abc	Fundamentals of Fluid Mechanics Fundamentals of Solid Mechanics	9	9	9
JP 290 abc	Jet Propulsion Seminar	1	1	1
	Electives	18	18	18
		48	48	48

APPLIED MECHANICS

Program for degree of Master of Science in Applied Mechanics

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar	1	1	1
AM 125 abc	Engineering Mathematical Principles[1]	9	9	9
	Electives as below[2]*	Minimum 54 per year		
	Free electives[3]*	Minimum 51 per year		
	Total	Minimum 135 per year		

Electives

(See Notes 1 and 2 below)

		Units per Term 1st	2nd	3rd
AMa 104	Matrix Algebra	9	.	.
AMa 105 ab	Introduction to Numerical Analysis	.	11	11
AM 110 abc	Theory of Elasticity, etc.	6	6	6
AM 111	Experimental Stress Analysis	.	9	.
AMa 170 abc	Linear and Nonlinear Elasticity	9	9	9
AMa 151 abc	Perturbation Methods	9	9	9
AMa 153 abc	Stochastic Processes	9	9	9
AM 140 abc	Plasticity	9	9	9
AM 141 abc	Wave Propagation in Solids	9	9	9
AM 150 abc	Mechanical Vibrations	6	6	6
AM 174 abc	Advanced Dynamics I	6	6	6
AM 176 abc	Advanced Dynamics II	6	6	6
Ae 101 abc	Elements of Gas Dynamics	9	9	9
Ae 210 abc	Fundamentals of Solid Mechanics	9	9	9
Ae 216	Structural Dynamics	.	9	.
Ae 217	Aeroelasticity	.	.	9
EE 173 abc	Foundations of Systems Theory and Its Application to Automatic Control	9	9	9
AM 130 abc	Applications of Classical Physics I	9	9	9
Hy 101 abc	Fluid Mechanics	9	9	9
JP 221	Rocket Trajectories and Orbital Mechanics	.	6	.
Ph 106 abc	Topics in Classical Physics	9	9	9

[1]With Faculty approval, AM 125 abc may be replaced by Ma 108 abc (Advanced Calculus), AMa 101 abc (Methods of Applied Mathematics I), or other satisfactory substitute.

[2]Substitution for electives listed above may be made with the approval of the student's advisor and the Faculty in Applied Mechanics.

[3]Students are encouraged to consider a Humanities elective as part of their free elective.

*The elective units may be divided among the 3 terms in any desired manner.

ASTRONOMY

Program for degree of Master of Science in Astronomy

Science electives at least 108 units.

Humanities electives at least 27 units.[1]

The choice of astronomy and other science elective courses must be approved by the department. At least 36 units of these 135 units must be selected from Ay 108, Ay 131, Ay 132, Ay 133, Ay 136, Ay 202, Ay 210, Ay 211. Placement examinations in astronomy and physics will be required. See catalog pages 125 and 236. The courses Ay 112, Ph 106, Ph 125 may be required of those students whose previous training in some of these subjects proves to be insufficient.

[1]For list of Humanities electives, see page 262.

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 that the student has completed at least one year of residence and 135 units of graduate work, which shall include at least 81 units of professional work at an advanced level and at least 27 units of free electives. He must have received a passing grade on each of two placement examinations. In general the degree is not conferred until the end of the second year of residence. The degree does not designate any of the disciplines of the Division, but is an M.S. in Biology.

CHEMICAL ENGINEERING

Program for degree of Master of Science in Chemical Engineering

		Units per Term 1st	2nd	3rd
ChE 102	Applied Physical Chemistry (2-0-7)	9	.	.
ChE 167 abc	Introduction to Chemical Engineering Research (0-12-3)[1]	15	15	15
	Electives,[2] at least	21	30	30
		45	45	45

A minimum of 135 units of graduate subjects, with three terms of graduate registration at the Institute, is required for master's degree. Of the 135 units, 81 must be in advanced professional subjects.

Students admitted for work toward the M.S. in Chemical Engineering will be required to take three placement examinations, one each in industrial and general chemistry, transport phenomena and the unit operations of chemical engineering, and engineering thermodynamics of one-component systems. (See page 222.) Any remedial work prescribed as a result of unsatisfactory performance in one or more of these placement examinations must be completed satisfactorily.

[1]A student originally admitted to work toward the Ph.D. degree can substitute an equal amount of research, ChE 280, for all or part of this requirement, but must also submit a research report in thesis form and have it accepted by the chemical engineering faculty.

[2]A minimum of 18 units of these electives must be in advanced chemical engineering subjects; the remainder are to be chosen from other approved advanced subjects but may also include up to 30 units of freely elected graduate courses, which may be in humanities as well as in engineering and science subjects. In addition to the 81 units of advanced professional subjects, AM 113 ab must be taken if the equivalent has not been studied previously.

CHEMISTRY

Program for degree of Master of Science in Chemistry

During the week preceding General Registration for the first term of graduate study, graduate students admitted to work for the M.S. degree will be required to take written placement examinations in the fields of inorganic chemistry and organic chemistry (on Monday) and physical chemistry (on Tuesday). These examinations will cover their respective subjects to the extent that these subjects are treated in the undergraduate chemistry option offered at this Institute and in general will be designed to test whether the student possesses an understanding of general principles and a power to apply these to specific problems, rather than a detailed informational knowledge. Graduate students are expected to demonstrate a proficiency in the above subjects not less than that acquired by abler undergraduates. Students who have demonstrated this proficiency in earlier residence at this Institute may be excused from these examinations.

In the event that a student fails to show satisfactory performance in any of the placement examinations he will be required to register for a prescribed course, or courses, in order to correct the deficiency promptly. In general no graduate credit will be allowed for prescribed undergraduate courses. If the student's performance in the required course or courses is not satisfactory, he will not be allowed to continue his graduate studies except by special action of the Division of Chemistry and Chemical Engineering on receipt of his petition to be allowed to continue.

The needs of Chemistry majors vary so widely in specialized fields of this subject that no specific curricula can be outlined. Before registering for the first time, a candidate for the master's degree should consult a member of the Committee on Graduate Study of the Division.

All masters' programs at the Institute require at least one year of residence and 135 units of graduate work, of which 81 units must be at an advanced professional level. For the degree in chemistry, these 81 units must include at least 40 units of chemical research and at least 30 units of advanced courses in science. The remaining 54 units are electives which 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 Chairman of the Division at least ten days before the degree is to be conferred. The copies of the thesis should be prepared according to the directions formulated by the Dean of Graduate Studies and should be accompanied by a statement approving the thesis, signed by the staff member directing the research and by the Chairman of the Committee on Graduate Study of the Division.

Candidates must satisfy the department of languages that they are able to read scientific articles in at least one of the following languages: German, French, or Russian.

CIVIL ENGINEERING

Program for degree of Master of Science in Civil Engineering

		Units per Term 1st	2nd	3rd
	Humanities Electives (3-0-6; or 4-0-6)[1]	9(or 10)	9(or 10)	9(or 10)
CE 130 abc	Civil Engineering Seminar (1-0-0)	1	1	1
	Electives (minimum total for year, 108)	36	36	36
	Total (minimum for MS, 138)	46	46	46

Electives

Courses are grouped into five general areas. A program for the MS degree must include electives from at least three areas with a minmum of 12 units from each, and must be approved by the adviser. Students who have not had AM 95 abc or its equivalent will be required to include AM 113 ab and AM 116 as part of their elective units. (Ma 112 may be taken in place of AM 116.) Other courses not listed here may be elected if approved by the Civil Engineering Faculty.

[1]For list of Humanities electives, see page 262.

Electives in Structures

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

Electives in Soil Mechanics

CE 105	Introduction to Soil Mechanics (2-3-4)	9	.	.
CE 115 ab	Soil Mechanics (3-0-6; 2-3-4)	9	9	.
CE 150	Foundation Engineering (3-0-6)	.	.	9

Electives in Hydraulics and Water Resources

CE 155	Hydrology (3-0-6)	9	.	.
CE 160	Advanced Hydrology[2]	.	.	.
Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
Hy 103 abc	Advanced Hdyraulics and Hydraulic Structures (3-0-6)	9	9	9
Hy 105	Analysis and Design of Hydraulic Projects[2]	.	.	.
Hy 111	Fluid Mechanics Laboratory			
Hy 121	Advanced Hydraulics Laboratory[2]	.	.	.
Hy 134	Flow in Porous Media (3-0-6)	.	.	9

Electives in Environmental Health Engineering

CE 145 ab	Environmental Health Biology (2-4-4; 2-3-4)	.	10	9
CE 146 abc	Analysis and Design of Environmental Systems (3-3-6)	12	12	12
CE 152 ab	Environmental Radiation (2-3-4)	.	9	9
CE 153	Seminar in Environmental Health Eng. (2-0-1)	.	.	3
CE 156	Industrial Wastes (3-0-6)	9	9	.
CE 170 ab	Behavior of Disperse Systems in Fluids (3-0-6)	9	9	.
Ch 124 abc	Elements of Physical Chemistry (4-0-2)			
Bi 107 abc	Biochemistry (3-0-7; 0-8-2)	10	10	10

Electives in Mathematics

AMa 101 abc	Methods of Applied Mathematics	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AM 113 ab	Engineering Mathematics (4-0-5)	.	9	9
AM 116	Complex Variables & Applications (4-0-8)	12	.	.
AM 125 abc	Engineering Mathematical Principles	9	9	9
Ma 112	Elementary Statistics	9 or	9	.

[2]Six or more units as arranged, any term.

ELECTRICAL ENGINEERING

Program for degree of Master of Science in Electrical Engineering

EE 201 abc	Research Seminar in Electrical Engineering	6 units
	Electives as below	Minimum 102 units
	Free electives	Minimum 27 units
	TOTAL	Minimum 135 units

Suggested Electives

EE 112 abc	Network Synthesis (3-0-6)	9	9	9
EE 125 abc	Advanced Electronics (3-0-6)	9	9	9
EE 126	Topics in Solid State Devices and Circuits (2-0-4)	.	.	6
EE 131 abc	Physics of Semiconductors and Semiconductor Devices (3-0-6)	9	9	9
EE 133 abc	Solid State Theory (3-0-6)	9	9	9
EE 135 abc	Electronic Processes in Solids (3-0-6)	9	9	9
EE 155 abc	Electromagnetic Fields (3-0-6)	9	9	9
EE 161 abc	Communication Theory (3-0-6)	9	9	9
EE 172 abc	Linear Feedback Principles	9	9	9
EE 173 abc	Modern Control Processes (3-0-6)	9	9	9
EE 180 abc	Data Processing Systems and Switching Theory (3-0-6)	9	9	9
EE 194	Microwave Laboratory (1-3-2)	.	6	.
EE 291	Advanced Work in Electrical Engineering	.	.	.
Ph 112 abc	Atomic and Nuclear Physics (4-0-8)	12	12	12
Ph 125 abc	Quantum Mechanics (3-0-6)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9
Ph 209 abc	Electromagnetism and Electron Theory (3-0-6)	9	9	9
Ph 216 abc	Introduction to Plasma Physics (3-0-6)	9	9	9
Ph 220	Introduction to Solid State Physics (3-0-6)	.	.	9
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
IS 181 ab	Linear Programming (3-0-6)	.	9	9
AMa 101 abc	Principles of Applied Mathematics (3-0-6)	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-0-6)	.	9	9
AMa 153 abc	Stochastic Processes (3-0-6)	9	9	9
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
	Other electives as approved by Electrical Engineering faculty.			

NOTES

1A minimum total of 135 units is required for the M.S.E.E. degree, and is usually achieved in one academic residence year beyond the Bachelor's degree.

2Students are urged to consider including a humanities course in the free electives.

3If, as a result of the placement examinations (see p. xxx), a student is required to take AM 113, AM 116, or EE 151, no more than 30 units from these courses may be offered for the M.S. degree.

ENGINEERING SCIENCE

Program for degree of Master of Science in Engineering Science

AMa 101 abc Methods of Applied Mathematics I or AM 125 abc Engineering Mathematical Principles or Ph 129 abc Methods of Mathematical Physics		9	9	9
	Electives from Group I or Group II below (minimum total for year 54 units, of which at least 27 units must be from courses in Group I)...	18	18	18
	Free Electives (minimum total for year, 54 units)...	18	18	18
		45	45	45

Electives

Group I

AM 101 abc	Nuclear Reactor Theory	9	9	9
AM 102 abc	Applied Nuclear Physics	6	6	6
AM 130 abc	Introduction to Classical Theoretical Physics I	9	9	9
AM 131 abc	Introduction to Classical Theoretical Physics II	9	9	9
AMa 170 abc	Linear and Nonlinear Elasticity Theory	9	9	9
EE 133 abc	Solid State Electronics	9	9	9
EE 135 abc	Electronic Processes in Solids	9	9	9
Hy 101 abc	Fluid Mechanics	9	9	9

Group II

AMa 104	Matrix Algebra	9	.	.
AMa 105 ab	Introduction to Numerical Analysis	.	11	11
Ma 108 abc	Advanced Calculus	12	12	12
Ph 106 abc	Topics in Classical Physics	9	9	9
Ph 112 abc	Atomic and Nuclear Physics	9	9	9
Ph 125 abc	Quantum Mechanics	9	9	9
Ph 216 abc	Introduction to Plasma Physics	9	9	9

GEOLOGY

Requirements for M.S. Degree in Geology, Geochemistry, and Geophysics

Master's Degree students in Geology, Geochemistry, or Geophysics will be expected to have satisfied, either before arrival or in their initial work at the Institute, the basic requirements of the undergraduate Geology, Geochemistry, or Geophysics curriculum (p. 227, and 255-257). Particular attention is called to requirements in petrology, field geology, chemistry, physics, and mathematics; competence in these subjects will be evaluated during the Placement Examination. Twenty-seven units of such course work may be counted toward the Institute requirement of 135 graduate units. In addition, students must satisfy the Institute requirement of 81 units of advanced graduate work by taking, in consultation with the student's advisor, courses numbered over 100 in geology or other science and engineering options that are not required in the Geology, Geochemistry, and Geophysics undergraduate curriclum. Humanities work may be included in the 27 units of free electives. For most students, two years will be required to meet the Master's Degree requirements.

Only in exceptional cases will the Division permit a student to undertake work leading to an Engineer's Degree in the Geological Sciences. If such instances arise, a program of prescribed study will be worked out with each student on an individual basis.

Students with limited experience in geological field work may be required to take all or a portion of Ge 120 abc as a prerequisite to Ge 121 abc or Ge 123. By approval of the Committee on Field Geology the field geology requirements may be satisfied by evidence of equivalent training obtained elsewhere.

MATERIALS SCIENCE

Program for degree of Master of Science in Materials Science

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)[2]	1	1	1
	Electives as below*	Minimum	75 per year	
	Free Electives*[3]	Minimum	57 per year	
	Total	Minimum	135 per year	

Electives

(See Notes 1 and 2 below)

		1st	2nd	3rd
Ae 102 abc	Static and Dynamic Elasticity (3-0-6)	9	9	9
Ae 213	Fracture Mechanics (3-0-6)	.	9	.
Ae 215	Theory of Finite Strains (3-0-6)	9	.	.
Ae 219	Mechanics of Inelastic Materials (3-0-6)	Any term.		
Ae 221	Theory of Viscoelasticity (3-0-6)	Any term.		
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AM 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
AM 102 abc	Applied Nuclear Physics (2-0-4)	6	6	6
AM 103 a	Nuclear Radiation Measurements Laboratory (1-4-4)	.	9	.
AM 103 b	Nuclear Engineering Laboratory (1-4-4)	.	.	9
AM 110 a	Introduction to the Theory of Elasticity (2-0-4)	6	.	.
AM 110 b	Theory of Plates and Shells (2-0-4)	.	6	.
AM 110 c	Mechanics of Materials (2-0-4)	.	.	6
AM 111	Experimental Stress Analysis (1-6-2)	.	9	.
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 126 abc	Applied Engineering Mathematics (3-0-9)	12	12	12
AM 130 abc	Applications of Classical Theoretical Physics I (3-0-6)	9	9	9
AM 131 abc	Applications of Classical Theoretical Physics II (3-0-6)	9	9	9
AM 140 abc	Plasticity (3-0-6)	9	9	9
AM 141 abc	Wave Propagation in Solids (3-0-6)	9	9	9
AM 150 abc	Mechanical Vibrations (2-0-4)	6	6	6
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
Ch 121 ab	Nature of the Chemical Bond (2-0-4)	.	6	6
EE 131 abc	Physics of Semiconductor and Semiconductor Devices (3-0-6)	9	9	9
MS 102	Pyrometry (1-6-2)	.	.	9
MS 103 ab	Physical Metallurgy Laboratory (0-9-0) (0-6-0)	9	6	.
MS 105	Mechanical Behavior of Metals (2-0-4)	6	.	.
MS 112 ab	Advanced Physical Metallurgy (3-0-6)	.	9	9
MS 115 ab	Crystal Structure and Properties of Metals and Alloys (3-0-6)	.	9	9
MS 116	X-Ray Metallography Laboratory I (0-6-3)	.	.	9
MS 120	Physics of Solids (3-0-6)	9	.	.
MS 150	Introduction to Principles of Polymer Science (3-0-6)	.	9	.
MS 205 a	Theory of Crystal Dislocations (3-0-6)	.	9	.
MS 205 b	Dislocations and the Mechanical Properties of Crystalline Solids (3-0-6)	.	.	9
Ma 112	Elementary Statistics (3-0-6)	9 or	9	.

[1]Students who have not had the equivalent of AM 95 abc are required to take AM 113 ab and AM 116, which may not be included in the non-free electives.

[2]Substitution for electives listed above may be made with the approval of the student's advisor and the Faculty in Materials Science.

*The elective units may be divided among the 3 terms in any desired manner.

[3]Students are urged to consider including a humanities course in the free electives.

ME 101 abc	Advanced Design (1-6-2)	9	9	9
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ph 112 abc	Atomic and Nuclear Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (4-0-5)	9	9	9

MATHEMATICS AND APPLIED MATHEMATICS

As nearly all mathematics and applied mathematics students are working for the doctor's degree, and follow programs arranged by the student in consultation with members of the staff, no specific master's degree curriculum is outlined. Additional information is given on page 137.

MECHANICAL ENGINEERING

Program for degree of Master of Science in Mechanical Engineering

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)[2]	1	1	1
	Electives as below*	Minimum	75 per year	
	Free electives*[3]	Minimum	57 per year	
	Total	Minimum	135 per year	

Electives (See Notes 1 and 2 below)

AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
AM 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
AM 102 abc	Applied Nuclear Physics (2-0-4)	6	6	6
AM 103 a	Nuclear Radiation Measurements Laboratory (1-4-4)	.	9	.
AM 103 b	Nuclear Energy Laboratory (1-4-4)	.	.	9
	Introduction to the Theory of Elasticity (2-0-4)	6	.	.
AM 110 b	Theory of Plates and Shells (2-0-4)	.	6	.
AM 110 c	Mechanics of Materials (2-0-4)	.	.	6
AM 111	Experimental Stress Analysis (1-6-2)	.	9	.
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 150 abc	Mechanical Vibrations (2-0-4)	6	6	6
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
Hy 101 abc	Advanced Fluid Mechanics (3-0-6)	9	9	9
Hy 121	Advanced Hydraulics Laboratory	6	6	6
Hy 201 abc	Hydraulic Machinery (2-0-4)	6	6	6
Hy 203	Cavitation Phenomena (2-0-4)	6	.	6
JP 170	Jet Propulsion Laboratory (0-9-0)	.	.	9
MS 102	Pyrometry (1-6-2)	.	.	9
Ma 112	Elementary Statistics (3-0-6)	9 or	9	.
ME 101 abc	Advanced Design (1-6-2)	9	9	9
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
ME 126	Fluid Mechanics and Heat Transfer Laboratory (0-6-3)	.	.	9
ME 127	High Frequency Measurements in Fluids and Solids (2-6-1)	.	9	.
ME 200	Advanced Work in Mechanical Engineering	.	.	.
ME 300	Thesis Research	.	.	.
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9

*The elective units may be divided among the 3 terms in any desired manner.

[1]Students who have not had the equivalent of AM 95 abc are required to take AM 113 ab and AM 116, which may not be included in the non-free electives.

[2]Substitution for electives listed above may be made with the approval of the student's advisor and the Faculty in Mechanical Engineering.

[3]Students are urged to consider including a humanities course in the free electives.

MECHANICAL ENGINEERING
(JET PROPULSION OPTION)

Program for degree of Master of Science in Mechanical Engineering

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
JP 120 abc	Chemistry Problems in Propulsion (3-0-6)	9	9	9
JP 121 abc	Rockets and Air Breathing Engines (3-0-6)	9	9	9
	Electives as below*[2]	Minimum 21 per year		
	Free electives*[3]	Minimum 57 per year		
	Total	Minimum 135 per year		

Electives (See Notes 1 and 2 below)

		1st	2nd	3rd
AM 110 a	Introduction to the Theory of Elasticity (2-0-4)	6	.	.
AM 110 b	Theory of Plates and Shells (2-0-4)	.	6	.
AM 110 c	Mechanics of Materials (2-0-4)	.	.	6
AM 150 abc	Mechanical Vibrations (2-0-4)	6	6	6
EE 172 abc	Linear Feedback Principles (3-0-6)	9	9	9
Hy 101 abc	Advanced Fluid Mechanics (3-0-6)	9	9	9
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
JP 221 abc	Rocket Trajectories and Orbital Mechanics (2-0-4)	6	6	6
Ae 104 abc	Experimental Methods in Aeronautics (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
AM 103 a	Nuclear Radiation Measurements Laboratory (1-4-4)	.	9	.
JP 170	Jet Propulsion Laboratory (0-9-0)	.	9	.
AM 103 b	Nuclear Energy Laboratory (1-4-4)	.	.	9
ME 126	Fluid Mechanics and Heat Transfer Laboratory (0-6-3)	.	.	9

*The elective units may be divided among the 3 terms in any desired manner.

[1]Students who have not had the equivalent of AM 95 abc are required to take AM 113 ab and AM 116, which may not be included in the non-free electives.

[2]Substitution for electives listed above may be made with the approval of the student's advisor and the Faculty in Mechanical Engineering.

[3]Students are urged to consider including a humanities course in the free electives.

MECHANICAL ENGINEERING
(NUCLEAR ENERGY OPTION)

Program for degree of Master of Science in Mechanical Engineering

E 150 abc	Seminar (1-0-0)	1	1	1
AM 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
AM 102 abc	Applied Nuclear Physics (2-0-4)	6	6	6
AM 103 a	Nuclear Radiation Measurements Laboratory (1-4-4)	.	9	.
AM 103 b	Nuclear Energy Laboratory (1-4-4)	.	.	9
	Electives as below* [2]	Minimum 12 per year		
	Free electives* [3]	Minimum 57 per year		
	Total	Minimum 135 per year		

Electives (See Notes 1 and 2 below)

AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AM 110 a	Introduction to the Theory of Elasticity (2-0-4)	6	.	.
AM 110 b	Theory of Plates and Shells (2-0-4)	.	6	.
AM 110 c	Mechanics of Materials (2-0-4)	.	.	6
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 150 abc	Mechanical Vibrations (2-0-4)	6	6	6
Ma 112	Elementary Statistics (3-0-6)	9 or	9	.
EE 172 abc	Linear Feedback Principles (3-0-6)	9	9	9
Hy 101 abc	Advanced Fluid Mechanics (3-0-6)	9	9	9
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
MS 115 ab	Crystal Structure and Properties of Metals and Alloys (3-0-6)	9	9	.
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9

*The elective units may be divided among the 3 terms in any desired manner.

[1]Students who have not had the equivalent of AM 95 abc are required to take AM 113 ab and AM 116, which may not be included in the non-free electives.

[2]Substitution for electives listed above may be made with the approval of the student's advisor and the Faculty in Mechanical Engineering.

[3]Students are urged to consider including a humanities course in the free electives.

MECHANICAL ENGINEERING

Program for degree of Mechanical Engineer

Specific requirements for the degree of Mechanical Engineer are given on page 213. The following list will suggest possible subjects from which a program of study may be organized:

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

MECHANICAL ENGINEERING
(JET PROPULSION OPTION)

Program for degree of Mechanical Engineer (Jet Propulsion Option)

		Units per Term 1st	2nd	3rd
JP 280 abc	Jet Propulsion Research (Thesis)	18	18	18
	Electives (not less than)	30	30	30
		48	48	48

The list of subjects which could be chosen as electives for the sixth-year work is given above.

PHYSICS

Program for degree of Master of Science in Physics

Ph 112 abc ....27 units
(If this course was taken as part of an undergraduate program, or an equivalent course was taken elsewhere and a satisfactory score made on the placement examination, it may be replaced by 27 units of any graduate courses.)

Physics Electives ....81 units
These must be selected from Ph 115 abc, Ph 129 abc, Ph 201 abc, Ph 203 abc, Ph 205 abc, Ph 209 abc, Ph 213 abc, Ph 216 abc, Ph 217, Ph 220, Ph 227 abc, Ph 230 abc, Ph 231 abc, Ph 236 ab, Ph 237 abc.

Non-Physics Electives ....27 units
These must be graduate courses from any option, including Humanities, except Physics.

NOTE: Each program must be approved by the Departmental Representative. With his approval, students who have the proper preparation may substitute other graduate courses in science or engineering for some of those listed above.

Section VI

SUBJECTS OF INSTRUCTION

AERONAUTICS

ADVANCED SUBJECTS

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

Ae 102 abc. Static and Dynamic Elasticity. *9 units (3-0-6); each term. Prerequisites: AM 97, AM 98.* Fundamentals of applied elasticity with examples from aircraft, missile, and spacecraft structures. Exact solutions for two- and three-dimensional problems. Approximate methods of attack on complex problems including energy methods and analog techniques of various types. A concise review of vibration principles supplemented by engineering examples of structural components subjected to dynamic loads. Text: *Elasticity in Engineering,* Sechler. Instructor: Babcock.

Ae 103 abc. Performance and Flight Dynamics of Aircraft and Spacecraft. *9 units (3-0-6); each term. Prerequisite: AM 95 a, b.* This course is intended to give a broad picture of modern applied aero- and space dynamics with an emphasis on the fundamental mechanisms involved. Topics include: Vector and dyadic treatment of the basic field and conservation equations of continuum fluids and the Navier-Stokes equations. Drag and thrust of momentum generating devices. The incompressible laminar and turbulent boundary layer with pressure gradients. The vector and scalar potential. Inviscid incompressible flow solutions. Application of the complex variable and conformal mapping. Lift in two and three dimensions. Thin airfoil theory. Separation on airfoils. Lifting line and surface theory. Integrated vehicle performance. Static and dynamic stability and control of aerospace vehicles. Instructor: Lissaman.

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

Ae 105 bc. *Research Laboratory in Fluid Mechanics. *9 units (0-0-9); second and third terms. Prerequisite: Ae 104 a and permission of instructor.* Introduction to experimental research for students who may wish to continue in this field. Closely supervised research covering problem formulation, shop practice, instrumentation and measuring technique, data interpretation, documentation, and technical writing. Instructor: Coles.

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

Ae 150 abc. Aeronautical Seminar. *1 unit (1-0-0); each term.* Speakers from campus and outside research and manufacturing organizations discuss current problems and advances in aeronautics.

Ae 200 abc. Research in Aeronautics. *Units to be arranged.* Theoretical and experimental investigations in the following fields: aerodynamics, compressibility, fluid and solid mechanics, supersonic and hypersonic flow, aeroelasticity, structures, thermoelasticity, fatigue, photoelasticity. Instructors: Staff.

Ae 201 abc. Fundamentals of Fluid Mechanics. *9 units (3-0-6); each term. Prerequisites: Ae 101, AM 113, AM 116 or AM 125.* Theoretical foundations of the mechanics of inviscid and viscous fluids pertinent to aeronautics. The first half, covering inviscid fluids, includes: incompressible flow theory; incompressible two-dimensional airfoil, three-dimensional wing, and slender body theories; linearized compressible potential flows and wing theory; oblique shocks; method of characteristics; exact solutions of the two-dimensional compressible flow equations; similarity laws for subsonic, transonic, supersonic, and hypersonic flows; introduction to hypersonic aerodynamics. The second half, dealing with viscous fluids, includes: physical properties of real gases; Navier-Stokes equations and their exact solutions; low Reynolds number approximate solutions; high Reynolds number phenomena emphasizing boundary layer concepts and their mathematical treatments. Instructors: Millikan, Lees, Kubota, Saffman.

Ae 203 abc. Flight Mechanics and Applied Aerodynamics. *9 units (3-0-6); each term. Prerequisites: Ae 101, Ae 103, AM 113, 116.* Atmospheric flight mechanics, controlled motion of airplanes and rockets, atmospheric perturbation effects, gyroscopic coupling effects. Orbital flight mechanics, launching trajectories, space trajectories, orbital perturbations. Multi-stage rocket performance. Re-entry mechanics and aerodynamic heating. Special topics in wing theory, linearized incompressible and supersonic lifting surface theory and non-stationary wing theories. Instructor: Stewart.

Ae 208 abc. Fluid Mechanics Seminar. *1 unit (1-0-0); each term.* A seminar course in fluid mechanics. Weekly lectures on current developments are presented by staff members, graduate students, and visiting scientists and engineers. Instructor: Liepmann.

Ae 209 abc. Seminar in Solid Mechanics. *1 unit (1-0-0); each term.* A seminar for staff and students of all divisions whose interests lie in the general field of solid mechanics. Reports on current research by staff and students on the campus are intermixed with seminars given by invited lecturers from companies and other research institutions. Instructors: Staff.

Ae 210 abc. Fundamentals in Solid Mechanics. *9 units (3-0-6); each term. Prerequisite: Ae 102 or equivalent.* Theoretical foundations of the mechanics of elastic, anelastic and plastic bodies. Basic methodology is emphasized. The first part is a matrix approach to the theory of elasticity, dynamics of elastic and viscoelastic systems. The second part is continuum mechanics: it includes tensor analysis; stress and strain tensors; linear elasticity; vibrations and elastic waves; variational principles and their applications; irreversible thermodynamics, heat conduction, thermoelasticity, viscoelasticity; finite strain; plasticity; theory of stability. The third part deals with some special methods for boundary value problems: it includes theory of biharmonic functions; strain potential; stress functions; Galerkin, Papkovich, Neuber functions; integral transformations. Instructors: Fung, Sechler.

Ae 211 abc. Applied Solid Mechanics. *9 units (3-0-6); each term. Prerequisites: Ae 102 or equivalent.* Applications of the principles of solid mechanics to engineering problems connected with aircraft, missiles, boosters, and spacecraft. Examples of critical structural components are discussed with particular emphasis upon defining and utilizing appropriate analytical techniques which may range from complex variables to variational solutions or computer programs, depending upon the problem. Typical illustrations include large deflection analysis of heated plates, structural integrity of viscoelastic solid fuel rockets, strength analysis of heated turbines, stress and shock wave propagation in real materials, stress analysis of pressure vessels and expandable shell configurations, and failure characteristics of rate-sensitive media.

Note: The following group of courses, Ae 212 to 223, represents a series of one-term courses in Advanced Solid Mechanics. They will be given as student demand requires and staff facilities permit.

Ae 212. Shell Theory. *9 units (3-0-6); one term.* General mathematical formulation of the theory of thin elastic shells. Membrane and bending stresses in shells. Elastic stability. Surveys of recent advances in the non-linear theories of stressing and buckling of shells. Instructor: Hegemier.

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

Ae 214. Special Problems of Space Environment. *9 units (3-0-6); offered second term 1965-66.* The effect of space environment on living bodies, materials, and structures. Hard vacuum, ionizing and particle radiation. Micrometeroid impact, damage, and protection. Radiation shielding. Differences between short time and long time missions. Solar radiations, flares, and storms. Instructor: Sechler.

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

Ae 216. Structural Dynamics. *9 units (3-0-6); offered third term 1965-66.* Selected problems of structural dynamics that are of special interest to aerospace engineers. Topics may include 1) the causes, effects, and control of structural dynamics of flight vehicles including free, forced, and self excited oscillations, 2) ground shock, base hardening, ground wind, and silo firing problems, and 3) testing techniques, design criteria, and methods of analysis and calculation pertaining to structural dynamics. Instructor: Fung.

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

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

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

Ae 220. Nonlinear Problems in Structures and Aeroelasticity. *9 units (3-0-6); one term.* Large deflection of beams and plates. Edge layer theories. Post-buckling behavior of plates. Nonlinear vibrations of plates and shells. Buckling of arches and shells. Nonlinear problems in static aeroelasticity. Flutter of buckled plates. Flutter of airfoils with nonlinear stiffness and damping characteristics. Stall flutter.

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

Ae 223. Design Criteria for Missiles, Boosters, and Spacecraft. *9 units (3-0-6); one term.* A review of the static and dynamic design criteria for structural components relating to the missile and space program. Items affecting payload capability for a given mission and the relationship between reliability and design criteria. The impact of new materials and analysis methods on the designer. Instructor: Sechler.

Note: The following group of courses Ae 231-Ae 239 includes one-term advanced courses in Fluid Mechanics which will be offered from time to time as demand warrants and staff availability permits. The courses which will be offered in 1965-66 are indicated.

Ae 231. Molecular Theory of Fluid Motion. *(3-0-6); one term. Prerequisites: Ae 101, AM 125 or equivalent.* Distribution function, characteristic function. Law of large numbers, central limit theorem. Random walk. Fokker-Planck equation. Elementary kinetic theory and application to simple flows. Boltzmann equation and its extension to liquids and plasmas. Krook's model, moment equations, etc. Instructors: Lagerstrom, L. Lees, Liepmann.

Ae 232. Gasdynamics of Upper Atmosphere Flight. *9 units (3-0-6); offered third term 1965-66. Prerequisites: Ae 101, AM 113 ab and AM 116, or AM 125.* Fluid mechanical problems of upper atmosphere flight. Properties of the planetary atmospheres. "Free-molecule" flows and surface interactions. Drag and heat balance of satellites. Maxwell-Boltzmann equation and method of solution. Low Reynolds number flows according to the Navier-Stokes equations, including boundary layer-shock wave interactions. Ionized gases at low density. Plasma waves and the wake of a satellite in the ionosphere. Instructor: L. Lees.

Ae 234. Hypersonic Aerodynamics. *9 units (3-0-6); offered first term 1965-66. Prerequisites: Ae 101, Ae 201 a, AM 125.* An advanced course dealing with aerodynamic problems of flight at hypersonic speeds. Topics are selected from: Hypersonic small-disturbance theory, blunt body theory, boundary layers and shock waves in real gases, heat and mass transfer, testing facilities and experiments. Text: *Hypersonic Flow Theory*, Hayes and Probstein. Instructor: Cole.

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

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

(In 1965-66 this course will be given in the second term under the course designation Ay 203. See the section under Astronomy for details. Instructor: R. Lüst.)

Ae 237. Shock Tube Theory and Techniques. *9 units (3-0-6); Prerequisites: Ae 101, AM 95 or AM 113, AM 116.* Review of shock waves in moving co-ordinate systems, in real and perfect gases. Simple expansion waves. Basic shock tube equation; various shock tube parameters. Reflected shock waves. Effects of area change. Driver types and characteristics. Non-ideal behavior in shock tubes; diaphragm opening effects, boundary layer effects. Shock tube techniques and measurements. Illustrations of shock tube applications; shock wave structure, shock wave interactions, experiments on chemical and physical properties of gases, reaction rates, aerodynamic experiments, light gas guns, etc.

Ae 238. Homogeneous Turbulence. *9 units (3-0-6); offered 2nd term 1965-66. Prerequisites: Ae 201 or permission of instructor.* Kinematics of homogeneous turbulence, correlation and spectrum tensors. Properties of the large eddy structure. The universal equilibrium theory. The fine scale structure of turbulence. Turbulent diffusion. Magnetohydrodynamic turbulence. Analytical theory of homogeneous turbulence. Instructor: Saffman.

Ae 239. Turbulent Shear Flows. *9 units (3-0-6). Prerequisites: Ae 101, AM 113, 116.* Equations of mean motion and review of boundary layer concepts. Similarity arguments for turbulent shear flows and extension to energy processes. Integral methods; single and multi-parameter methods of calculation. Discussion of transition, roughness, heat and mass transfer. Applications in geophysics and astrophysics. Wakes, free shear layers, separated flows. (Subject matter will vary from year to year.) Instructor: Coles.

Aeronautics—Jet Propulsion

(For Jet Propulsion see pages 328-331)

Air Force—Aerospace Studies

***AS 1 abc. Foundations of Aerospace Power.** *4 units (1-1-2); three terms. Prerequisite: Open only to those students who are recipients of Air Force Financial Aid Grants.* An introductory examination of the factors of aerospace power, major ideological conflicts, requirements for military forces in being, responsibilities of citizenship, development and traditions of the military profession, organization of the armed forces as factors in the preservation of national security, and the United States Air Force as a major factor in the security of the free world. Instructors: Air Force Staff.

****AS 2 abc. World Military Systems.** *4 units (1-1-2); three terms. Prerequisite: AS 1 abc.* A study of world military forces to include the mission, organization, functions and characteristics of Free World land, naval and air forces and their place in Allied regional security organizations in comparison to the mission, organization, functions and characteristics of Communist air, land, and naval forces and the operations of Communist regional security organizations. Instructors: Air Force Staff.

****AS 3 abc. Growth and Development of Aerospace Power.** *7 units (2-1-4); three terms. Prerequisite: Satisfactory completion of AS 1 abc and AS 2 abc or the six week Air Force summer field training.* A survey course about the nature of war; the development of airpower in the United States; mission and organization of the Defense Department; Air Force concepts, doctrine, and employment; astronautics and space operations; and the future development of aerospace power. Instructors: Air Force Staff.

*****AS 4 abc. The Professional Officer.** *7 units (2-1-4); three terms. Prerequisite: AS 3 abc.* The meaning of professionalism, professional responsibilities, the military justice system; leadership theory, functions, and practices; management principles and functions; problem solving; management tools, practices, and controls. Instructors: Air Force Staff.

Anthropology

An 1. Race, Language and Culture. *9 units (3-0-6); first term; Senior Elective.* Human evolution and the origin of language and other elements of culture. Descriptive analysis of hunting and gathering societies in the Old and New Worlds. The development of racial, linguistic and cultural diversity. Instructor: Scudder.

An 2. Social and Cultural Anthropology. *9 units (3-0-6); second term; Senior Elective.* The agricultural revolution and the racial, linguistic and cultural consequences of large-scale neolithic population movements. The social organization of selected pastoral and subsistence cultivation societies. Instructor: Scudder.

An 3. Theories of Social Change. *9 units (3-0-6); third term; Senior Elective.* Social change with particular emphasis on the development of the pre-industrial city, the great world religions, and the relationship of contemporary peasant societies to urbanization and industrialization. Instructor: Scudder.

*During the first and third terms of the freshman year no military classroom instruction will be provided. During these terms certain Institute courses are substituted for the military classroom phase. The substituted courses contribute to precommission officer education requirements and are Institute required courses for all freshmen. During these terms the cadet will participate only in the leadership laboratory, one hour per week. Instructors: Air Force Staff.

**New Officer Education courses, beginning the fall of 1964, representing an updating and improvement of the AFROTC curriculum which are more closely aligned with contemporary requirements for the professional education and preparation of Air Force officers. OE-100 and OE-400 will be implemented in the fall of 1965.

***During the senior year H-23, Modern War (3-0-6) and H-16, American Foreign Relations (3-0-6), must be substituted in the first and second terms for some of the areas of instruction depicted above.

APPLIED MATHEMATICS

ADVANCED SUBJECTS

AMa 101 abc. Methods of Applied Mathematics I. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Review of basic complex variable analysis; analytic continuation; ordinary linear differential equations with applications to special functions, asymptotic expansions; integral transforms. Applications to boundary value problems and integral equations. Instructor: Knowles.

AMa 104. Matrix Algebra. *9 units (3-0-6); first term. Prerequisite: AM 95 abc or equivalent.* Theory of matrices from the standpoint of mathematical physics and as used in the formulation of problems on high-speed analog and digital computers. Canonical forms are developed for self adjoint and for general matrices. Text: *Principles of Numerical Analysis,* Householder. Instructor: Franklin.

AMa 105 ab. Introduction to Numerical Analysis. *11 units (3-2-6); second and third terms. Prerequisites: Ma 108 or AM 95 or equivalent; Ma 5, Ma 31 or AMa 104 or equivalent; and familiarity with coding procedures by the middle of the first quarter of the course.* The topics considered include: Interpolation and quadrature. Numerical solution of algebraic and transcendental equations. Matrix inversion and determination of eigenvalues. Numerical solution of ordinary differential equations. Numerical solution of elliptic, parabolic, and hyperbolic partial differential equations. Instructor: Todd.

AMa 151 abc. Perturbation Methods. *9 units (3-0-6); three terms. Prerequisite: AMa 101 or equivalent.* The course discusses uniformly valid approximations in various physical problems. Generalized boundary layer technique. Coordinate straining techniques; Poincare's method. Problems with several time scales; averaging techniques; method of Krylov-Bogoliubov. Eigenvalue problems. Examples taken from linear and nonlinear vibrations, orbital problems, viscous flow, elasticity. Not offered in 1965-66.

AMa 152 abc. Linear and Nonlinear Wave Propagation. *9 units (3-0-6); three terms. Prerequisite: AMa 101 or equivalent.* Mathematical formulation, hyperbolic equations, characteristics, shocks. Combined effect of nonlinearity and diffusion. Wave propagation with relaxation effects. Dispersive waves, group velocity, geometry of waves, nonlinear dispersive waves. Diffraction theory. The emphasis is on solving physical problems and the mathematical theory is developed through a wide variety of problems in gas dynamics, water waves, plasma physics, electromagnetism. Instructor: Whitham.

AMa 153 abc. Stochastic Processes. *9 units (3-0-6); three terms. Prerequisite: Ma 108; or AM 95 and 116.* An introductory course designed to proceed from an elementary and often heuristic discussion of a variety of stochastic processes in physics to a unified mathematical treatment of the subject. Topics will include: Concepts of power spectra and correlation functions and their use in problems like shot effect, Brownian motion, wave propagation in media with random inhomogeneities, turbulence, etc. Response of systems of oscillators to random inputs. Fokker-Planck equation and its application to nonlinear oscillator problems. General theory of Markoff processes. Instructors: Caughey, Lagerstrom.

AMa 170 abc. Linear and Nonlinear Elasticity Theory. *9 units (3-0-6). Prerequisite: AMa 101 or equivalent.* Kinematics of deformation, momentum equations, stress-strain relations and energy considerations in the nonlinear theory of elastic solids; the classical linearized theory in two and three dimensions, including complex variable methods, mixed boundary value problems, displacement potentials, variational principles, elastic waves; theories of thin bodies, including recent work; finite strain theory for incompressible materials; problems in the stability of elastic equilibrium.

AMa 190. Reading and Independent study. *Units by arrangement.*

AMa 201 abc. Methods of Applied Mathematics II. *9 units (3-0-6); three terms. Prerequisite: AMa 101 or equivalent.* First order partial differential equations; classification of higher order equations; well-posed problems. Fundamental solutions and Green's functions; eigenfunction expansions; solution by integral transforms. Singular integral equations. Instructors: Cohen, Cole.

AMa 251 abc. Application of Group Theory. *9 units (3-0-6); first and second terms. Prerequisite: Some knowledge of linear algebra.* Applications of group theory to differential equations and to physics, in particular quantum mechanics, will be discussed. Mathematical topics to be covered include: Basic concepts of group theory. Infinitesimal transformations and Lie algebras. General notions of group representations. Detailed discussion of classical groups (symmetric, orthogonal, unitary, Lorentz, etc.) and of their representations. Instructor: Lagerstrom.

AMa 290. Applied Mathematics Colloquium. *2 units. Three terms.*

AMa 291. Seminar in Applied Mathematics. *Units by arrangement.*

AMa 300. Research in Applied Mathematics. *Units by arrangement.*

Other courses particularly suitable in making up a program in Applied Mathematics include:

Ma 109	Delta Functions and Generalized Functions
Ma 137	Introduction to Lebesgue Integrals
Ma 143	Functional Analysis and Integral Equations
Ma 144	Probability
Ma 205	Numerical Analysis
AM 130	Applications of Classical Theoretical Physics I
AM 131	Applications of Classical Theoretical Physics II
AM 174	Advanced Dynamics I
AM 181	Linear Programming
AM 204	Hydrodynamics of Free Surface Flows
Ae 233	Mathematical Fluid Dynamics
Ae 235	Magneto-Fluid Dynamics
Ae 236	Topics in Plasma Physics
Ph 125	Quantum Mechanics
Ph 209	Electromagnetism and Electron Theory
Ph 227	Thermodynamics, Statistical Mechanics, and Kinetic Theory
EE 161	Communication Theory

Applied Mechanics

Undergraduate Subjects

AM 95 abc. Engineering Mathematics. *12 units (4-0-8); first, second and third terms. (Graduate students needing this material should take AM 113 ab and/or AM 116.) Prerequisites: Ma 1 abc, Ma 2 abc, or equivalent. AM 95 a may be taken simultaneously with Ma 2 c by sophomores with advanced standing in mathematics.* A course in the mathematical treatment of problems in engineering and physics. Emphasis is placed on the formulation of problems as well as their mathematical solution. The topics studied include: vector analysis as applied to formulation of field theory problems; a basic introduction to analytic functions of complex variables; special functions such as the Bessel functions and Legendre functions; series of orthogonal functions; partial differential equations and boundary value problems, and an introduction to integral transforms. Text: *Differential Equations Applied in Science and Engineering,* Wayland. Instructors: Knowles, Wayland, and staff.

AM 97 abc. Analytical Mechanics of Deformable Bodies. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 1 abc and Ma 2 abc.* Basic principles of stress and strain, displacements and strains in a continuum, stress-strain relations, strain energy methods, and stress failures. Equations of the Theory of Elasticity, uniqueness, and St. Venant's principle. Applications to beams, elastic instability, axially symmetrical problems, stress concentrations, torsion, plates and shells, wave propagation, and plastic and inelastic behavior, stresses and strains as tensors, numerical methods and experimental methods in stress analysis, variational methods. Instructors: Housner, Vreeland.

AM 98 abc. Analytical Dynamics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 1 abc, Ma 2 abc.* The classical mechanics of particles, groups of particles and rigid bodies studied on the basis of Hamilton's principle and Newton's laws of motion; conservation principles; central force problems; Lagrange's and Euler's equations; vibrating systems with one and many degrees of freedom, including the general normal mode theory; dynamics of rigid bodies. Instructors: Caughey, Hudson, Iwan.

ADVANCED SUBJECTS

AM 101 abc. Nuclear Reactor Theory. *9 units (3-0-6); each term. Prerequisite: AM 95 abc or equivalent.* Neutron chain reactions and the criticality condition; the slowing down of neutrons in an infinite medium; one-speed diffusion of neutrons in multiplying and non-multiplying systems; combined slowing down and diffusion; bare and reflected homogeneous reactors; effects of heterogeneity; time dependent behavior of reactors; control rod theory; elements of transport theory. Instructors: Lurie, Shapiro.

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

AM 103 a. Nuclear Radiation Measurements Laboratory. *9 units (1-4-4); second term. Prerequisite: Ph 2 abc.* A one-term laboratory course designed to familiarize students with basic nuclear detecting and measuring techniques. The instruments are used to determine the properties of various types of radiation and to observe the nature of their inaction with matter. Instructor: Shapiro.

AM 103 b. Nuclear Energy Laboratory. *9 units (1-4-4); third term. Prerequisites: AM 103 a, AM 101 (may be taken concurrently.)* Measurements associated with nuclear reactor parameters are made. Steady state neutron flux distributions in moderators and in a subcritical assembly are analysed. Dynamic techniques are also employed with the use of a pulsed neutron generator. Instructor: Shapiro.

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

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

AM 110 a. Introduction to the Theory of Elasticity. *6 units (2-0-4); first term. Prerequisite: AM 95 abc.* Fundamental concepts of elasticity theory. Equations of stress equilibrium and strain compatibility. Solution of two-dimensional problems. Photoelastic method of stress measurements. Analysis of stress and strain in three dimensions. Solution of torsion problems. Wave propagation in elastic solids. Instructor: Housner.

AM 110 b. Theory of Plates and Shells. *6 units (2-0-4); second term. Prerequisite: AM 95 abc.* Simplifications introduced in elastic theory. Laterally loaded plates with various boundary conditions. Elastic stability of plates. Membrane theory of shells. General theory of shells. Instructor: Housner.

AM 110 c. Mechanics of Materials. *6 units (2-0-4); third term. Prerequisite: AM 110 a.* Use of tensors in elastic theory. Nonlinear stress-strain relations. Theory of plasticity. Theories of failures of stressed materials. Instructor: Housner.

AM 111. Experimental Stress Analysis. *9 units (1-6-2); second term. Prerequisite: AM 97 abc or equivalent.* Static and dynamic stress and strain measurements, including the use of piezoelectric materials; wire resistance strain gages; mechanical, optical, inductance, and capacitance displacement gages; photoelastic materials; brittle lacquer coatings; X-rays, and associated instrumentation and recording systems. Instructors: Staff.

AM 113 abc. Engineering Mathematics. *9 units (4-0-5); second and third terms. For graduate students only. Prerequisites: Ma 1 abc, Ma 2 abc, or equivalent.* A course for graduate students who have not had the equivalent of AM 95 abc. Emphasis is placed on the setting up of problems as well as their mathematical solution. The topics studied include: vector analysis, ordinary differential equations emphasizing power series solutions; special functions such as the Bessel functions and Legendre functions; partial differential equations and boundary value problems, with emphasis on application of series of orthogonal functions; and an introduction to transform methods. Text: *Differential Equations Applied in Science and Engineering,* Wayland. Instructors: Knowles, Wayland, and staff.

AM 116. Complex Variables and Applications. *12 units (4-0-8); first term and third terms. Only six units credit for those students who have completed or are simultaneously enrolled in Ma 108. Prerequisites: Ma 1 abc, Ma 2 abc, or equivalent.* A basic introduction to analytic functions of a complex variable. Emphasis is placed on application of conformal mapping to boundary value problems and on techniques and applications of contour integration. Text: *Introduction to Complex Variables and Applications,* Churchill. Instructors: Knowles, Wayland, and staff.

AM 125 abc. Engineering Mathematical Principles. *9 units (3-0-6); each term. Prerequisites: AM 95 abc* or *AM 113 ab, AM 116,* or *Ma 108,* or *equivalent.* Nonlinear first-order ordinary differential equations; ordinary linear differential equations of second order, Sturm-Liouville theorems, Green's functions, asymptotic expansions and method of steepest descent; integral transform theory; partial differential equations of first and second order; applications to vibrations, elasticity, acoustic and electromagnetic wave propagation, kinetic theory and fluid mechanics problems. Instructors: Fung, L. Lees.

AM 130 abc. Introduction to Classical Theoretical Physics I. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 95 abc, or equivalent.* Analytical mechanics, heat conduction, thermodynamics, kinetic theory of gases, transport theory, statistical mechanics. Instructors: (by terms) Plesset, Plesset, Wu.

AM 131 abc. Introduction to Classical Theoretical Physics II. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 95 abc, or equivalent.* Principles of continuum mechanics, electrodynamics, special relativity. Instructors: (by terms) Wu, Hsieh, Hsieh.

AM 140 abc. Plasticity. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 95 abc, AM 110 ac.* Yield criteria and stress-strain relations for perfectly plastic and strain-hardening materials; stable materials; uniqueness theorems. Plastic torsion and bending. Plane strain theory and problems of incipient flow for metals and soils. Axially symmetric problems. Limit analysis theorems and applications. Plasticity theories for beams, plates, and shells. Minimum weight design. Instructor: Shield.

AM 141 abc. Wave Propagation in Solids. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 95 abc, AM 110 a.* Theory of wave propagation in solids with applications to problems. Waves in the infinite and semi-infinite elastic medium. Problems of wave scattering and diffraction. Dispersion of waves in bounded, elastic solids. Exact and approximate linear elasticity theories governing waves in rods, beams, plates and shells. Use of integral and multi-integral transforms and related techniques, to derive exact and approximate transient elastic wave solutions. Introduction to theory of waves in viscoelastic and plastic media. Instructor: Miklowitz.

AM 150 abc. Mechanical Vibrations. *6 units (2-0-4); first, second, and third terms. Prerequisites: AM 95 abc, or permission of the instructor.* Theory of vibrating systems with applications to problems of structural dynamics and mechanical design. Theory of resonant vibration, energy dissipation in vibrating systems, periodic and transient exciting forces, random exciting forces, general normal mode theory based on Lagrange's equations, matrix methods in vibration problems, wave propagation techniques, vibrations in continuous systems, methods of nonlinear analysis, including perturbation techniques, Kryloff-Bogoliuboff methods, and topological approaches. Nonlinear resonance theory, including subharmonic and ultraharmonic vibrations and studies of stability in nonlinear systems. Instructors: Caughey, Hudson, Iwan.

AM 155. Dynamic Measurements Laboratory. *9 units (1-6-2); first term.* Experimental studies of the behavior of dynamic systems, using the latest electric analog techniques. Free oscillations, and steady state and transient-forced oscillations of linear and nonlinear systems are considered. Instructors: Caughey, Hudson, Iwan.

AM 160. Vibrations Laboratory. *6 units (0-3-3); second term. Prerequisite: AM 150 abc, or permission of the instructor.* Experimental analysis of typical problems in structural dynamics and mechanical vibrations. Measurement of strains, accelerations, frequencies, etc., in vibrating systems, and the interpretation of the results of such measurements. Consideration is given to the design, calibration, and operation of the various types of instruments used for the experimental study of dynamics problems. Instructors: Caughey, Hudson, Iwan.

AM 174 abc. Advanced Dynamics I. *6 units (2-0-4). Prerequisites: AM 125 abc and AM 150 abc or equivalents.* The first two terms will cover advanced topics in linear and nonlinear vibration theory. The third term will be devoted to noise and stochastic processes applied to vibration problems. This course will be given every other year to alternate with AM 176. Offered in 1964-65. Instructor: Caughey.

AM 176 abc. Advanced Dynamics II. *6 units (2-0-4). Prerequisites: AM 125 abc and AM 150 abc or equivalents.* The first term will be devoted to topics in acoustics. The second and third terms will cover topics in stability and control of dynamic systems. This course will be given every other year to alternate with AM 174. Instructor: Caughey.

AM 200. Special Problems in Advanced Mechanics. Dynamics of solid and deformable bodies, fluids, and gases; mathematical and applied elasticity. By arrangement with members of the staff, properly qualified graduate students are directed in independent studies. Hours and units by arrangement.

AM 201 abc. Advanced Reactor Theory. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 101 abc and AM 102 abc, or equivalent.* The neutron transport equation. Slowing-down problems: resonance escape and thermalization problems. Mono-energetic diffusion; the Milne problem. Non steady state problems; pulsed neutrons and reactor kinetics. Numerical solutions; digital computer codes for diffusion problems. Instructor: Leonard.

AM 204 abc. Hydrodynamics of Free Surface Flows. *9 units (3-0-6); each term. Prerequisites: Hy 101 abc, AM 125 abc and AM 116, or equivalent.* Theory of surface waves in a liquid; initial value problems and boundary value problems. Wave pattern due to moving disturbances. Wave resistance of a floating or submerged body. Theory of thin ships. Lifting surfaces in flows having a free surface: planing surfaces, hydrofoils. Theory of tidal waves. The mathematical method of characteristics will be applied to the problems of the flow in open channels, river waves and flood waves. Free boundary theory; theories of physical cavity flows. Dynamics and stability of vapor bubbles in a liquid. Water entry problems. Given in alternate years. Offered in 1966-67. Instructor: Wu.

AM 205 abc. Theory of Solids. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 112 abc or equivalent.* Thermal properties of solids. Theory of conduction and optical properties. One electron formulation of the many body problem. Theory of cohesion. Bardeen-Cooper-Schriever theory of superconductivity. Instructor: Willens.

AM 250 abc. Research in Applied Mechanics. Research in the field of Applied Mechanics. By arrangement with members of the staff, properly qualified graduate students are directed in research. Hours and units by arrangement.

ASTRONOMY

UNDERGRADUATE SUBJECTS

Ay 1. Introduction to Astronomy· *9 units (3-1-5); third term.* This course surveys astronomy, spectroscopy and astrophysics. Reading in an elementary text is supplemented by lectures on current topics, emphasizing the applications of physics in astronomy. Instructor: Greenstein.

ADVANCED SUBJECTS

Ay 108 ab. Astronomical Instruments and Radiation Measurement. *9 units (3-1-5), (3-2-4); first and second terms.* The use of the photographic plate as a scientific instrument; quantitative techniques in laboratory photography. Astronomical optics. Theory of reflectors, schmidts and spectrographs. Photoelectric detectors, amplifiers. Photometric systems and their applications. Given alternate years. Not given in 1965-66.

Ay 112 abc. General Astronomy. *9 units (3-3-3); first, second and third terms. Prerequisites: Ph 2 abc, Ma 2 abc.* The planets, the sun and solar-terrestrial relations. Physical properties of the stars and the spectral sequence. Binary and variable stars. Dynamics of the galaxy, extragalactic nebulae. Introduction to astrophysics of stellar interior and atmospheres. Instructors: Münch, Greenstein, Zirin.

Ay 131 ab. Stellar Atmospheres. *9 units (3-0-6); first and second terms. Prerequisites: Ay 112 abc, Ph 112 abc, or equivalents.* Atomic spectroscopy. The theory of radiative equilibrium in stellar asmospheres. The continuous spectrum of the stars; the line absorption coefficient and spectral lines. Line broadening theory. Analysis of stellar spectra. Abundances of the elements and nucleosynthesis theory. Given alternate years. Not given in 1965-66.

Ay 132 ab. Stellar Interiors. *9 units (3-0-6); first and second terms. Prerequisites: Ay 112 abc, Ph 112 abc, or their equivalents.* Introduction to the study of stellar interiors; polytropes; opacity and energy generation. Stellar models. Red giants and white dwarfs. Stellar evolution. Pulsating stars. Instructor: Oke.

Ay 133 ab. Radio Astronomy. *9 units (3-0-6); second and third terms.* For seniors and graduate students. Radio measurements of the flux and brightness of celestial radio sources. Principles of receivers, antennae and interferometers. Solar noise, bursts, the normal and disturbed sun. Theory of thermal emission. Galactic noise. Theory of non-thermal emission, cosmic rays. Discrete sources and their identification. The 21-cm hydrogen line in absorption and emission and galactic structure. Instructors: Schmidt, Scheuer.

Ay 135. Topics in Modern Observational Astronomy. *6 units (1-4-1); first term.* Seminar and laboratory course for graduate students on modern observational techniques and methods for reducing data. Instructors: Greenstein, Oke.

Ay 136. Solar System Astronomy. *9 units (3-0-6); first term.* Structure of planets and satellites. Interpretation of colorimetric, radiometric and spectroscopic observations. Composition and thermal balance of planetary atmospheres. Interplanetary matter and fields. Comets. Cosmogonical theories. Not given in 1965-66.

Ay 140 abc. Seminar in Astrophysics. *4-12 units; first, second, and third terms.* Discussions on the large-scale distribution of matter in the universe, statistics of the distribution of nebulae and clusters of nebulae. Morphology of nebulae. Theory and discussion of observational data on stars of special interest, such as supernovae, white dwarfs, variable stars, and emission line stars. Practical work of reduction of data obtained with the Schmidt telescopes on Palomar Mountain. Meetings throughout the year according to agreement. Instructor: Zwicky.

Ay 141 abc. Research Conference in Astronomy. *2 units; first, second, and third terms.* Meets weekly to discuss work in progress in connection with the staff of the Mount Wilson and Palomar Observatories.

Ay 142. Research in Astronomy, Radio Astronomy, and Astrophysics. *Units in accordance with the work accomplished.* The student should consult a member of the department and have a definite program of research outlined with him before registering. Eighteen units required for candidacy.

Ay 202. The Solar Atmosphere. *9 units (3-1-5); second term.* The physical state of the solar atmosphere as derived from observations. Solar activity, flares, and magnetic fields. Deviations from local thermodynamic equilibrium in atomic processes. Instructors: Zirin, Howard.

Ay 203. Hydrodynamic and Magnetohydrodynamic Problems in Astrophysics. *9 units (3-0-6); second term.* The terrestrial magnetosphere, the interplanetary plasma and magnetic fields. Solar problems; heating mechanisms in the chromosphere and corona. The interstellar plasma and magnetic fields. Magnetic stars. Instructor: Lüst.

Ay 208. Modern Observational Astronomy. *6 units (1-5-0); first, second or third term. Prerequisites: Ay 135 which may be taken concurrently.* An observational course for graduate students in astronomy in which modern astronomical techniques are used in conjunction with the various telescopes and auxiliary instruments on Mount Wilson and at Palomar. Students will be permitted to register for only one term. Instructor: Oke.

Ay 210. Interstellar Matter. *9 units (3-0-6); second term.* The interstellar gas and dust. Reddening, absorption and polarization of light. Interstellar absorption lines. Ionized and neutral regions. Excitation of emission lines. The dynamics of gas clouds. Star formation. Instructor: Münch.

Ay 211. Stellar Dynamics and Galactic Structure. *9 units (3-0-6); third term.* Dynamical and kinematical description of stellar motions. Galactic rotation and the density distribution. Dynamics of clusters; relaxation times. Structure and mass of the galaxy and external systems. Instructor: Schmidt.

Ay 215. Seminar in Theoretical Astrophysics. *4 units (1-0-3). Prerequisites: Ay 131 and/or Ay 132.* Seminar on recent developments for advanced students. The current theoretical literature will be discussed by the students.

Ay 217. Theoretical Astrophysical Spectroscopy. *9 units (3-0-6); first term. Prerequisite: Ph 125, or equivalent.* Fundamentals of atomic spectra; angular momentum and Racah coefficients. Calculation of transition probabilities and collision cross-sections. Forbidden lines. Instructor: Zirin.

Ay 234. Seminar in Radio Astronomy. *8 units (2-0-6); second term. Prerequisite: Ay 133 ab.* Recent developments in radio astronomy for the advanced student. Current publications and research in progress will be discussed by students and staff. Given alternate years. Not given in 1965-66.

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

Ay 204. Advanced Stellar Spectroscopy.

Ay 206. Variable Stars.

Ay 207. Stellar Luminosities and Colors.

Ay 209. Planetary and Diffuse Nebulae.

Ay 212. Content and Evolution of Our Own and Other Galaxies.

Ay 213. Selected Topics in Observational Cosmology.

Ay 214. Theoretical Cosmology.

Ay 216. Advanced Stellar Interiors.

BIOLOGY

UNDERGRADUATE SUBJECTS

Bi 1. Elementary Biology. *9 units (3-3-3); second term.* A study of the organism as a structural and functional entity, and of the relation of biological problems to human affairs. Instructors: Sinsheimer, and staff.

Bi 3. Plant Biology. *12 units (3-6-3); second term. Prerequisite: Bi 1, Bi 9, or consent of instructor.* Principles of plant structure, plant diversity, and plant function. Instructor: Bonner.

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: Delbrück, and staff.

Bi 10. Animal Biology: *12 units (3-6-3); first term.* Principles of animal structure, function, and diversity. Instructor: Brokaw.

Bi 20. Mammalian Anatomy and Histology. *12 units (2-6-4); third term.* Macroscopic and microscopic structure of a mammal, including elementary instruction in preparation of tissue for microscopic inspection. Instructors: van Harreveld, Keighley.

Bi 22. Special Problems. *Units to be arranged; first, second, and third terms.* Special problems in one of the fields represented in the undergraduate biology curriculum; to be arranged with instructors before registration. Instructors: Biology teaching staff.

ADVANCED SUBJECTS

[A] Subjects open to graduate students, but not to be counted toward a major for the degree of Doctor of Philosophy.

Bi 106. Introductory Developmental Biology of Animals. *12 units (2-6-4); third term. Prerequisite: Bi 10.* A lecture and laboratory course dealing with the development of various invertebrate and vertebrate animals, with emphasis on their common features as well as specialized adaptations. Principles and properties of developing systems are further illustrated by experimental embryological exercises and discussions. Instructor: Tyler.

Bi 107 abc. Biochemistry. *10 units (3-0-7; 3-0-7; 0-8-2); first, second and third terms. Prerequisites: Ch 41.* A lecture and laboratory course on the chemical constitutions and chemical changes that characterize living matter. In the third quarter emphasis is placed on laboratory work concerned with principles and methods in current use. Instructors: Borsook, Mitchell, Wood.

Bi 109. Advanced Genetics Laboratory. *Units to be arranged; second term.* An advanced laboratory course in the genetics of Drosophila. Instructor: Lewis.

Bi 114. Immunology. *9 units (2-4-3); first term. Prerequisite: Ch 41 abc.* A course on the principles and methods of immunology and their application to various biological problems. Instructor: Owen.

Bi 117. Psychobiology 1. *9 units (2-4-3); third term.* An introduction to study of the brain and behavior. May be taken with or without laboratory. The laboratory provides a study of the vertebrate nervous system. Offered in alternate years according to demand. Instructor: Sperry.

Bi 118. General Physiology. *10 units (3-3-4); first term.* A lecture and laboratory course on selected topics like nervous excitation and conduction, synaptic transmission, inhibition, muscle contraction, sense organ physiology, etc. Instructors: Strumwasser, van Harreveld, Wiersma.

Bi 119. Advanced Cell Biology. *12 units (3-4-5); second term. Prerequisites: Bi 9, Bi 107.* This course covers the principles of general microbiology and of the growth and differentiation of the cells of higher organisms. Regulatory circuits in nucleic acid and protein synthesis; mechanisms of control of enzyme activity; regulation of cell multiplication; surface properties of cells. Instructor: Attardi.

Bi 120. Mammalian Anatomy and Histology. *9 units; third term.* This subject is the same as Bi 20 but with reduced credit for graduate students. Graduate students majoring in Biology receive no credit for this subject. Instructors: Keighley, van Harreveld.

Bi 121. Bio-Systems Analysis. *6 units (2-0-4); first, second, and third terms. Same as EE 185 abc.* This course presents a systematic consideration and application of the methods of systems analysis, information theory and computer logic to problems in neurobiology. The subjects to be considered include the mechanical properties of striated muscle, the analysis of neuronal integrative mechanisms and reflex behavior in terms of logical net theory. The course will seek to describe some aspects of human cortical activity in terms of information theory and conceptual modeling. The course will be conducted as a research seminar and the detailed subject matter will change from year to year. Instructors: Fender, and staff.

Bi 122 Genetics. *10 units (3-3-4); first term. Prerequisite: Bi 1 or Bi 9.* A course presenting the fundamentals of genetics in relation to general biological problems. Instructor: Lewis.

Bi 126. Genetics of Microorganisms. *10 units (2-4-4); second term. Prerequisite: Bi 122.* The genetics of algae, fungi, protozoa, and bacteriophage with laboratory work to illustrate the suitability of different microorganisms to particular kinds of genetic analysis. Instructors: Edgar, Emerson, and staff.

Bi 127. Biochemical Genetics. *10 units (2-4-4); third term. Prerequisites: Bi 122 and Bi 126.* A course dealing with gene action at the molecular and cellular levels. Topics covered include genetic control of metabolism and biosynthetic pathways, genetic determination of protein structure, gene-enzyme relationships, genetic control mechanisms, suppressors, and complementation. May be taken without the laboratory, for reduced credit, with permission of instructor. Instructor: Horowitz.

Bi 128. Advanced Microtechnique. *6 units (1-4-1); third term.* Theory and practice of preparing biological material for microscopic examination; histochemical methods; phase contrast microscopy; methods in electron microscopy. Instructor: Tyler.

Bi 129 ab. Biophysics. *6 units (2-0-4); first and second terms.* The subject matter to be covered will be repeated approximately in a three-year cycle. During the first term the subject matter will be organized according to various biological functions, such as replication, contractility, sensory processes, endogenous rhythms, etc. Each function will be discussed in its various biophysical aspects. During the second term the subject matter will be organized according to methods of research. This course together with Bi 132 constitutes an integrated program covering the physical and physico-chemical approaches to biology. Instructor: Delbrück.

Bi 132 ab. Biophysics of Macromolecules. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 or equivalent.* A study of the structure and properties of biological macromolecules. Emphasis is placed on both the methods of investigation and the results. Topics covered include: polymer statistics and thermodynamics, sedimentation, light scattering, spectroscopy, X-ray diffraction, and electron microscopy. Offered 1964-65 and alternate years. Instructors: Davidson, Hodge, Sinsheimer, Vinograd.

Bi 133. Biophysics of Macromolecules Laboratory. *14 units (0-10-4); second term.* A laboratory course designed to provide an intensive training in the techniques for the characterization of biological macromolecules. Open to selected students. Instructor: Vinograd.

[B] Subjects primarily for graduate students.

Bi 201. General Biology Seminar. *1 unit; all terms.* Meets weekly for reports on current research of general biological interest by members of the Institute staff and visiting scientists. In charge: Haagen-Smit, Sinsheimer, Wiersma.

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

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

Bi 205. Experimental Embryology Seminar. *1 unit; all terms.* Reports on special topics in the field; meets twice monthly. In charge: Tyler.

Bi 206. Immunology Seminar. *1 unit; all terms.* Reports and discussions. In charge: Owen, Tyler.

Bi 207. Biophysics Seminar. *1 unit; all terms.* A seminar on the application of physical concepts to selected biological problems. Reports and discussions. Open also to graduate students in physics who contemplate minoring in Biology. Instructor: Sinsheimer.

Bi 214 abc. Chemistry of Bio-Organic Substances. *3 units (1-0-2); first, second, and third terms. Prerequisite: Ch 41 abc.* A series of lectures on selected topics of organic chemistry that have special interest from a biological viewpoint. Instructor: Haagen-Smit.

Bi 217. Quantitative Organic Microanalysis. *Units to be arranged; second term.* Laboratory practice in the methods of quantitative organic microanalysis required for structure determination of organic compounds. Students must obtain permission from the instructor before registering for this subject as the enrollment is necessarily limited. Instructor: Haagen-Smit.

Bi 218. Virology. *9 units (2-3-4); second term. Prerequisite: Bi 119.* Virus classification and structure; biochemical mechanisms of virus reproduction; host-virus relationships in the framework of cell regulatory mechanisms; virus-determined changes in the physiological properties of the host cell. Not offered in 1965-66. Instructors: Attardi, and staff.

Bi 220 abc. Developmental Biology of Animals. *6 units (2-0-4); first, second, and third terms.* Lectures and discussion of biological and chemical problems and principles of embryonic development of animals, with reference to correlative studies on other organisms. Topics covered include: origin of the germ cells, maturation of the gonads, spermatogenesis and oogenesis, breeding habits, endocrinological influences, fertilization, cleavage, germ layer and organ formation, processes of embryonic determination and induction, specific protein biosynthesis, embryonic metabolism, cell-interactions and properties of cultured cells, metamorphosis, regeneration, etc. The course may be taken for 5 consecutive terms since the subject matter will be duplicated only in alternate years. Instructor: Tyler.

Bi 221. Developmental Biology Laboratory. Units to be arranged; all terms. A laboratory course designed to give the student first-hand experience with biological and chemical methods of study and experimentation with developing animals. Included are methods of cell isolation, transplantation, cytochemistry, protein biosynthesis, micromanipulation, metabolism, etc. Instructor: Tyler.

Bi 230. Psychobiology 2. *Units to be arranged. First, second, and third terms. Prerequisite: consent of instructor.* An advanced course on the neural organization of behavior. Instructor: Sperry.

Bi 240 abc. Plant Physiology. *6 units (2-0-4); first, second, and third terms.* Reading and discussion of the problems of plant physiology. Instructors: Bonner, Lang.

Bi 241 abc. Advanced Biochemistry. *6 units (2-0-4); first, second, and third terms.* Detailed discussions of biochemical topics on an advanced level. Instructors: Bonner, Dreyer.

Bi 260. Advanced Physiology. *Units to be arranged. Second term.* A course in the methods of physiology, with special reference to nerve and muscle, with opportunity for research. Instructors: Strumwasser, van Harreveld, Wiersma.

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

Bi 280-290. Biological Research. *Units to be arranged. First, second, and third terms.* Students may register for research in the following fields after consultation with those in charge: Animal physiology (280), biochemistry (281), bio-organic chemistry (282), embryology (283), genetics (284), immunology (285), marine zoology (286), plant physiology (287), biophysics (288), psychobiology (289).

Chemical Engineering

UNDERGRADUATE SUBJECTS

ChE 50. Applications of Chemistry. *9 units (3-0-6); second term.* Selected problems in fields such as fuel cells, saline water recovery, fluidized catalytic cracking, and manufacture of rocket fuels are used as case histories in the application of physics, mathematics, chemistry, and economics to current problems in industrial chemistry. Instructor: Corcoran.

ChE 61 ab. Industrial Chemistry. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 abc.* A critical study is made of selected chemical process industries in order to give the student a better understanding of the direct application of basic chemical engineering principles. Emphasis is placed on his learning to use good judgment in applying the principles of material and energy balances, thermodynamics, chemical reaction kinetics, and economics. The student is also given the opportunity to design a new chemical process or critically discuss an existing one in the form of one or more technical reports. Instructor: Cokelet.

ChE 63 ab. Introduction to Thermodynamics. *9 units (3-0-6); first term; 6 units (2-0-4); second term.* Basic thermodynamic laws and expressions for one-component closed systems and for simple steady-flow systems. The treatment includes imperfect substances and frictional processes. Text: *Thermodynamics of One-Component Systems,* Lacey and Sage. Instructor: Pings.

ChE 64. Applied Chemical Thermodynamics. *9 units (3-0-6); third term.* Introduction to the thermodynamics of open multicomponent systems. Special emphasis on chemical equilibria, including computation of yield and displacement of equilibria by changes in temperature and pressure. Brief consideration of optimization and dynamic response of systems at chemical equilibrium. Instructor: Pings.

ChE 66 ab. Transport Phenomena. *12 units (3-0-9); first, second terms. Prerequisite: AM 95 abc.* An introduction to momentum transfer, energy transfer, and mass transfer as applied to chemical engineering problems. Both microscopic and macroscopic phenomena are treated, and emphasis is on the quantitative application of the basic equations of change to situations occurring in the process industry. Text: *Transport Phenomena,* Bird, Stewart, and Lightfoot. Instructor: Seagrave.

ChE 67 ab. Chemical Engineering Laboratory. *9 units (0-7-2); second, third terms. Prerequisites: ChE 63 ab, ChE 66 a.* Training and practice in the methods of chemical engineering laboratory measurements. Several short projects, illustrative of problems in transport phenomena, unit operations, and chemical kinetics, are carried out. Instructor: Shair.

ChE 73. Unit Operations. *12 units (3-0-9); third term. Prerequisite: ChE 66 ab.* A sequel to ChE 66, with special emphasis on multi-stage and equilibrium operations, along with an introduction to the empirical and graphical methods applicable to unit operations problems. Instructor: Seagrave.

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.

ChE 81. Special Topics in Chemical Engineering. *Units by arrangement.* Occasional advanced work involving reading assignments and a report on special topics. Permission of the instructor is required. No more than 12 units in ChE 81 may be used to fulfill elective requirements in the Chemical Engineering Option.

ADVANCED SUBJECTS

ChE 101 ab. Applied Chemical Kinetics. *9 units (2-0-7); second, third terms.* Homogeneous and heterogeneous kinetics are studied with applications to chemical reactions of current interest. Special emphasis is given to transition state theory, reaction models in heterogeneous catalysis, and the roles of energy and material transfer in both homogeneous and heterogeneous reactions. Flow and nonflow systems are studied. Instructor: Corcoran.

ChE 102. Applied Physical Chemistry. *9 units (2-0-7); first term.* Detailed consideration is given to the application of the principles of chemical equilibria and chemical kinetics to problems in electrochemistry, plasmas, phase equilibria in solid and liquid systems, hydrocarbon reforming, and other topical areas. Instructor: Corcoran.

ChE 103 abc. Advanced Transport Phenomena. *9 units (2-0-7) first term; 12 units (3-0-9) second, third terms. Prerequisites: ChE 66 ab, ChE 73, AM 95 abc, or taking AM 113 ab concurrently.* A study of the transfer of momentum, energy, and material in situations of practical interest. Emphasis is placed on the derivation of the applicable differential equations and solution to determine the distributions of velocity, pressure, temperature, and composition, and the fluxes of momentum, energy, and material in fluid systems. Both laminar and turbulent flow are considered. Instructors: Gavalas, Sage, Cokelet.

ChE 104 ab. Thermodynamics of Multicomponent Systems. *9 units (2-0-7); first, second terms. Prerequisites: ChE 63 ab, AM 95 abc, or taking AM 113 ab concurrently.* A discussion from the quantitative standpoint of the volumetric and phase behavior of pure substances and of binary, ternary, and multicomponent fluid systems at physical and at physicochemical equilibrium is presented. Development of the background necessary for a working knowledge of multicomponent open systems of particular interest to the engineer follows. The solution of problems relating to the application of multicomponent thermodynamics to industrial practice is an important part of this course. Texts: *Volumetric and Phase Behavior of Hydrocarbons,* Sage and Lacey; *Thermodynamics of Multicomponent Systems,* Sage. Instructor: Sage.

ChE 163 ab. Introduction to Thermodynamics. *6 units (3-0-3) first term; 4 units (2-0-2) second term.* This subject is the same as ChE 63 ab, but with reduced credit for graduate students. No graduate credit is given for this subject to students in chemical engineering.

ChE 166 ab. Transport Phenomena. *8 units (3-0-5); first, second terms. Prerequisite: AM 95 abc, or taking AM 113 ab concurrently.* This subject is the same as ChE 66 ab, but with reduced credit for graduate students. No graduate credit is given for this subject to students in chemical engineering.

ChE 167 abc. Introduction to Chemical Engineering Research. *15 units (0-12-3); first, second, third terms.* A course for Master's degree students in chemical engineering providing instruction and experience in the methods and techniques of research. The first term is devoted to short projects illustrating typical research and measurement problems in chemical engineering. During the second and third terms each student works on an individual research project under the direction of a member of the staff. Instructor: Shair.

ChE 170. Chemical Process Control. *9 units (3-0-6); third term. Prerequisite: AM 113 ab (may be taken concurrently).* A treatment of the dynamic response and control of process elements and systems in chemical engineering. Emphasis is on the analysis, design, and stability of control systems. Instructor: Gavalas.

ChE 171 ab. Chemical Engineering Applied Mathematics. *9 units (2-0-7); first, second terms. Prerequisite: AM 95 abc or AM 113 ab.* A course in the mathematical treatment of physical and chemical problems arising in chemical engineering. Laplace transformation and inversion by elementary methods and by contour integration. Solution of boundary value problems by eigenfunction expansions. Elements of matrix theory. Finite differences and the numerical solution of ordinary and partial differential equations. Concepts of probability and statistical treatment of data. Instructor: Friedlander.

ChE 173. Unit Operations. *8 units (3-0-5); third term. Prerequisite: 166 ab.* This subject is the same as ChE 73, but with reduced credit for graduate students. No graduate credit is given for this subject to students in chemical engineering.

ChE 201. Chemical Reactor Design. *9 units (2-0-7); first term. Prerequisites: ChE 66 ab, ChE 101 ab.* Detailed consideration is given to the design of chemical reactors with emphasis on optimization, stability, and the role of simultaneous energy, material, and momentum transport. Significant design problems are solved by use of high-speed digital computing equipment available at the Computing Center. Instructor: Corcoran.

ChE 202. Advanced Problems in Transport. *9 units (2-0-7); third term. Prerequisite: ChE 103 abc.* Problems of some complexity of a quasi-research nature will be solved by group effort in the fields of material, thermal, and momentum transport. The field of interest to the student will be taken into account in establishing the problem or problems to be solved. Primary emphasis will be placed upon the synthesis of the student's background knowledge to arrive at an adequate solution to an engineering problem of some difficulty. Instructor: Sage.

ChE 264 ab. Molecular Theory of Fluids. *9 units (3-0-6); first, second terms.* A study of the models and mathematical theories of the gaseous and liquid states. The rigorous kinetic theory of equilibrium and transport properties of dilute gases is presented. Models of the liquid state are discussed and their limitations noted. An introduction is given to the use of high-speed computers for the random walk estimation of transport coefficients and for Monte Carlo analysis of the many-body problem. Some emphasis is placed on the prediction of macroscopic properties from molecular parameters. Given by arrangement. Instructor: Pings.

ChE 280. Chemical Engineering Research. Offered to Ph.D. candidates in chemical engineering. The main lines of research now in progress are:

Turbulent heat transfer.
Turbulent mass transfer.
Phase and thermodynamic behavior of fluids.
Measurements of transport coefficients.
Reaction kinetics and mechanisms.
Combustion.
Applied mathematics.
Liquid state physics.
Rheology and flow of suspension, and emulsions.
Optimization and stability studies.
Mechanics of dispersions.
Plasma chemistry.

ChE 291 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. Instructor: Corcoran.

CHEMISTRY

UNDERGRADUATE SUBJECTS

Ch 1 abc. General and Quantitative Chemistry. *12 units (3-6-3); first, second, third terms.* Lectures, recitations, and laboratory exercises dealing with the general principles of chemistry. Fundamental laws and theories of chemistry are discussed and illustrated by factual material. In the first and second terms of the laboratory, analytical experiments involving quantitative gravimetric, volumetric, optical, electrical, and radiochemical measurements are provided; in the third term, use is made of a system of qualitative and semiquantitative analysis for selected elements representative of the periodic system. The stress in the course is on quantitative reasoning and on accurate and intelligent work in the laboratory. Texts: *Quantitative Chemistry,* Waser; *Qualitative Elemental Analysis,* Swift and Schaefer. Instructors: Waser, Schaefer, other staff members, and assistants.

Ch 14. Quantitative Analysis. *10 units (2-6-2); first term. Prerequisite: Ch 1 abc or equivalent.* Laboratory instruction in advanced analytical chemical measurements, supplemented by lectures in which the principles involved in the laboratory work are emphasized. Text: *Chemical Analysis,* Laitinen. Instructors: Anson, Swift.

Ch 16. Chemical Instrumentation. *8 units (0-6-2); first term. Prerequisite: Ch 1 abc.* Laboratory practice designed to familiarize the student with selected instruments, used both for process and control and for research. Not offered in 1965-66. Instructor: Sturdivant.

Ch 21 abc. Physical Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 abc; Ph 2 abc; Ma 2 abc.* A lecture and recitation course. The main emphasis is on the principles of statistical mechanics, thermodynamics, and atomic and molecular theory, and their application to the quantitative interpretation of the properties of matter. Instructors: Kuppermann, Dickerson.

Ch 24 abc. Elements of Physical Chemistry. *10 units (4-0-6); first, second, third terms. Prerequisites: Ch 1 abc; Ma 2 abc; Ph 2 abc.* The first two terms cover classical thermodynamics from the chemical point of view and its application to thermochemistry, to homogeneous and heterogeneous equilibria, to the colligative properties of solutions, and to cell potentials; chemical crystallography. The third term will consider steady-state thermodynamics and its application to electrical and material transport phenomena; chemical kinetics. Ch 24 ab is not open to undergraduates majoring in chemistry. Instructor: Hughes.

Ch 26 ab. Physical Chemistry Laboratory. *8 units (0-6-2); second, third terms. Prerequisites: Ch 1 abc; Ch 21 a.* Laboratory exercises which provide both illustrations of classical principles in physical chemistry and an introduction to problems of current interest, and techniques of contemporary research. Text: *Experiments in Physical Chemistry,* Badger. Instructors: Badger, Chan.

Ch 41 abc. Chemistry of Covalent Compounds. *4 units (2-0-2); first, second, third terms. Prerequisite: Ch 1 abc.* The chemistry of covalent compounds, emphasizing molecular structure, chemical dynamics, and synthesis. Most examples will be drawn from organic chemistry but inorganic compounds will also be treated when appropriate. Special emphasis will be accorded spectroscopic methods for study of structural and dynamic problems. Text: *Basic Principles of Organic Chemistry,* Roberts and Caserio. Instructors: Roberts, Hammond.

Ch 46 abc. Experimental Methods of Covalent Chemistry. *6 units (1-5-0); first, second, third terms. Prerequisites: 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. Instructors: Richards and assistants.

Ch 80. Chemical Research. *Offered to B.S. candidates in chemistry.* If Ch 80 units are to be used as electives in the Chemistry Option, a thesis must be submitted in duplicate before May 10 of the year of graduation and be approved by the research director. The thesis must contain a statement of the problems, appropriate background material, a description of the research work, a discussion of the results, conclusions, and an abstract. The thesis may cover only a portion of the research. No more than 60 units of undergraduate research may be used as electives in the Chemistry Option without special permission.

Ch 81. Special Topics in Chemistry. Occasional advanced work involving reading assignments and a report on special topics. Permission of the instructor is required. No more than 12 units in Ch 81 may be used as electives in the Chemistry Option.

Ch 90. Oral Presentation. *2 units (1-0-1); first term.* Training in the technique of oral presentation of chemical topics. Practice in the effective organization and delivery of reports before groups. Instructors: Corey, Booth.

ADVANCED SUBJECTS

Ch 113. Advanced Inorganic Chemistry. *9 units (3-0-6); third term. Prerequisite: Ch 21 abc.* An introduction to modern concepts of inorganic chemistry, including electronic structures, molecular structures, and reactivities of typical inorganic molecules. Not offered in 1965-66.

Ch 117. Electroanalytical Chemistry. *4 units (2-0-2); second term.* The theory and practice of selected electroanalytical techniques are presented. Topics covered include diffusion currents, polarography, amperometry, coulometry, chronopotentiometry, and other electrochemical methods. Instructor: Anson.

Ch 118 ab. Electroanalytical Chemistry Laboratory. *6 units (0-6-0); second, third terms.* Laboratory experiments involving the use of electroanalytical instruments. Instructor: Anson.

Ch 122 ab. The Structure of Molecules. *6 units (2-0-4); first, second terms.* A discussion of the arrangement of atoms in molecules and crystals. A non-mathematical and semi-empirical treatment is given to the various types of interatomic forces and their relationship to the chemical and physical properties of substances. Text: *Nature of the Chemical Bond,* Pauling. Instructors: Marsh, Waser.

Ch 124 abc. Elements of Physical Chemistry. *6 units (4-0-2); first, second, third terms.* This course is the same as Ch 24 abc with reduced credit for graduate students. Instructor: Hughes.

Ch 125 abc. Introduction to Chemical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or the equivalent.* This course provides a basic quantitative introduction to quantum mechanics (with some applications to spectroscopy) and statistical mechanics. Stress is on fundamental methods, rather than applications. Most other graduate courses in physical chemistry will assume a knowledge of the contents of this course. Instructors: Chan, Robinson, Davidson.

Ch 127 ab. Nuclear Chemistry. *6 units (2-0-4); first, second terms. Prerequisite: Ch 21 abc or equivalent.* Nuclear masses and energetics. Rates and statistics of radioactive decay. Alpha and beta decay. Gamma emission and other forms of nuclear de-excitation. Interaction of radiation with matter. Nuclear reactions and isotope production. Nuclear fission. Introduction to nuclear models. Chemical applications of radioactivity. Instructor: Burnett.

Ch 129 abc. The Structure of Crystals. *9 units (3-0-6); first, second, third terms.* The nature of crystals and X-rays and their interaction. The various diffraction techniques. The theory of space groups and the use of symmetry in the determination of the structures of crystals. The detailed study of representative structure investigations. The quantitative treatment of X-ray diffraction. Fourier-series methods of structure investigation. Given in alternate years. Offered in 1965-66. Instructor: Sturdivant.

Ch 130. Photochemistry. *6 units (2-0-4); first term. Prerequisite: Ch 21 abc.* Lectures and discussions on photochemical processes, especially in their relation to quantum phenomena. The following topics are included: the photochemical absorption law; the processes–excitation, dissociation, ionization–accompanying the absorption of radiation; subsequent processes including fluorescence and collisions of the second kind; photosensitization; quantum yield and its relation to photochemical mechanism; kinetics of homogeneous thermal and photochemical reactions; catalysis and inhibition; temperature coefficients of photochemical reactions. Instructor: Wulf.

Ch 132 ab. Biophysics of Macromolecules. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 or the equivalent.* A study of the structure and properties of biological macromolecules. Emphasis is placed on both the methods of investigation and the results. Topics covered include: polymer statistics and thermodynamics, sedimentation, light scattering, spectroscopy, X-ray diffraction, and electron microscopy. (This course is the same as Bi 132 ab.) Given in alternate years. Not offered in 1965-66. Instructors: Davidson, Hodge, Sinsheimer, Vinograd.

Ch 133. Biophysics of Macromolecules Laboratory. *14 units (0-10-4); second term.* A laboratory course designed to provide an intensive training in the techniques for the characterization of biological macromolecules. (This course is the same as Bi 133.) Open to selected students. Instructor: Vinograd.

Ch 135 ab. Chemical Dynamics. *9 units (3-0-6); second, third terms. Prerequisite: Ch 21 abc or equivalent required; Ch 125 a and concurrent registration in Ch 125 b recommended.* The mechanics and statistical mechanics of reactive collisions; the kinetics and mechanism of chemical reactions. Text: *Kinetics and Mechanism,* Frost and Pearson. Instructors: Kuppermann, Davidson, Hammond.

Ch 136. The Chemistry of Complex Ions. *6 units (2-0-4); first term. Prerequisite: Ch 21 abc (Ch 125 ab is recommended).* A semi-quantitative, semi-descriptive study of the properties of the transition-metal complex ions from the point of view of ligand field theory. Topics covered include visible spectra, optical rotation, magnetic properties, and thermodynamic properties. Text: *Introduction to Transition-Metal Chemistry,* Orgel. Not offered in 1965-66. Instructor: Davidson.

Ch 144 abc. Advanced Organic Chemistry. *9 units (3-0-6); first, second, third terms.* A survey of synthetic and theoretical organic chemistry at an advanced level with emphasis on stereochemistry. Applications of fundamental principles to the chemistry of naturally occurring substances. Instructor: Ireland.

Ch 145. Advanced Organic Chemistry Laboratory. *7 units (1-5-1); first term. Prerequisites: Ch 41 abc, Ch 46 abc.* Advanced laboratory practice, synthetic experiments, use of kinetics in mechanistic studies, and selected optional work. Not offered in 1965-66. Instructors: Hammond, Brown, and assistants.

Ch 148 ab. Characterization of Organic Compounds. *4 units (2-0-2); first, second terms. Prerequisites: Ch 41 abc, Ch 46 abc.* Lectures and recitations emphasizing the analytical methods of organic chemistry. Consideration of the general problem of the characterization of organic compounds by qualitative and quantitative procedures. Instructor: Brown.

Ch 149 ab. Laboratory in Characterization of Organic Compounds. *6 units (0-6-0); first, second terms. Prerequisites: Ch 41 abc, Ch 46 abc, and consent of instructor.* Laboratory exercises to accompany Ch 148. The isolation, purification, and identification of organic compounds with emphasis on instrumental methods. Qualified students may pursue research work. Instructors: Brown and assistants.

Ch 180. Chemical Research. *Offered to M.S. candidates in chemistry.*

Ch 190. Oral Presentation. *2 units (1-0-1); first term.* Training in the technique of oral presentation of chemical topics. Any graduate student in chemistry may be required to register for the course if, during his candidacy examination, or for any other reason, he gives evidence of needing instruction in oral presentation. Instructors: Waser, Corey, Booth.

Ch 223 ab. Statistical Mechanics. *9 units (3-0-6); second, third terms. Prerequisite: Ch 125 abc or equivalent.* Equilibrium statistical mechanics with applications to thermodynamics of gases, liquids, and solids, including chemical equilibria. Non-equilibrium statistical mechanics; transport phenomena. Given in alternate years. Offered in 1965-66. Instructor: Pings.

Ch 224 abc. Special Topics in Magnetic Resonance. *4 units (2-0-2); first, second, third terms.* The principles of magnetic resonance will be discussed. Emphasis will be placed on nuclear interactions within molecules and their effects on magnetic resonance. Current developments in theoretical methods for *ab initio* calculations of magnetic properties will also receive attention. Texts: *The Principles of Nuclear Magnetism,* Abragam; *Principles of Magnetic Resonance,* Slichter. Not offered in 1965-66. Instructor. Chan.

Ch 225 abc. Advanced Chemical Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or the equivalent.* Basic concepts and the laws of thermodynamics are reviewed. The theories of heterogeneous and chemical equilibrium are developed according to the methods of J. Willard Gibbs. A systematic treatment is presented of the thermodynamic properties of pure systems, mixtures, chemical reactions, electrochemical systems, surface phases, and systems under the influence of external fields. The theory of heterogeneous equilibrium and phase diagrams is developed analytically. The third term is largely devoted to the thermodynamics of irreversible processes. Not offered in 1965-66.

Ch 226 ab. Molecular Quantum Mechanics. *9 units (3-0-6); second, third terms. Prerequisite: Ch 125 a and concurrent registration in Ch 125 b or equivalent.* The basic material is the electronic structure of atoms and molecules, including the separation of nuclear and electronic motions in molecules, the methods of obtaining wave functions, and the approximations and errors involved in both. A selection of related topics such as intermolecular forces and the effects of external fields will also be included. Instructors: McKoy, Pitzer.

Ch 228 abc. Advanced Topics in Chemical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Consent of instructor.* This course will be devoted to special current topics in areas of chemical physics, such as molecular spectroscopy, group theory, electron scattering, molecular scattering, etc. The contents will vary from year to year and the course may be taken for credit more than once. In 1965-66, the topics will be:

First term. Interaction of Matter and Radiation. Brief review of classical electromagnetic theory; elliptically, circularly, and linearly polarized light; classical and quantum-mechanical Hamiltonian for a charged, nonrelativistic particle in an electromagnetic field; time-dependent perturbation theory; quantization of the field; elementary aspects of Dirac theory for relativistic particles; concept of electron spin; electric and magnetic dipole radiation and electric quadrupole radiation; Raman effect and other second-order processes; nonlinear optical effects; group theoretical basis for selection rules for transitions. Reference texts: *Principles of Optics,* Born and Wolf; *Quantum Theory of Radiation,* Heitler; *Quantum Mechanics,* Dirac; *Quantum Mechanics of One- and Two-Electron Atoms,* Bethe and Salpeter; *Infrared and Raman Spectra,* Herzberg; *Spectra of Diatomic Molecules,* Herzberg; *Theory of Atomic Spectra,* Condon and Shortly. Instructor: Robinson.

Second term. Quantum Processes in Photosynthesis. Fundamental concepts related to exciton effects in molecular aggregates will be treated. Excitation transfer, excitation annihilation, delayed fluorescence, singlet and triplet exciton band widths, and vibrational and electronic relaxation in condensed phases will be discussed. A model for photosynthesis will be introduced and modern notions of energy transfer and trapping mechanisms in photosynthesis will be considered within the framework of the fundamental concepts. Emphasis will be put on physical rather than biological subject matter. Reference material: Review article in *Annual Review of Physical Chemistry,* Vol. 15, 1964, Robinson; "Photosynthetic Mechanisms in Green Plants," papers presented at NAS-NRC symposium, Warrenton, Virginia, 1963. Instructor: Robinson.

Third term. Chemical Reactions in Crossed Molecular Beams. Theoretical aspects of the mechanics of reactive collisions between molecules. Experimental techniques in crossed molecular beam studies and interpretation of the experimental results. References: Recent papers in the scientific literature, especially in the *Journal of Chemical Physics.* Instructor: Kuppermann.

Ch 229 abc. X-Ray Diffraction Methods. *6 units (2-0-4); first, second, third terms: Prerequisite: Ch 129 abc or equivalent.* An advanced discussion of the techniques of structure analysis by X-ray diffraction. Given in alternate years. Not offered in 1965-66. Instructors: Dickerson, Hughes, Marsh.

Ch 231 abc. Applications of Molecular Orbital Theory. *6 units (2-0-4); first, second, third terms. Prerequisite: A knowledge of elementary wave mechanics and matrix algebra.* A review of the methods of molecular orbital theory and its applications in chemical physics. The concepts of Hückel theory, electron densities, and bond orders are introduced, followed by simple applications to electronic excited states, electron spin resonance, and reactivity problems. The orbital point of view is used to describe diatomic and polyatomic molecules, transition metal ions, and molecular crystals. Group theory is used to classify orbitals according to their symmetry. At a more advanced level, self-consistent orbitals are discussed, and the method of configurational interaction for dealing with electron correlation effects in spectra. If time permits, the course will touch on excitons, triplet states, bond alternation, vibronic coupling, intermolecular forces, and magnetic properties. Not offered in 1965-66.

Ch 234. Introduction to the Spectra of Molecules. *6 units (2-0-4); first term.* The theory of the structure of the spectra of both the diatomic and simpler polyatomic molecules is presented, and the transition rules and their relation to the symmetry elements of molecules are discussed. Emphasis is laid on the methods of interpreting and analyzing molecular spectra, and it is shown how from an analysis one obtains information regarding the structure and other properties of a molecule of interest to the chemist. Problems are given in the interpretation of actual data. Instructor: Badger.

Ch 242 ab. Chemistry of Natural Products. *4 units (2-0-2); first, second terms. Prerequisite: Ch 41 abc.* The chemistry of antibiotics, alkaloids, pigments, steroids, terpenes, etc. is used as a vehicle for a discussion of the general principles of structural elucidation, total synthesis, and biogenesis of natural products. Not offered in 1965-66. Instructor: Richards.

Ch 244 ab. Molecular Biochemistry. *6 units (3-0-3); first, second terms.* The chemistry of enzyme reactions with special emphasis on modern methods for elucidating the mechanisms of enzyme action and the influence of enzyme structure on biological function. Enzymes with a wide variety of functions will be considered; e.g., peptidases, oxidases, reductases, phosphatases, enzymes involved in the synthesis of nucleic acids, and other important bio-synthetic processes. Techniques discussed for elucidation of mechanisms will include kinetic studies, tracer techniques, studies of model systems, methods for isolation, purification, and determination of the structure of the enzyme, and the effect of structural modification on enzyme function. The molecular basis of biological control mechanisms will also be considered. Instructors: Richards, Raftery.

Ch 246 abc. Structures and Reactions of Organic Compounds. *4 units (2-0-2); first, second, third terms. Prerequisites: Ch 41 abc, Ch 21 abc.* Special methods for study of organic compounds and reactions. Topics discussed vary from year to year but usually include applications of the molecular orbital approach and nuclear magnetic resonance spectroscopy to problems of structure and reactivity. Texts: *Spin-Spin Splitting* and *Molecular Orbital Calculations,* Roberts. Given in alternate years. Offered in 1965-66. Instructor: Roberts.

Ch 247 ab. Organic Reaction Mechanisms. *6 units (2-0-4); first, second terms. Prerequisite: Ch 144 abc or equivalent.* Various tools for the study of organic reaction mechanisms will be discussed with major emphasis on kinetic methods. Not offered in 1965-66. Instructor: Hammond.

Ch 253 ab. Chemistry of the Enzymes. *6 units (2-0-4); first, second terms.* Consideration of the nature and mechanism of enzyme action. Not offered in 1965-66.

Ch 254 ab. The Chemistry of Amino Acids, Peptides, and Proteins. *6 units (2-0-4); second, third terms. Prerequisite: Ch 41 abc.* A discussion of the chemical reactions, structures, and functions of amino acids, peptides, and proteins. Given in alternate years. Offered in 1965-66. Instructor: Schroeder.

Ch 255 abc. Chemistry of Bio-organic Substances. *3 units (1-0-2); first, second, third terms.* Lectures on selected subjects of organic chemistry such as alkaloids, essential oils, and other major groups of natural products. Instructor: Haagen-Smit.

Ch 258. Immunochemistry. *8 units (2-3-3); second term. Prerequisite: Consent of instructor.* Two formal lectures and two conferences and demonstrations of laboratory experiments each week, review of literature, and either a special research project or a review paper dealing with some aspect of immunochemistry. Emphasis is on the isolation and characterization of antigens and types of antibody molecules and the manifestations of their physical and biological interactions. Texts: *Methods of Immunology,* Campbell, Garvey, Cremer, and Sussdorf; *Principles of Immunology,* Cushing and Campbell; *Fundamentals of Immunology,* Boyd; *Experimental Immunochemistry,* Kabat and Mayer; and *The Proteins,* Neurath and Bailey. Given in alternate years. Not offered in 1965-66. Instructors: Campbell, Garvey, and associates.

Ch 280. Chemical Research. *Offered to Ph.D. candidates in chemistry.* The main lines of research now in progress are:

In physical chemistry, chemical physics, and inorganic chemistry—
- Electronic structures of simple molecules and molecular fragments.
- Low energy electron scattering.
- Spectroscopic studies of the chemistry of free radicals trapped at low temperatures.
- Kinetics of chemical reactions including photochemical reactions.
- Experimental and theoretical molecular kinetics.
- Reactions in crossed molecular beams.
- Molecular beam spectroscopy.
- Determination of the structure of crystals by the diffraction of X-rays.
- Application of quantum mechanics to chemical problems.
- Molecular structure by spectroscopic methods.
- Nature of the metallic bond and the structure of metals and intermetallic compounds.
- Microwaves and nuclear resonance.
- Distribution of chemical compounds between immiscible phases.
- Kinetics and mechanics of electrode reactions.
- Inorganic and analytical methods.
- Bonding in and structures of transition-metal complexes.

In organic chemistry—
- Mechanisms of organic reactions in relation to electronic theory.
- Isolation of alkaloids and determination of their structure.
- Structural elucidation and biosynthesis of natural products.
- Total synthesis of natural products.
- Chemistry and reaction mechanisms of metallocenes.
- Isotope effects in organic and biochemical reactions.
- Chemistry of small-ring carbon compounds.
- Application of isotopic tracer and nuclear magnetic resonance techniques to problems in organic chemistry.
- Relation of structure to reactivity of organic compounds.
- Organic chemistry of metal chelates.
- Solution photochemistry.
- Reactions of free radicals in solutions.

In fields of application of chemistry to biological and medical problems—
- Mechanism of antigen-antibody reactions and the structure of antibodies.
- Functional significance of antibodies.
- Chemical and physical properties of blood.
- Isolation and characterization of cellular antigens.
- Mechanisms of enzyme action.
- Chemical analysis of proteins and determination of the order of amino-acid residues in polypeptide chains.
- Physical chemical studies of nucleic acids and viruses.
- Crystal structures of amino acids, peptides, and proteins.
- Plant hormones and related substances of physiological importance.
- Investigation of mammalian and bacterial polysaccharides including the blood-group specific substances.
- Behavior of biological macromolecules in the ultracentrifuge.

Ch 290 abc. Chemical Research Conference. *First, second, third terms.* These conferences consist of reports on investigations in progress in the chemical laboratories and on other researches which are of current interest. Every graduate student in chemistry is expected to attend these conferences. Seminars in special fields (immunochemistry, analytical chemistry, crystal structure, chemical physics, organic chemistry) are also held.

Civil Engineering

UNDERGRADUATE SUBJECTS

CE 10 abc. Structural Analysis and Design. *9 units (3-0-6); first, second and third terms. Prerequisites: AM 97 abc.* Analysis of lumped-parameter structural systems, including the basic concepts of relaxation. The design of structural components using such materials as steel and reinforced concrete. Instructor: McCormick.

CE 17. Civil Engineering. *9 units (3-0-6); third term. Prerequisite: Senior standing.* Selected comprehensive problems of civil engineering systems involving a wide variety of interrelated factors. Instructors: Staff.

ADVANCED SUBJECTS

CE 105. Introduction to Soil Mechanics. *9 units (2-3-4); first term. Prerequisites: AM 97,* A general introduction to the physical and engineering properties of soil, including origin, classification and identification methods, permeability, seepage, consolidation, settlement, slope stability, lateral pressures and bearing capacity of footings. Standard laboratory soil tests will be performed. Text: *Principles of Soil Mechanics,* Scott. Instructor: Scott.

CE 115 ab. Soil Mechanics. *9 units (3-0-6); first term. 9 units (2-3-4); second term. Prerequisite: CE 105 or equivalent, may be taken concurrently.* A detailed study of the engineering behavior of soil through the examination of its chemical, physical and mechanical properties. Classification and identification of soils, surface chemistry of clays, inter-particle reactions, and their effect on sediment deposition and soil structure. Permeability and steady state water flow, transient flow and consolidation processes, leading to seepage and settlement analyses. In the second term, attention is given to stress-deformation behavior of soils, elastic stability, failure theories, and problems of plastic stability. Study is devoted to the mechanics of soil masses under load, including stress distributions and failure modes of footings, walls and slopes. Laboratory tests of the shear strength of soils will be performed. Text: *Principles of Soil Mechanics,* Scott. Instructor: Scott.

CE 120 ab. Advanced Structural Analysis. *9 units (3-0-6); first and second terms. Prerequisite: CE 10 or equivalent.* Advanced methods of structural analysis, including the solution of differential equations, energy methods, moment distribution and relaxation methods, finite difference and numerical methods, applied to special structures such as elastic and plastic frames, unstable columns and frames, suspension bridges, arches, prismatic shells. Instructor: McCormick.

CE 121. Analysis and Design of Structural Systems. *9 units (0-9-0); third term. Prerequisite: CE 120 ab.* The analysis and design of complete structural systems. In general, students will work on a single problem for the entire term. The problem may be primarily one of analysis or one of design. Instructor: McCormick.

CE 123. Dynamics of Structures. *9 units (3-0-6); third term. Prerequisites: AM 150 ab, CE 120.* Analysis of structures and their response to dynamic loads such as blast and earthquakes. Consideration will be given to both elastic and plastic deformations. Instructor: Housner.

CE 124. Special Problems in Structures. *9 units (3-0-6); any term.* Selected topics in the field of structures to meet the needs of first-year graduate students. Instructors: Housner, McCormick.

CE 130 abc. Civil Engineering Seminar. *1 unit (1-0-0); each term.* Conferences participated in by faculty and graduate students of the Civil Engineering department. The discussions cover current developments and advancements within the fields of civil engineering and related sciences, with special consideration given to the progress of research being conducted at the Institute.

CE 145 ab. Environmental Health Biology. *10 units (2-4-4), second term; 9 units (3-0-6), third term. Prerequisites: Ch 41 abc or equivalent (may be taken concurrently).* An exposition of basic biological principles concerning interrelations between organisms, particularly those directly affecting man and his environment. Emphasis is placed on the influences of microorganisms as illustrative of the ways populations react on each other and condition the physical and chemical environment. Unique features of the terrestrial, freshwater, and marine environments are discussed and extensive reading is required, covering a broad scope of biological literature. Instructor: North.

CE 146 abc. Analysis and Design of Environmental Systems. *12 units (3-3-6); each term. Prerequisites: ME 17 ab, ME 19 ab, AM 113 ab, CE 145 ab, and CE 155, or equivalents. (The graduate prerequisites may be taken concurrently.)* A series of selected problems in the application of basic science and engineering science to water supply and treatment for municipal, industrial, and irrigation use; removal, treatment, and disposal of liquid and solid wastes; the theory of unit operations as applied to environmental systems; the design of works; and economic aspects of projects. Instructors: McKee, Gram.

CE 150. Foundation Engineering. *9 units (3-0-6); third term. Prerequisite: CE 115 ab.* Methods of subsoil exploration. Study of types and methods of design and construction of foundations for structures, including spread and combined footings, mats, piles, caissons, retaining walls, cofferdams, and methods of underpinning. Instructor: Scott.

CE 152 ab. Environmental Radiation. *9 units (2-3-4); second and third terms. Prerequisites: Ch 1 abc, Ph 2 abc, Ma 2 abc, ME 17 ab, ME 19 ab.* Engineering analysis of the problems associated with ionizing radiations in the human environment, especially in water, waste water, and air; evaluation of radiation sources; interactions of radiation with matter; methods of detection and measurement; use of radioactive tracers; acute and chronic effects on health; radioactive waste disposal; and engineering principles of control. Instructor: Gram.

CE 153. Seminar in Environmental Health Engineering. *3 units (2-0-1); third term.* Special seminars and field trips to cover several aspects of engineering in environmental health not normally included in formal courses; e.g., engineering aspects in problems of epidemiology; sanitation of swimming pools, hospitals, and housing; engineering control of insects, rodents, and vermin; waste disposal in the marine environment; occupational hazards, and environmental control in space. Instructors: Staff and visiting lecturers.

CE 155. Hydrology. *9 units (3-0-6); first term. Prerequisites: Ma 2 abc, Ph 2 abc.* An introductory study of the occurrence and movement of water on the earth's surface, including such topics as precipitation, evaporation, transpiration, infiltration, ground water, runoff, and flood flows; applications to various phases of hydraulic engineering such as water supply, irrigation, water power, and flood control; the use of statistical methods in analyzing hydrologic data. Instructor: Brooks.

CE 156. Industrial Wastes. *9 units (3-0-6); third term. Prerequisite: CE 146 ab.* A study of the industrial processes resulting in the production of liquid wastes; the characteristics of such wastes and their effects upon municipal sewage-treatment plants, receiving streams, and ground waters; and the theory and methods of treating, eliminating, or reducing the wastes. Instructor: McKee.

CE 160. Advanced Hydrology. *6 or more units as arranged; any term. Prerequisite: CE 155.* Advanced studies of various phases of hydrology. The course content will vary depending on needs and interests of students enrolling in the course. Instructor: Brooks.

CE 170 ab. Behavior of Disperse Systems in Fluids. *9 units (3-0-6); first and second terms. Prerequisites: ME 19 ab, Ch 21 abc or equivalents.* Studies of the mechanical and physicochemical behavior of particles in fluids with applications to gas cleaning, cloud physics, emulsion stability and water treatment. The first term is concerned primarily with stochastic problems including fluctuation theories of new phase formation, the theory of the Brownian movement, and theories of coagulation and convective diffusion. The second term deals with mechanical problems including impaction and sedimentation in flow systems, theories of filtration of particles from fluids, and experimental methods for measuring particle size distributions. Not offered in 1965-66. Instructor: Friedlander.

CE 200. Advanced Work in Civil Engineering. *6 or more units as arranged; any term.* Members of the staff will arrange special courses on advanced topics in civil engineering for properly qualified graduate students. The following numbers may be used to indicate a particular area of study.

CE 201. Advanced Work in Structural Engineering.

CE 202. Advanced Work in Soil Mechanics.

CE 203. Advanced Work in Environmental Health Engineering.

CE 204. Advanced Work in Water Resources.

Hy 200. Advanced Work in Hydrodynamics or Hydraulic Engineering.

CE 300. Civil Engineering Research.

Computers and Machine Methods of Computation

(See courses listed under Information Sciences)

Economics

Undergraduate Subjects

Ec 4 ab. Economic Principles and Problems. *6 units (3-0-3); first and second terms, or second and third terms.* A course in economic theory, institutions, and problems. The first half stresses analysis of money, national income, economic growth, and business fluctuations. The second half emphasizes the understanding of wages, prices, and profits in individual industrial and farm enterprises as well as international economic relations. Instructors: Sweezy, Brockie, Untereiner, Oliver, Noll.

Ec 13. Reading in Economics. *Units to be determined for the individual by the department.*

Ec 18. Industrial Organization. *7 units (3-0-4); third term.* After outlining the historical background of industry with the economic changes involved, this subject surveys the major problems facing management, especially in factory operations. The principal topics included are organization, plant layout, costs and budgets, methods, time and motion study, production control, labor relations, and wage scales. Instructor: Gray.

Ec 25. Business Law. *7 units (3-0-4); third term.* A survey of the law governing business activities and relationships. Contracts, agency, sales, insurance, negotiable instruments, employment, property rights, trusts and estates, and forms of business organization are studied. Instructor: Untereiner.

Ec 48. Introduction to Industrial Relations.* *9 units (3-0-6). Senior Elective.* This course stresses the personnel and industrial relations functions and responsibilities of supervisors and executives. The history, organization, and activities of unions and the provisions of current labor legislation are included. The relationships of a supervisor or executive with his employees, his associates, and his superiors are analyzed, and the services which he may receive from the personnel department are examined. The course also discusses the use of basic tools of supervision. Instructor: Gray.

ADVANCED SUBJECTS**

Ec 100 abc. Business Economics. *9 units (3-0-6); first, second, third terms. Open to graduate students.* This course endeavors to bridge the gap between engineering and business, especially industry. It is intended for two groups of technically trained students: 1) those who wish, sooner or later, to take advantage of opportunities in industry beyond their strict technical fields, and 2) those who will be engaged in teaching and in scientific research, but who wish to get an understanding of industry in both its technical and philosophical aspects. The broad assumptions in the course are that technical training is an excellent approach to positions of general responsibility in business and industry, and that technically trained men going into industry can make significant contributions to the improved functioning of the economy. The principal divisions of the subject matter of the courses are: 1) industrial organization and finance, 2) factory management with emphasis on automation, 3) industrial sales, 4) personal investments, and 5) business economic topics, especially the business cycle. This treatment provides a description of the industrial economy about us and of the latest management techniques. The points of most frequent difficulty are given special study. The case method of instruction is used extensively in the course. Instructor: Gilbert.

Ec 104. Government Regulation.* *9 units (3-0-6); third term. Senior Elective.* A study of government's growing role in the functioning of the private business system. Conditions leading to, and objectives sought by regulation of competition, quality and price. The evolution and functioning of a "mixed" economy. Emphasis on public utilities: methods and objectives of their regulation and problems of determining rate base, reasonable return and spread of rates. Instructor: Untereiner.

Ec 106 abc. Business Economics (Seminar). *Units by arrangement; first, second, third terms. Open to graduate students.* This seminar is intended to assist the occasional

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**Advanced students in Economics should be aware that IS 181 ab, Linear Programming, 9 units (3-0-6) second and third terms, is valuable for its economic applications. Credit in this course may be counted toward the fulfilment of requirements for a Ph.D. minor in Economics.

graduate student who wishes to do special work in some part of the field of business economics or industrial relations. Special permission to register for this course must be secured from the instructors. Instructors: Gilbert, Gray.

Ec 110. Industrial Relations. *9 units (3-0-6); first term. Not open to students who have taken Ec 48, Introduction to Industrial Relations.* An introductory course dealing with basic problems of employer-employee relationships and covering the internal organization of an enterprise, the organization and functions of unions, and the techniques of personnel administration with emphasis on the problems of setting wage rates. Instructor: Gray.

Ec 111. Business Cycles and Governmental Policy. *9 units (3-0-6); second term.* A study of the nature, causes, and possible control of economic fluctuations with special emphasis on the interrelationship of business cycles and such fiscal matters as national debt control, national budgetary control, and the maintenance of high levels of employment, production, and purchasing power. The course also integrates the international problems of war, reconstruction, trade, and investment with the analysis of business cycles and internal fiscal policies in order to provide a unified theory of national and international equilibrium. May be taken as a senior elective. Instructor: Brockie.

Ec 112. Modern Schools of Economic Thought. *9 units (3-0-6); third term.* A study of economic doctrine in transition, with particular emphasis on the American contribution. Against a background of Marshall and Keynes, a critical examination will be made of the institutional, collective, quantitative, social, experimental, and administrative schools of economics. Instructor: Brockie.

Ec 113. Reading in Economics. *Same as Ec 13 but for graduate credit.*

Ec 120. International Economic Relations.* *9 units (3-0-6); third term; Senior Elective.* An investigation of the factors influencing the flow of goods and services between markets. Particular attention is paid to the techniques of exporting and importing, foreign investments, the balance of international payments, foreign exchange rates and controls, international monetary and commodity agreements, and the international inter-relationships of politics and economics. Open to all students who have taken Ec 4 ab or the equivalent. Instructor: Oliver.

Ec 121. Price Theory.* *9 units (3-0-6); first term; Senior Elective.* A theoretical analysis of the price system, with special reference to the nature and problems of the U.S. economy. The course includes a study of consumer preference, the structure and conduct of markets, factor pricing, measures of economic efficiency, and the interdependence of markets in reaching a general equilibrium. Instructor: Noll.

Ec 122. Econometrics.* *9 units (3-0-6); second term; Senior Elective.* The application of statistical techniques to economic data. Included in the course is a presentation of the statistical model most useful to the theory of consumer demand, to price theory, and to the prediction of levels of over-all economic activity. Instructor: Noll.

Ec 123. The Russian Economy.* *9 units (3-0-6); third term; Senior Elective.* A study of the Russian soviet economic system and a comparison of the Russian economy with the economics of Western Europe and the United States. Instructor: Sweezy.

Ec 125 abc. Technical Cooperation (Seminar).* *9 units (3-0-6). Senior Elective.* The primary objective of the seminar is to provide students with the opportunity for an examination of the economic and technical problems of raising living standards in newly developing countries. The emphasis in Ec 125 a is on the economics of develop-

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

ment, formerly included in Ec 124. The emphasis in Ec 125 b is on the role of science and engineering in promoting economic development. The emphasis in Ec 125 c is on the development problems of specific areas of the world. Guest lecturers and faculty from other divisions will participate in the seminar. Research projects will be undertaken by the students. Instructor: Oliver.

Ec 126 ab. Money, Income, and Growth.* *9 units (3-0-6); first and second terms. Senior Elective.* Open to students who have taken Ec 4 ab and to other qualified students with the consent of the instructor. This course starts with an intensive study of Keynes' "General Theory of Employment" and then goes on to post-Keynesian developments in the theory of income, consumption, investment and growth. The course also covers the theory of wages and productivity and the relation of technical progress to increases in productivity and real income. It deals with economic policy as well as economic theory, especially the application of monetary, fiscal, and other policies to problems of inflation, depression, unemployment, automation, and growth. The third term is devoted largely to a study of the Russian economy and a comparison of the Russian economy with the economies of Western Europe and the United States. Instructor: Sweezy.

Ec 127 abc. Problems in Economic Theory (Seminar). *Units by arrangement; first, second, third terms. Prerequisite: Ec 126 or its equivalent.* Consideration of selected topics in economic theory. Instructors: Members of the staff and guest lecturers.

IS 181 ab. Linear Programming. *9 units (3-0-6).* See page 328.

Electrical Engineering

UNDERGRADUATE SUBJECTS

EE 5. Introductory Electronics. *9 units (3-0-6); third term. Prerequisite: Ph 2 ab.* This is an introductory course to provide a background in electronics for students both in engineering and in other fields. The subjects covered will be simple a.c. circuit theory, properties of vacuum tubes and transistors, simple rectifiers and switching circuits. Instructor: Langmuir.

EE 13 abc. Linear Network Theory. *9 units (3-0-6); three terms. Prerequisites: Ma 2 abc, Ph 2 abc and AM 95 or Ma 108 or AM 116 (first term) concurrently.* Introduction to the analysis of linear networks in both the time and the frequency domain. Topics presented include graphs, networks, loop and node equations, transient and steady state, power, frequency response, two-terminal-pair networks, Fourier series, Fourier and Laplace transforms, feedback, noise and distributed linear systems. Instructors: Wilts, Mason.

EE 14 abc. Electronic Circuits. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 abc, Ph 2 abc.* A course covering the general area of active devices and their circuit applications. Transistor and vacuum tube amplifiers, biasing, gain, frequency response, class A, B and C power output circuits and their limitations. Nonlinear electronics, diodes, rectifiers, mixers, switching circuits, saturation, power converters, etc. Texts: *Transistor Circuit Analysis,* Joyce and Clarke; *Electronic Fundamentals and Applications,* Ryder. Instructor: Martel.

EE 20 abc. Physics of Electronic Devices. *9 units (3-O-6); first, second, third terms. Prerequisite: Ph 2 abc.* The application of modern physical principles to materials and devices important in present technological applications. Topics include: energy bands in solids, electrical properties of semiconductors, metals and dielectrics, semiconductor devices, plasmas, gas tubes, excitation and relaxation of electronic systems and reference to luminescence and stimulated emission. Text: *Solid State Physical Electronics,* Van Der Ziel. Instructor: Mead.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

EE 90 abc. Laboratory in Electronics. *3 units (0-3-0); each term. Prerequisite: Ph 2.* An introductory laboratory normally taken in the junior year. The experiments are designed to acquaint the student with the techniques and the equipment used in electrical measurements. The characteristics of linear passive electrical circuits, the properties of electron devices and the behavior of simple linear and nonlinear active circuits are measured and compared with theoretical models. Instructor: Nicolet.

EE 91 abc. Experimental Projects in Electrical Engineering. *5 units (0-4-1); each term. Prerequisite: EE 90 abc or equivalent.* A general laboratory program designed to give the student an opportunity to do original experiments in the fields of electrical engineering and applied physics. Emphasis is placed not only upon modern laboratory techniques but also upon the selection of significant projects, the formulation of the experimental approach and the interpretation of the data. Facilities are available for experiments involving electronic circuits, electronic circuit elements, cryogenics, lasers, magnetism, optics, microwaves, thermionics and electronic properties of semiconductor materials. Text: Literature References. Instructor: Humphrey.

ADVANCED SUBJECTS

EE 112 abc. Network Synthesis. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 13 abc.* The analysis and synthesis of lumped and distributed parameter circuits. Mathematical properties of network functions. Realization theory for driving-point and transfer functions, including the synthesis techniques of Bode, Brune, Cauer, Darlington, Foster, Guillemin and others. The approximation problem, the scattering matrix, the Deschamps chart, and selected topics of research importance. Texts: *Synthesis of Passive Networks,* Guillemin; *Principles of Microwave Circuits,* Montgomery et al. Instructor: George.

EE 125 abc. Advanced Electronics. *9 units (3-0-6); first, second, third terms.* An integrated treatment of the theory and application of solid-state electronic devices, with emphasis on methods of engineering analysis and design. Physics of insulators, semiconductors, and conductors. Basic equations of current flow in various media. Principle of charge-controlled devices. Junctions between media, and application to vacuum and solid-state diodes. Detailed treatment of p-n junctions. Ideal and real semi-conductor triodes, and their static and incremental models. Practical design of feedback and d-c amplifiers using junction and field-effect transistors. Circuit noise problems. Instructor's permission required for undergraduate registration. Not offered in 1965-66. Instructor: Middlebrook.

EE 126. Topics in Solid State Devices and Circuits. *6 units (2-0-4); third term. Prerequisites: EE 125 ab.* Advanced treatment of a selection of topics including silicon-controlled rectifiers, field-effect transistors and their applications. A term paper will be required. Not offered in 1965-66. Instructor: Middlebrook.

EE 131 abc. Physics of Semiconductors and Semiconductor Devices. *9 units (3-0-6); three terms.* Introduction to the concepts of semiconductor devices. Includes topics such as the solid state, electric properties of solids, Boltzmann and Fermi statistics, properties of regular arrays, mechanical and electrical filters, band theory of crystals, electrons, holes, semiconductors, theory of p-n junctions and of semiconductor devices. Not offered in 1965-66. Instructor: Nicolet.

EE 133 abc. Solid State Theory. *9 units (3-0-6); first, second and third terms. Prerequisites: Ph 125 abc, its equivalent, or instructor's permission.* An introduction to solid state theory. Topics discussed include: Lattice vibrations; thermal properties of solids; ferro and paraelectricity; electro-optics; dia-, para-, and ferromagnetism, paramagnetic resonance of free electrons and of electrons in crystals, semiconductor theory, and nonlinear optics. Certain selected device applications are also treated including the maser, laser, and injection laser. Instructor: Yariv.

EE 135 abc. Electronic Processes in Solids. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 20 or equivalent.* A treatment of topics in the field of applied solid state physics relating to the current research activities of the staff. Topics to be covered in detail include superconductivity, ferromagnetism, semiconductors and hot electron transport in insulators and metals. Instructors: Nicolet, Mead, Wilts.

EE 151 abc. Electromagnetism. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc; Ma 2 abc; AM 95 ab.* A course in theoretical electricity and magnetism, primarily for electrical engineering students. Topics covered include electrostatics, magnetostatics, Maxwell's equations, waveguides, cavity resonators, and antennas. EE 151 c will include topics on propagation in the ionosphere, propagation over the earth's surface, and modern microwave tubes. Text: *Electromagnetic Fields and Waves,* Langmuir. Instructor: Wilts.

EE 155 abc. Electromagnetic Fields. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 151 abc.* An advanced course in classical electromagnetic theory and its application to guided waves, cavity resonators, antennas, artificial dielectrics, propagation in ionized media, propagation in anisotropic media, magnetohydrodynamics, and to other selected topics of research importance. Text: Course notes. Instructor: Papas.

EE 161 abc. Communication Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 13 abc.* Mathematical methods in modern communication theory. Representation of signals, sampling theorems and linear filters. A review of probability theory and an introduction to stochastic processes. The autocorrelation function, cross-correlation function and power spectral density. Linear filtering of stochastic processes. Gaussian processes, Poisson processes and event generators. Zero-memory nonlinear filters. The Wiener filter, the matched filter, and the decision theoretic model for the detection of signals and the estimation of signal parameters. An introduction to information theory: entropy, channel capacity and coding theorems. Instructor: Grettenberg.

EE 172 abc. Linear Feedback Principles. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 95 abc or equivalent.* Design procedures for achieving system specifications despite large parameter variations, and for attenuation of disturbances. Cost of feedback and fundamental limitations on the achievable benefits. Conditionally stable designs; feedback design for nonminimum phase and unstable plants; use of minor positive feedback loops. Canonic feedback structures. Noise and its role in synthesis of multiple loop systems. Approximate methods for rate of parameter variations and nonlinear plants. Multivariable system design. Sampled data systems. Statistical design techniques. Text: *Synthesis of Feedback Systems,* Horowitz. Instructor: Horowitz.

EE 173 abc. Modern Control Processes. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 95 abc or equivalent.* System representation: continuous systems and discrete systems. Linear systems: controllability and observability. Stability: Second Method of Liapunov; Method of Popov. The deterministic optimal control problem: classical variational methods; Pontriagin's maximum principle; Bellman's dynamic programming; optimization via linear and nonlinear programming; the simplex method. Computational methods: The quasilinearization method; gradient methods; approximation in policy space. Stochastic problems: linear filtering and estimation; nonlinear filtering; stochastic optimal control, stochastic approximation. Adaptive control systems: The identification problem; The decision problem. Instructor: Sridhar.

EE 185 abc. Bio-Systems Analysis. *6 units (2-0-4); first, second, third terms.* Same as Bi 121 abc. This course presents a systematic consideration and application of the methods of systems analysis, information theory and computer logic to problems in neurobiology. The subjects to be considered include the mechanical properties of striated muscle, the analysis of neuronal integrative mechanisms and reflex behavior in terms of logical net theory. The course will seek to describe some aspects of human cortical activity in terms of information theory and conceptual modeling. The course will be conducted as a research seminar and the detailed subject matter will change from year to year. Instructors: Fender, and staff.

EE 191. Advanced Work in Electrical Engineering. Special problems relating to electrical engineering will be arranged to meet the needs of students wishing to do advanced work. Primarily for undergraduates. Students should consult with their advisors before registering for this course.

EE 194. Microwave Laboratory. *6 units (1-3-2); second term. Prerequisite: EE 151 ab, or may be taken concurrently.* Covering experiments on microwave generation, bridges, precise impedance measurement, nodal shift methods, and the properties of microwave circuit elements such as matched T's, directional couplers and antennas. Instructor: Gould.

EE 201. Research Seminar in Electrical Engineering. *2 units.* Meets once a week for discussion of work appearing in the literature and in industry. All advanced students in electrical engineering and members of the electrical engineering staff are expected to take part. In charge: staff.

EE 221 abc. Topics in Physical Electronics. *4 units (1-0-3); first, second, third terms. Prerequisite: EE 124 abc.* Principles of electromagnetic interaction with solids and ionized gases and current applications. Content to vary from year to year. Typical topics are: microwave noise in electron beams, magnetic resonance and relaxation, cyclotron resonance, oscillations and waves in plasmas. Not offered in 1965-66.

EE 243 abc. Quantum Electronics Seminar. *6 units (3-0-3).* Advanced treatment of topics in the field of quantum electronics. Each weekly seminar consists of one lecture of a series on the elements of radiation theory, partial coherence, dispersion, nonlinear optics, laser media, and spectroscopy, followed by a discussion of a current research paper. Text: Class notes and selected references. Instructors: George, Yariv.

EE 255 abc. Boundary-Value Problems of Electromagnetic Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 155 abc, or equivalent.* This course presents the mathematical techniques (Fourier-Lamé method, integral equation method, variational principles) that are available for the solution of boundary-value problems arising from the study of antennas, waveguides, and wave propagation. Text: *Randwertprobleme Der Mikrowellenphysik,* Borgnis and Papas; also class notes. Instructor: Papas.

EE 261 abc. Advanced Communication Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 161 abc.* An advanced course in statistical communication theory. Topics covered include statistical techniques for the determination of optimum data processing systems, methods of coding and signal selection, and sequential techniques for learning unknown system parameters. The course will emphasize areas of current research in the field. Instructor: Braverman. Not offered in 1965-66.

EE 280 abc. Advanced Course in Machine Computing Methods for Engineering Analysis. *9 units (2-3-4); first, second third terms.* The application of analog and digital methods to problems in engineering analysis. Specific system and design analysis problems in such fields as electricity and magnetism, solid mechanics, fluid mechanics, aeroelasticity and thermal conductivity will be solved by both analog and digital methods with the comparison of various machine computing techniques. Course open only to advanced graduate students and by permission of instructor. Instructors: Franklin, McCann.

EE 281. Seminar in Electronic Computers. *4 units (1-0-3); first, second, third terms.* Special topics on new developments in digital and analog computers and their applications to engineering analysis. Instructor: McCann.

EE 291. Advanced Work in Electrical Engineering. Special problems relating to electrical engineering will be arranged to meet the needs of students wishing to do advanced work. Primarily for graduate students. Students should consult with their advisors before registering for this course.

ENGINEERING

E 10 ab. Technical Presentations. *2 units (1-0-1); first and second terms.* A course concerned with oral presentations of technical material. Instructors: Staff.

E 11 ab. Technical Presentations. *2 units (1-0-1); first and second terms.* A course concerned with oral presentations of technical material coordinated with EE 7 ab. EE 7 ab must be taken concurrently with E 11 ab. Instructors: Staff.

E 150 abc. Engineering Seminar. *1 unit (1-0-0); each term.* All candidates for the M.S. degree in Applied Mechanics, Materials Science and Mechanical Engineering are required to attend any graduate seminar in any division each week of each term.

ENGINEERING GRAPHICS

Gr 1. Basic Graphics. *3 units (1-2-0); first term.* This course deals with the fundamental aspects of projective geometry and graphical techniques used by the scientist and engineer as an aid in spatial visualization, communication and in creative design. Emphasis is placed on the effective use of freehand sketching in perspective, orthographic projection and other useful forms of representation. The student's ability to visualize three-dimensional forms and spatial relationships is logically developed through a series of freehand problems followed by basic descriptive geometry solutions analyzing some of the general relationships which exist among points, lines and planes. Accuracy, neatness and clarity of presentation are encouraged throughout the course. Instructors: Kiceniuk, and staff.

Gr 5. Descriptive Geometry. *6 units (0-6-0); third term. Prerequisite: Gr 1.* The course is primarily for geology students and is designed to supplement the study of shape description as given in Gr 1 and to present a graphical means of solving the more difficult three-dimensional problems. The student reviews geometrical relationships of straight lines and planes, then advances to curved lines, single and double curved surfaces, warped surfaces and intersections. Methods of combining the analytical solution of the simpler problems with the graphical solution are discussed and applied. Emphasis is placed throughout the course on practical problems in mining and earth structures and on the development of an ability to visualize in three dimensions. Instructors: Staff.

Gr 7. Advanced Graphics. *Maximum of 6 units. Elective; second and third terms. Prerequisite: Gr 1.* Further study in the field of graphics as applied to engineering problem analysis and in design for production. Through a coordinated series of discussions, laboratory problems and field trips the student is introduced to work in various branches of engineering as well as to some of the broad aspects of human engineering, aesthetics and various economic factors as they affect design. Instructors: Staff.

ENGLISH

UNDERGRADUATE SUBJECTS

En 1 a. Literature. *6 units (3-0-3); first term.* A study of literary documents illustrating Rationalism, chosen from seventeenth and eighteenth century poets, essayists and philosophers. Frequent analytical and critical papers are assigned. Instructors: J. Kent Clark and staff.

En 1 bc. Nineteenth and Twentieth Century Literature. *11 units (3-0-8); second and third terms.* A study of the chief intellectual and literary movements from the early nineteenth century to the present. Included among the topics are the romantic reaction to eighteenth century rationalism, the nineteenth century hero, the impact of science on religion and literature, effects of reform and revolution, romantic theories of art, the movement toward "realism," the growth of relativism, the problems of engagement and identity, the anti-hero, and the modern concern with war and peace. The study will also involve a consideration of the principal literary forms: poetry, drama, narrative prose and literary criticism. Frequent analytical and critical papers are assigned.

En 7 abc. Advanced Literature. *8 units (3-0-5); first, second, third terms.* Advanced study of major literary works in various forms. The reading of the first term is focused on tragedy and epic, the second term on Shakespeare and the third term on the novel.

En 8. Contemporary English and European Literature.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* A survey of English and Continental literature from 1859 to the present time. Emphasis is placed on the influence of science, particularly biological and psychological theory, on content and techniques. Instructor: Eagleson.

En 9. American Literature.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* A study of major literary figures in the United States from Whitman and Mark Twain to those of the present time. The larger part of the course is concerned with contemporary writers. An emphasis is placed on national characteristics and trends as reflected in novel and short story, biography, poetry, and drama. Instructor: Langston.

En 10. Modern Drama.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* A study of leading European, British, and American dramatists from Ibsen to writers of the present time. Special attention is given to dramatic technique, and to the plays both as types and as critical comments upon life in the late nineteenth and twentieth centuries. Instructor: O. Mandel.

En 11. Literature of the Bible.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* A study of the Old and New Testaments, and the Apocrypha, exclusively from the point of view of literary interest. The history of the English Bible is reviewed, and attention is brought to new translations. Opportunity is offered for reading modern fiction, poetry, and drama dealing with Biblical subjects.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

En 12 abc. Debating. *4 units (2-0-2).* A study of the principles of argumentation; systematic practice in debating; preparation for intercollegiate debates. Instructor: Booth.

En 13. Reading in English and History. *Units to be determined for the individual by the department.* Collateral reading in literature and related subjects, done in connection with regular courses in English or history, or independently of any course, but under the direction of members of the department.

En 14. Special Composition. *2 units (1-0-1).* This subject may be prescribed for any student whose work in composition, general or technical, is unsatisfactory.

En 15 abc. Journalism. *3 units (1-0-2); first, second, third terms.* A study of the elementary principles of newspaper writing and editing, with special attention to student publications at the Institute. Instructor: Hutchings.

En 18. Modern Poetry.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* A study of three or four major poets of the twentieth century, such as Yeats, T. S. Eliot and W. H. Auden. Modern attitudes toward the world and the problem of belief. Some consideration of recent theories of poetry as knowledge. Instructor: Clark.

En 20. Summer Reading. *Units to be determined for the individual by the department. Maximum 8 units. Elective.* Reading in literature, history, philosophy, and other fields during summer vacation, books to be selected from a recommended reading list, or in consultation with a member of the staff. Critical essays on reading will be required.

En 21. Introduction to the Visual Arts.* *(3-0-6). Senior Elective.* The vocabularies of analysis for the study of painting, sculpture and architecture. Approaches to the study of art history, and case studies of selected art forms. Instructor: Wark.

ADVANCED SUBJECTS

En 100 abc. Seminar in Literature. *9 units (2-0-7); first, second, third terms.* A survey of recent critical methods, from I. A. Richards to the present time, and the application of these methods to the work of such major writers as Joyce, Yeats, Eliot and Mann. The influence of modern psychology and anthropology on creative writing and criticism. Instructor: Mayhew.

En 122 abc. Senior Seminar. *9 units (2-0-7). For majors only.* Selected topics in literary history and criticism, in English and American authors, periods and types. Seminar reports and papers.

En 124 ab. Medieval Literature.* *9 units (3-0-6). Senior Elective. Prerequisite En 7.* A two-term sequence designed to give an introduction to medieval English language and literature, culminating in a detailed study of Chaucer.

En 125 abc. Sixteenth and Seventeenth Centuries.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* A course designed to acquaint the student with the principal figures and genres of the perior from the Reformation to the Restoration. It includes the Humanists, Elizabethan poetry, non-Shakespearian drama, seventeenth century prose writers, metaphysical and cavalier poets, Dryden, and Milton.

En 126. Eighteenth Century.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* Study of dominating figures of the eighteenth century, particularly Pope and Johnson, and of the Restoration and eighteenth century drama.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

En 127. Earlier English Novel.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* The novel from Richardson and Fielding to Scott and Jane Austen.

En 128. Victorian Novel.* *9 units (3-0-6). Senior Elective. Prerequisite: En 7.* Critical study of chief Victorian novelists, in the context of their age. Social, political, and literary influences.

En 130. American Renaissance.* *9 units (3-0-6). Senior Elective. Prerequisite:* Study of the emergence of distinctively American literature and culmination in Emerson, Thoreau, Melville, and Hawthorne. Their influence on subsequent American writing.

French

(See under Languages)

Geological Sciences

Undergraduate Subjects

Ge 1. Physical Geology. *9 units (4-2-3); first term. Prerequisites: Ch 1 abc, Ph 1 abc.* An introduction to the basic principles of the earth sciences. Geology, geochemistry and geophysics in relation to materials and processes acting upon and within the earth's crust. Consideration is given to: rocks and minerals; structure and deformation of the earth's crust; earthquakes; volcanism; and the work of wind, running water, ground water, the oceans, and glaciers upon the earth's surface with the aim of stimulating the student's interest in the geological aspects of the environment in which he will spend his life. Text: *Principles of Geology,* Gilluly, Waters, and Woodford. Instructors: Allen, Sharp, and Teaching Fellows.

Ge 2. Geophysics. *9 units (3-0-6); second term. Prerequisites: Ge 1, Ma 2 ab, Ph 2 ab.* A selection of topics in the field of geophysics using, as fully as possible, the prerequisite background. Included are consideration of the earth's gravity and magnetic fields, geodesy, seismology, and the deformation of solids, tides, thermal properties, radioactivity, age determinations, the continents, the oceans, and the atmosphere. Observations followed by their analysis in terms of physical principles. Instructor: Smith.

Ge 3. Mineralogy—The Crystalline State. *9 units (3-3-3); second term. Prerequisites: Ge 1, Ch 1, Ph 1.* Basic atomistic relationships in the crystalline state; crystallography; crystal structure of representative minerals; solid state transformations; ionic theory of solids; physical properties in relation to crystal structure. Problems and laboratory study on: stereographic projection, morphological crystallography, crystal structure and mineral identification. Instructor: Wasserburg.

Ge 5. Geobiology. *9 units (3-0-6); third term. Prerequisites: Ge 1, Ch 1, Bi 1, or consult instructor.* An examination, chiefly in biological terms, of processes and environments governing the origin and differentiation of secondary materials in the crust throughout the span of earth history. Consideration is given to the environmental influence of the change from a reducing to an oxidizing atmosphere upon the evolution of life processes and to the subsequent progression of organisms and organic activity throughout the oxidizing era as recorded in the sedimentary rocks of the earth's crust. Special attention is devoted to organic progression and differentiation in time and space in terms of environment. Instructors: Lowenstam, Brown.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

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.

Ge 41 abc. Senior Thesis. *Units to be arranged.* Senior majors wishing to undertake some research and prepare a *suitable professional report* on some topic 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 Division faculty.

ADVANCED SUBJECTS

Courses given in alternate years are so indicated. Courses in which the enrollment is less than five may, at the discretion of the instructor, not be offered.

Ge 100. Geology Club. *1 unit (1-0-0); all terms.* Presentation of papers on research in geological science by the students and staff of the Division of the Geological Sciences and by guest speakers. Generally required of all senior and graduate students in the Division; optional for sophomores and juniors. Instructor: Kamb.

Ge 102. Oral Presentation. *2 units (1-0-1); first, second, or third term.* Training in the technique of oral presentation. Practice in the effective organization and delivery of reports before groups. Successful completion of this course is required of all candidates for the bachelor's, master's, and doctor's degrees in the Division. However, students taking more than one degree in the Division need not take Ge 102 for the second or third one. The number of terms taken will be determined by the proficiency shown in the first term's work. Instructors: Sharp, Booth, Murray.

Ge 103. Historical Geology. *9 units (2-2-5); second term. Prerequisite: Ge 1.* Distribution in time and space of stratified rocks; development of the biota since the beginning of the Cambrian; distribution of orogenies in time and space since the Precambrian; relation of major stratified rock types and orogenic areas to the Precambrian shields of the world. Instructor: Boucot.

Ge 108. Mathematical Techniques for Geologists. *6 units (3-0-3); first term.* A review of some of the mathematical methods used in formulating and solving geologic problems. The purpose of this course is to give new graduate students a reasonable proficiency with those mathematical techniques which will be used in advanced courses in the earth sciences.

Ge 111 ab. Invertebrate Paleontology. *10 units (2-6-2); second and third terms. Prerequisite: Ge 1.* Morphology and geologic history of the common groups of the lower invertebrates, with emphasis on their evolution and adaptive modifications. Second term: consideration of the higher invertebrates groups; preparation of fossils and problems of invertebrate paleontology. Instructors: Lowenstam, Boucot.

Ge 114. Mineralogy II—Optical Mineralogy. *12 units (3-8-1); first term. Prerequisites: Ge 3; or Ge 1, Ch 1, Ph 1 and permission of instructor.* Systematic study of the physical properties of important rock-forming minerals and mineral groups as a function of their crystal structure and chemical composition. The elements of optical crystallography and their application in microscopic mineralogy will be studied. The laboratory work will emphasize the development of basic competence in mineral identification using hand specimens and the petrographic microscope. Instructor: Silver.

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. Field trips will supplement laboratory study.

Ge 115 a. Igneous Petrology and Petrography. *12 units (3-6-3); second term. Prerequisites: Ge 114, Ch 24 a or 124 a or Ch 21 a.* The mineralogical and chemical composition, origin, occurrence, and classification of igneous rocks considered mainly in the light of chemical equilibrium and of experimental studies. Detailed consideration of the structure, phase relations, and identification of the feldspar, pyroxene, amphibole, olivine, and feldspathoid mineral groups. Instructor: Albee.

Ge 115 b. Sedimentary Petrology and Petrography. *10 units (3-4-3); third term. Prerequisite: Ge 115 a.* The mineralogic and chemical composition, occurrence, and classification of sedimentary rocks; consideration of the chemical, physical, and biological processes involved in the origin, transport, and deposition of sediments and their subsequent diagenesis. Detailed consideration of structure, phase relations, composition, and identification of clay minerals, carbonates, and Fe-Mn oxides. Laboratory study will include identification of clay minerals by X-ray diffraction.

Ge 115 c. Metamorphic Petrology and Petrography. *10 units (3-4-3); first term. Prerequisite: Ge 115 b.* 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. Introduction to use of universal stage and petrofabric diagrams. Instructor: Taylor.

Ge 120 a. Field and Structural Geology. *10 units (2-5-3); first term. Prerequisite: Ge 1.* A problem and field course in the interpretation and mapping of geologic structures. Topics treated during the first part of the term include the mechanical properties of rocks, geologic scale models, and the analytical solution of structural problems. The second part of the term is devoted primarily to elementary field techniques, including field mapping in several structurally complicated areas of southern California. Instructor: Allen.

Ge 120 b. Field Geology. *10 units (0-8-2); second term. Prerequisite: Ge 120 a.* Intensive field investigation of a single area of complex structural, stratigraphic, and petrologic problems. A professional report is required. Instructor: Taylor.

Ge 120 c. Geophysical Field Studies. *10 units (2-6-2); third term.* An integrated geophysical field program in an area of particular geological interest, using seismic refraction, gravity, and magnetic field measurements. Students take part in all phases of the program, such as surveying of stations, operation of equipment, reduction of data and interpretation. A final report, embodying calculations and interpretation, is required. Instructors: Smith, Anderson.

Ge 121 abc. Advanced Field Geology. *14 units (4-8-2), first term; 10 units (0-8-2), second term; 11 units (0-5-6), third term. Prerequisites: Ge 3, Ge 120 abc.* Interpretation of geologic features in the field, with emphasis on problems of the type encountered in professional geologic work. Advanced techniques of investigation are discussed. The student investigates limited but complex field problems in igneous, sedimentary, and metamorphic terranes. Individual initiative is developed, principles of research are acquired, and practice gained in field techniques, including the use of the plane table in geologic mapping. The student prepares reports interpreting the results of his investigations. Instructors: Silver (121 a); Kamb (121 b); Albee (121 c).

Ge 123. Summer Field Geology. *30 units. Prerequisite: Ge 120 abc.* Intensive field study of a 10-15 square mile area from a centrally located, temporary camp. Emphasis is placed on stratigraphic and structural interpretation, and on detailed mapping techniques, including the use of aerial photographs. Each student prepares a geologic map, stratigraphic and structural sections, and a complete geologic report. The work is performed under close supervision of regular staff members. The area chosen generally lies in a part of the Rocky Mountains, or the Basin and Range Province. The course is designed to complement the field training in southern California afforded by the regular school year courses, Ge 20 and Ge 121. The course begins the Monday following commencement (about June 15) and lasts for six weeks. It is required at the end of the junior year of candidates for the bachelor's degree in the geology and geochemistry options; of candidates for the Master of Science degree; and, at the discretion of the staff, of candidates for other advanced degrees in the Division of Geological Sciences. Registration is limited to students regularly enrolled in the California Institute of Technology or to those entering the following term. Text: *Suggestions to Authors,* Wood and Lane. Instructors: To be designated.

GE 126. Geomorphology. *10 units (4-0-6); second term.* Primarily a consideration of dynamic processes acting on the surface of the earth, and the genesis of landforms. Offered in 1965-66. Instructor: Sharp.

Ge 130 ab. Introduction to Geochemistry. *6 units (2-0-4); first and second terms. Prerequisites: Ch 14, Ch 21 abc or Ch 24 ab, Ma 2 abc, Ph 2 abc, Ge 1.* A lecture and problem course on the application of chemical principles to earth problems, involving topics in stable and radioactive isotopic geochemistry. Instructor: Epstein.

Ge 131. Geochronology. *6 units (2-0-4); third term. Prerequisite: Ge 130 ab.* A lecture and problem course covering topics in radioactive isotopes, and geochronology. Instructor: Patterson.

Ge 150. The Nature and Evolution of the Earth. *6 units (3-0-3).* Discussions at an advanced level of problems of current interest in the earth sciences. The course is designed to give graduate students in the geological sciences and scientists from other fields a broad sampling of data and thought concerning current problems. The lectures are given by members of the staff of the Division of the Geological Sciences. Staff members from other divisions and visiting lecturers from the outside also participate in the instruction. Students may enroll for any or all terms of this course without regard to sequence. Instructors: The staff and visitors.

Ge 151 a. Laboratory Techniques in the Earth Sciences. *5 units (0-5-0); second term.* Introductory training in the use of tools and techniques used in earth sciences research. Experiments of geological interest are done using the emission spectrograph, spectrophotometer, X-ray spectrometer, alpha and beta counters, mass spectrometers, wet chemical techniques and other available tools and techniques. The course carries a minimum of 5 units but additional units may be elected. In charge: Epstein.

Ge 165 a. Physics of the Earth's Interior. *6 units (3-0-3); second term.* A study of current knowledge concerning the interior of the earth using information from various earth-science disciplines. Introduction to relevant geophysical techniques and critical analysis of results. Interpretation of the fundamental data of seismology, geodesy, and heat flow using available high pressure laboratory data and equations of state with the aim of understanding the structure, composition, and phase of the earth's deep interior. Suitable for students in geology and as an elective in physics and engineering. Instructor: Anderson.

Ge 165 b. Interiors of the Terrestrial and Jovian Planets. *6 units (3-0-3); third term.* A study of the astronomical and dynamical evidence and some of the theories pertaining to the interiors of the planets. Mars, Venus, Moon and the Jovian planets will be covered. Topics to be treated include the mass-radius relation of cold bodies, the gravitational field and equilibrium configurations of the planets, internal density distributions inferred from dynamical considerations, equations of state and internal temperatures of the Jovian planets, composite model planets of hydrogen and helium, the terrestrial planets in the light of current knowledge of the earth's interior, thermal models for the planets, planetary magnetic fields. Instructor: Kovach.

Ge 171. Applied Geophysics. *10 units (4-0-6); second term.* The use of gravity, magnetic and seismic methods applied to geological field problems. Although not a prerequisite, this course may be taken as theoretical background for *Ge 120 c.* Instructor: Dix.

Ge 176. Elementary Seismology. *6 units (3-0-3); third term. Prerequisites: Ge 1, Ma 2 ab.* A survey of the geology and physics of earthquakes. Text: *Elementary Seismology,* Richter. Instructor: Richter.

Ge 212 ab. Thermodynamics of Geological Systems. *10 units each term (3-0-7); first and second terms.*

212 a. *Prerequisites: Ch 124 ab or Ch 21 abc.* An advanced treatment of chemical thermodynamics using the methods of Gibbs, with emphasis on applications to geologic problems. Topics to be covered include heat flow and heat sources, high pressure phase transformations, silicate phase equilibria, solid solutions, the effect of H_2O in silicate melts, and equilibrium in a gravitational field. Text: *Chemical Thermodynamics,* Prigogine and Defay. Instructor: Wasserburg.

212 b. *Prerequisite: 212 a.* Lectures and problems on the chemical and physical properties of aqueous solutions, with emphasis on the thermodynamic behavior of those electrolyte solutions important in nature. Topics to be covered include the effects of solution composition on mineral equilibria, Eh-pH diagrams, Debye Huckel theory, extension of thermodynamic data to high temperatures and pressures, non-ideality in mixed-gas systems, and reaction kinetics in systems involving water. Results will be applied to problems of metamorphic pore fluids, the magmatic gas phase, and hydrothermal vein deposits. Text: *Thermodynamics,* Lewis, Randall, Pitzer, and Brewer. Instructor: Taylor.

Ge 213. Seminar, to be offered at pleasure of the staff on special topics and problems of current interest in the fields listed below. *5 units. Prerequisites dependent upon topics.*

Ge 213 a—Mineralogy Seminar.

Ge 213 b—Petrology Seminar.

Ge 213 c—Geochemistry Seminar.

Ge 213 d—Geochronology Seminar.

Ge 214. Advanced Mineralogy. *10 units (3-3-4); first term. Prerequisite: Ge 115 abc.* Principles of optical and X-ray crystallography. The application of modern optical, powder diffraction, and single-crystal X-ray methods to the study of the feldspars, pyroxenes, micas, and other important mineral groups. Instructor: Kamb.

Ge 215 abc. Topics in Advanced Petrology. *Prerequisites: Ge 115, Ch 124, Ge 151 a.* Integrated lecture, laboratory, and seminar study of sedimentary, igneous, and metamorphic processes and their products. Laboratory and field studies will be pursued in close association with the classwork. Consideration of petrologic problems in terms of basic principles and modern approaches will be emphasized.

215 a. Advanced Sedimentary Petrology. *10 units (3-4-3); first term.*

215 b. Advanced Igneous Petrology. *12 units (3-6-3); second term.* Instructor: Silver.

215 c. Advanced Metamorphic Petrology. *12 units (3-6-3); third term.* Instructor: Albee.

Ge 216. Nuclear Problems in Geology. *10 units (3-0-7). Permission of instructor.* This course will cover a variety of topical material relating to nuclear processes which are of geologic importance. Topics to be covered include introductory discussion of theories of nucleosynthesis, naturally occcurring and extinct radioactivities and their daughter products, isotopic anomalies, heat generation in the earth, cosmic ray induced nuclides, methods of absolute age dating, age determinations on meteorites and rocks, the geologic time scale, element redistribution in radioactive parent-daughter systems, and residence times and mixing processes for some model systems. Instructor: Wasserburg.

Ge 220 ab. Lunar and Planetary Surfaces. *9 units (4-0-5); second and third terms. Prerequisite: Consult with instructor.* Observational evidence pertaining to the surface geology and geophysics of the Moon, Mars, Mercury, and the Galilean satellites is covered at an advanced level along with brief consideration of the probable surface conditions on other planets. The interpretation of visible, infrared, and microwave observations is considered in the context of: (1) the surface processes likely to have been operative in the past as well as present, and (2) the likely optical properties of silicate mineral aggregates in extraterrestrial surface environments. Instructor: Murray.

Ge 221. Astrogeology. *10 units (3-1-6); second term. Prerequisite: Ge 115 abc desirable.* Consult with instructor. A review of the distribution of solid objects in the solar system and the probabilities of their collision; physics and phenomenology of shock progation and cratering in rocks; shock metamorphism; fine-grained particles in space near the earth; distribution and characteristics of impact structures on the earth and applications to the interpretation of the stratigraphy, structure and history of the Moon. Instructor: Shoemaker.

Ge 222. The Chemistry of the Solar System. *6 units (3-0-3); first term. Prerequisite: Ge 30 ab or equivalent.* A discussion of the chemical composition in relation to other properties, of the Sun, planets (including Earth), satellites, comets, interplanetary gas and dust, and asteroids. Planetary atmospheres will be discussed in some detail. Special emphasis will be placed upon meteorites and their properties, including their motion and fall, morphology, chemistry, mineralogy and petrography as well as nuclear and chemical transformations induced by cosmic rays. Instructor: Brown.

Ge 225. Selected Topics in Planetary Science (Seminar). *5 units; second term.* Actual review of current research in a selected area of the chemistry, physics, or geology of the Moon, planets, or meteorites. In charge: Murray, Shoemaker, and other members of the staff.

Ge 229. Glacial Geology. *10 units (3-0-7); second term. Prerequisite: Ge 126.* Origin of glaciers, existing glaciers, glaciology and glacial mechanics, erosional and depositional features of mountain and continental glaciers, chronology of the Pleistocene. Text: *Glacial and Pleistocene Geology,* Flint. Not offered in 1965-66. Instructor: Sharp.

Ge 230. Geomorphology (Seminar). *5 units; third term.* Discussion of research and current literature in geomorphology. In charge: Sharp.

Ge 244 ab. Paleoecology (Seminar). *5 units; second and third terms.* Critical review of classic investigations and current research in paleoecology and biogeochemistry. In charge: Lowenstam.

Ge 245. Biostratigraphy (Seminar). *5 units; first, second and third terms.* A consideration of problems and principles of biostratigraphy, including regional, inter-regional, and world-wide correlations by means of fossils, and the problems arising from the consideration of animal geography. Instructor: Boucot.

Ge 247 a. Tectonics. *10 units (3-0-7); third term. Prerequisite: Ge 120 abc.* Structure and geophysical features of continents, ocean basins, geosynclines, mountain ranges, and island arcs. Structural histories of selected mountain systems in relation to theories of orogenesis. Offered in alternate years (1964-65). Instructors: Allen, Kamb.

Ge 247 b. Tectonophysics. *10 units (3-3-4); third term. Prerequisites: Ge 120 abc, Ge 108 or equivalent.* Analysis of stress and deformation in tectonic processes, using tensor representation. Elastic stress distributions, theory of fracture, and fault patterns. Theories of plasticity and steady-state creep, and their application to tectonic problems. Elastic and viscous buckling of layered media; folding. Convection and convective instability. Large-scale stress distributions and structural patterns in the earth. Tectonic models. Glaciers as natural tectonic laboratories. Offered in alternate years (1966-67). Instructors: Kamb, Allen.

Ge 247 c. Rock Deformation. *10 units (3-3-4). Recommended prerequisites: Ge 115 abc, PM 205 ab.* Brittle-ductile transition. Plasticity of single crystals, simple polycrystalline aggregates, and rocks of complex structure. Tensor theory of finite strain. Structural petrology and petrofabric analysis; microscopic features of deformed rocks; origin and interpretation of tectonite fabrics. Recrystallization. Thermodynamics of nonhydrostatic stress. Rheological properties of rocks on the time scale of tectonic processes. Offered in accordance with student interest. Instructor: Kamb.

Ge 261. Advanced Seismology: Theoretical. *6 units (3-0-3); first term. Prerequisite: Ph 108 abc.* Discusses essential material not covered in Ge 264 (Elastic Waves), including equations of electromagnetic seismographs and paths of seismic rays within the earth. Instructor: Richter.

Ge 264 ab. Elastic Waves. *8 units (4-0-4); first and second terms. Prerequisites: Ph 106 abc.* Experimental and theoretical aspects of elastic wave propagation in a layered half space, in plates, cylinders, and spheres, with application to seismic waves and underwater acoustics.

Ge 265 ab. Advanced General Geophysics. *9 units (3-0-6); second and third terms. Prerequisites: Ph 106 abc; Ph 108 abc; Ph 129 also desirable.* Topics from among the following areas will be selected: thermal regime of the earth, submarine geophysics; geomagnetism; planetary geophysics; gravity field; large-scale motions in the earth.

Ge 268 ab. Selected Topics in Theoretical Geophysics. *6 units (3-0-3); second and third terms. Prerequisite: Ph 129 abc or equivalent.* Discussion of seismic wave propagation, gravitational and magnetic fields, stress systems, and general thermodynamics as applied to earth processes. Content of course is altered somewhat from year to year depending mainly upon student needs. Instructor: Dix.

Ge 282 abc. Geophysics-Geochemistry (Seminar). *1 unit; first, second, third terms. Prerequisite: At least two subjects in geophysics or geochemistry.* Discussion of papers in geochemistry, general and applied geophysics. In charge: Epstein, Smith.

Ge 295. Master's Thesis Research. *Units to be assigned. Listed as to field according to the letter system under Ge 299.*

Ge 297. Advanced Study. Students may register for 8 units or less of advanced study in fields listed under Ge 299. Occasional conferences.

Ge 299. Research. Original investigation, designed to give training in methods of research, to serve as theses for higher degrees, and to yield contribution to scientific knowledge. These may be carried on in the following fields:

Geology:

- (A) Economic Geology
- (B) Field Geology
- (C) Geomorphology
- (D) Glaciology
- (E) Invertebrate Paleontology
- (F) Mineralogy
- (G) Paleoecology
- (H) Petrology
- (I) Sedimentation
- (J) Stratigraphy
- (K) Structural Geology

Geochemistry:

- (L) General Geochemistry
- (M) Geochronology
- (N) Isotopic Geochemistry
- (O) Meteorites

Geophysics:

- (P) Applied Geophysics
- (Q) General Geophysics
- (R) Geophysical Instruments
- (S) Seismology
- (T) Theoretical Geophysics

Planetary Science:

- (U) Planetary Observations
- (V) Laboratory Studies
- (W) Theoretical Studies

German
(See under Languages)

Government and International Affairs
Advanced Subjects

Gt 115 abc. Seminar on National Security.* *9 units (2-0-7). Senior Elective.* The object of this course is to afford an opportunity to study some of the problems faced by the U.S. Government in the world today. Consideration will be given to such matters as the process of policy formation within the government, the relationship of disarmament and arms control to defense policy, and the role of international organizations in the development of an orderly world society. Instructor: Elliot.

Gt 130. Comparative Politics.* *9 units (3-0-6). Senior Elective.* How parties, cliques, and pressure groups gain and use power in different political cultures. Instructor: Guyot.

Gt 140. Seminar in Foreign Area Problems.* *9 units (3-0-6); second term. Senior Elective.* The object of this course is to give students an opportunity to study in some detail problems current in certain selected foreign areas. Three or four areas will be considered each time the course is given, and the selection will normally vary from year to year. Instruction will be given mainly by area specialists of the American Universities Field Staff. Instructors: Munger, and members of AUFS.

Gt 141 abc. African Studies.* *9 units (2-0-7). Senior Elective.* Problems of transition from colonial status to independence in countries south of the Sahara. Racial and cultural tensions in the Union of South Africa. Instructor: Munger.

Gt 142. Southeast Asia after Colonialism.* *9 units (3-0-6). Senior Elective.* Consideration will be given to developments in Vietnam, Burma, Malaya, Indonesia, and the Philippines after independence from European and American rule. The course will be focused on the attempts of these new states to promote national unity, stimulate economic growh, and preserve democratic government. Instructor: Guyot.

History
Undergraduate Subjects

H 1 a. An Introduction to Modern Europe. *5 units (2-0-3); first term.* The beginnings of modern Europe, culminating in the era of the French Revolution. A selection is made of particular topics of lasting significance for the development of Europe as we know it. Included are such subjects as the English Revolution, the Enlightenment, the Ancient Regime, the French Revolution and the career of Napoleon. Particular attention is paid to some of the important political ideas which emerged in the period. There are regular and frequent written assignments. Instructors: D. C. Elliot and staff.

H 1 bc. Nineteenth and Twentieth Century Europe. *11 units (3-0-8); second and third terms.* A general study of historical development from the fall of Napoleon to the present. Included among the themes considered are the rise of nationalism and the growth of liberal democracy, the process of industrialization and the adjustment of attendant social disorders, the rise and fall of imperialism, the recurrence of war and revolution. Attention is also paid to the great statesmen and to the more important political thinkers of the period as well as to some of the more dramatic and illuminating events of this historical epoch. There are regular and frequent written assignments.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

H2 abc. History and Government of the United States. *6 units (2-0-4); first, second, third terms.* The evolution of the American nation and the American character, from the seventeenth century to the present. The course will include a study of the Constitution and form of government of the United States and the State of California, and will trace the evolution of national and local political institutions and ideas. Instructors: Kevles and staff.

H5 abc. Public Affairs. *2 units (1-0-1); first, second, third terms.* This course involves a discussion of selected problems which are of continuing significance for the American people. Particular attention will be paid to the development of foreign policy and to the impact of this policy upon other parts of the world. Instructors: Elliot, Sweezy, and guests.

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.

H 41. Summer Reading. *Units to be determined for the individual by the department. Maximum, 8 units. Elective.* Reading in history and related subjects during summer vacation. Topics and books to be selected in consultation with members of the department. A brief written report will usually be required.

ADVANCED SUBJECTS

H 101. Tutorial. Open to students majoring in history. Reading, preparation of a research paper, and preparation for a general examination, under the supervision of members of the staff.

H 105 abc. The Middle Ages.* *9 units (3-0-6). Senior Elective.* Successive terms will trace government, economic change, and intellectual and social life. Topics will include: first, the medieval origins of English parliamentary government, French autocracy, and German fragmentation; second, the economic consequences of the Germanic and Moslem conquests, the growth of the medieval economy, origin of towns, and technological change; third, medieval thought, social ideals, love, and chivalry. Instructor: Benton.

H 112. Europe since 1914.* *9 units (3-0-6); Senior Elective.* Since 1914 the world has felt the impact of two great wars and powerful revolutionary ideas. This course will analyze the upheavals of the twentieth century and their effect on domestic and international organization. Instructor: Fay.

H 116 Germany.* *9 units (3-0-6). Senior Elective.* 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). Senior Elective.* An attempt to discover and interpret the major recurring characteristics of Russian history and society, with attention particularly to developments in the Soviet period. Instructor: Ellersieck.

H 118. Britain.* *9 units (3-0-6). Senior Elective.* Main elements in the political life of modern Britain. Attention will be concentrated primarily on events since 1832, and emphasis will be placed on economic and social trends, on political and constitutional development, and on the lives of important statesmen. Instructor: Elliot.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

H 120. The British Empire nad Commonwealth.* *9 units (3-0-6). Senior Elective.* The growth of the imperial idea and the institutional development of the Empire and the Commonwealth with particular reference to Africa and Asia. Instructor: Huttenback.

H 121. India and Pakistan.* *9 units (3-0-6). Senior Elective.* The growth of Indian nationalism in the years before independence, and developments in India and Pakistan since partition. Special emphasis will be placed on the philosophical conflict between British and indigenous Indian attitudes and the consequent effect on contemporary India and Pakistan. Instructor: Huttenback.

H 130. History of War.* *9 units (3-0-6). Senior Elective.* An examination of instructive episodes in the evolution of warfare. Emphasis upon the role of political, economic and social factors in influencing the choice of organization, armament, tactics and the timing of conflict. Instructor: Ellersieck.

H 147. The Far West and the Great Plains.* *9 units (3-0-6). Senior Elective.* The exploration and development of the great regions of western America. Especial attention will be paid to the influence of the natural environment, and the exploitation of it by such industries as the fur trade, mining, cattle ranching, farming and oil. Instructor: Paul.

H 151. Industrial Change and an Age of Reform in America, 1865-1917.* *9 units (3-0-6). Senior Elective.* An examination of major political responses in the United States to the dislocations of an emergent industrial and urban society. Instructor: Woodbury.

H 152. The 1920's and the New Deal, 1919-1941.* *9 units (3-0-6). Senior Elective.* The economics and politics of the boom years and the Great Depression. Instructor: B. Jones.

H 153. America since 1940.* *9 units (3-0-6). Senior Elective.* The foreign and domestic politics of an emerging affluent society, with emphasis on the minority group revolution, the new conservatism, and the modification of American liberalism. Instructor: Kevles.

H 154. American Foreign Policy in the Twentieth Century.* *9 units (3-0-6). Senior Elective.* How American foreign policy has been formed and administered in recent times: the respective roles of the State Department, Congress, and the President, of public opinion and pressure groups, of national needs and local politics. Instructor: Paul.

H 157. Science in America, 1865-present.* *9 units (3-0-6). Senior Elective.* Social and political history of American science, emphasizing the role of science in government, industry, and university. Instructor: Kevles.

H 201. Reading and research for graduate students. Units to be determined for the individual by the staff.

HYDRAULICS

ADVANCED SUBJECTS

Hy 100. Hydraulics Problems. *Units to be based upon work done, any term.* Special problems or courses arranged to meet the needs of fifth-year students or qualified undergraduate students.

Hy 101 abc. Fluid Mechanics. *9 units; first, second, third terms. Prerequisites: ME 19 ab and Hy 111 or equivalent.* General equations of fluid motion; two- and

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

three-dimensional steady and non-steady potential motion; cavity and wake flow; surface waves, linear and nonlinear shallow-water waves, layered media, stability; acoustic fields, sound radiation and scattering, acoustic energy transport; one-dimensional steady gasdynamics, expansion fans, shock waves; two- and three-dimensional flow fields; laminar flow, Stokes and Oseen problems, laminar boundary layer; laminar instability, turbulence, turbulent shear flow; introduction to problems in heterogeneous flow, chemically reacting flow, sediment transport, flow through porous media. Instructor: Marble.

Hy 103 abc. Advanced Hydraulics and Hydraulic Structures. *9 units (3-0-6); first, second, third terms. Prerequisites: ME 19 ab and Hy 111 or equivalent.* Ideal fluid flow, turbulence and diffusion, boundary layers, dimensional analysis, hydraulic models, steady flow in open channels, hydraulic jump, high-velocity flow in open channels; theory and design of hydraulic structures such as inlets, chutes, energy dissipators, canals, transitions; sedimentation, surface waves and coastal engineering, and unsteady flow in pipes and channels. Instructors: Vanoni, Raichlen.

Hy 105. Analysis and Design of Hydraulic Projects. *6 or more units as arranged; any term.* The detailed analysis or design of a complex hydraulic structure or project emphasizing interrelationships of various components, with applications of fluid mechanics and/or hydrology. Students generally work on a single problem for the entire term, with frequent consultations with the instructor. Among possible problems or projects are multipurpose river storage projects, spillways, waterpower developments, pipelines, pumping stations, distribution and collection systems, flood control systems, ocean outfalls, water and sewage treatment plants, irrigation systems, navigation locks and harbors. Instructors: Vanoni, Brooks, Raichlen.

Hy 111. Fluid Mechanics Laboratory. *6-9 units as arranged with instructor; second or third term. Prerequisite: ME 19 ab.* A laboratory course illustrating the basic mechanics of incompressible fluid flow, and complementing the lecture course ME 19 abc. Students will usually select 4 or 5 regular experiments, but with the permission of the instructor they may propose special investigations of brief research projects of their own in place of some of the regular experiments. Objectives also include giving students experience in making engineering reports. Although the course is primarily for seniors, it is also open to first-year graduate students who have not had an equivalent course. Instructor: Raichlen.

Hy 121. Advanced Hydraulics Laboratory. *6 or more units as arranged; any term. Prerequisite: Consent of instructor.* A laboratory course primarily for fifth-year students dealing with flow in open channels, sedimentation, waves, hydraulic structures, hydraulic machinery, or other phases of hydraulics of special interest. Students may perform one comprehensive experiment or several shorter ones, depending on their needs and interests. Instructor: Staff.

Hy 134. Flow in Porous Media. *9 units (3-0-6); third term. Prerequisite: AM 95 abc or AM 113 ab and AM 116. (One term of the prerequisite courses may be taken concurrently.)* A study of the hydrodynamics of flow through porous media, with applications primarily in the field of ground water flow, including seepage through earth dams and levees, uplift pressures on dams and foundations, flow toward wells, ground water recharge, drainage, dispersion of contaminants, and salinity intrusion. Instructor: Brooks.

Hy 200. Advanced Work in Hydrodynamics or Hydraulic Engineering. *Units to be based upon work done; any term.* Special courses on problems to meet the needs of students beyond the fifth year.

Hy 201 abc. Hydraulic Machinery. *6 units (2-0-4); first, second, third terms.* A study of such rotating machinery as turbines, pumps, propellers, and blowers and their design to meet specific operating conditions. This course will be given in seminar form led by members of the Hydrodynamics and Mechanical Engineering staffs. Not given every year. Instructor: Acosta.

Hy 203. Cavitation Phenomena. *6 units (2-0-4); first or third term. Prerequisite: Graduate standing.* Study of the experimental and analytical aspects of cavitation and allied phenomena. Problems will be considered in the field of high speed flow and also for bodies moving in a stationary fluid. Instructor: Ellis.

Hy 210 ab. Hydrodynamics of Sediment Transportation. *9 units (3-0-6). Prerequisites: AM 95 abc and Hy 103 abc or Hy 101 abc.* A study of the mechanics of the entrainment, transportation, and deposition of solid particles by flowing fluids. This will include problems of water and wind erosion. Instructor: Vanoni.

Hy 211. Advanced Hydraulics Seminar. *4 units (2-0-2); every term.* A seminar course for advanced graduate students to discuss and review the recent technical literature in hydraulics and fluid mechanics. Emphasis will be on topics related to civil engineering which are not already available in courses offered by the Division of Engineering and Applied Science. The subject matter will be variable depending upon the needs and interests of the students. It may be taken any number of times with permission of the instructor. Instructor: Brooks.

Hy 300. Thesis.

Information Sciences

Several classes of courses are offered on the basic principles of information processing and machine computation. There are a number of non-credit coding courses given every term that are frequently prerequisites to certain credit courses and to the uses of the computers in the Booth Computing Center. The office of the Computing Center should be contacted concerning these.

The following courses listed under Information Sciences are directly concerned with the basic principles of computers, language theory and programming.

IS 110 abc. Principles of Digital Information Processing Systems. *9 units (3-3-3).* This course presents the principles and concepts of digital information processing systems with emphasis on the stored program synchronous computer. This includes switching theory and its application to the design of systems. The organization of digital processors at the machine language level is covered together with the basic concepts of formal algebraic languages, their uses and the translation between them and machine languages. The laboratory permits direct experimentation with a variety of systems ranging from basic subsystems to complete computers. Instructors: McCann, Ray.

IS 130 abc. Information Systems Synthesis. *9 units (3-0-6); three terms. Prerequisites: Fortran IV Coding Course and Machine Language Coding Course or equivalents.* This course presents a systematic consideration of the concepts and practices involved in the design of large-scale operating systems for information processing. The course starts with a treatment of the basic system design tools such as scanning, text encoding, list processing and storage allocation. Translation and communication processors are covered next. Design criterion and techniques for compilation, translation and buffering are discussed. The processing components are developed now into complete operating systems. The remainder of the course consists of a study of such concepts as shared-file processors, real-time computing and data collection, and multi-tasking processors. Text: class notes. Instructor: Caine.

IS 181 ab. Linear Programming. *9 units (3-0-6); second and third terms. Prerequisite: AMa 104 or MA 5 abc.* Engineering and economic applications of linear programming. Duality and equilibrium theorems. The simplex method. Integral linear programming. Assignment transshipment, and transportation problems. Applications to game theory. Computational methods. Instructor: Franklin.

IS 250 abc. Mathematical Linguistics. *9 units (3-0-6).* 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 language will be stressed together with the formalization of language structures suitable for computer simulation. Instructor: Thompson.

The following courses cover related basic mathematics and applied mathematics:

AMa 194. Matrix Algebra. See Applied Mathematics Section.

AMa 105 ab. Introduction to Numerical Analysis. See Applied Mathematics Section.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. See Mathematics Section.

Ma 121 ab. Combination Analysis. See Mathematics Section.

Ma 205 abc. Numerical Analysis. See Mathematics Section.

Ma 216 abc. Advanced Mathematical Logic. See Mathematics Section.

JET PROPULSION

ADVANCED SUBJECTS

JP 120 abc. Chemistry Problems in Propulsion. *9 units (3-0-6); each term. Open to all graduate students and to seniors by permission of instructor.* Propellant chemistry; descriptive discussions of atomic and molecular structure, standard heats of formation, normal vibrations, chemistry of propellants. Combustion thermodynamics; chemical equilibrium, quantitative evaluation of rocket propellants, thermodynamic functions for atoms and molecules. Introduction to flame theory; phenomenological chemical kinetics, transport properties, introduction to laminar and diffusion flames, detonation, combustion of solid propellants, heterogeneous combustion, turbulent flames. Text: *Chemistry Problems in Jet Propulsion,* Penner.

JP 121 abc. Rockets and Air Breathing Engines. *9 units (3-0-6); each term. Prerequisites: AM 95 ab, AM 116 or equivalent (may be taken concurrently with permission of instructor).* Basic performance and comparison of rocket and air breathing engines. Nozzle flow, under- and over-expansion, particle flow in nozzles, heat transfer and cooling of components. Cycle analysis of air-breathing engines; component performance; diffusers, combustion chambers, compressors, turbines, ducted fans; component matching and over-all performance. Properties and burning characteristics of solid propellants, solid propellant rocket motors; properties and burning characteristics of liquid propellants, propellant feed systems, liquid rocket motors, low frequency and high frequency instability; weight estimates, optimization of vehicle performance. Instructor: Zukoski.

JP 170. Jet Propulsion Laboratory. *9 units (0-9-0); third term.* Laboratory experiments related to propulsion problems. Instructor: Zukoski.

JP 201. Physical Mechanics. *9 units (3-0-6); any term. Prerequisite: JP 120 abc or equivalent.* Introduction to quantum mechanical and statistical mechanical methods for calculating thermodynamic properties, in particular properties of materials at high temperatures; transport theory. Not offered every year.

JP 202 abc. Quantitative Spectroscopy and Gas Emissivities. *9 units (3-0-6); each term. Prerequisite: Ph 112 or Ch 226 or JP 201 or equivalent.* This course will consist of the following subjects, with one term being devoted to each subject: (1) Black-body radiation laws, Einstein coefficients, integrated intensities and f-numbers. Spectral line widths and shapes; the curves of growth. Theoretical calculation of absolute intensities for atoms and molecules. (2) Theoretical calculation of equilibrium gas emissivities and absorptivities; infrared emissivities for diatomic molecules at low pressures; pressure-induced transitions. Infrared emissivities of polyatomic molecules. Emissivity calculations for heated air. Emissivity calculations for a hydrogen plasma. Relation between gas absorptivities and emissivities. Spectroscopic techniques for temperature measurements. (3) Radiative transfer problems in ionized gases; emission of radiation behind shock fronts; the influence of radiative transfer on the flow equations; radiant heat transfer to hypersonic vehicles during re-entry of the atmosphere. Approximate emissivity calculations for polyelectronic atoms. Line broadening in ionized gases. Not offered every year. Text: *Quantitative Molecular Spectroscopy and Gas Emissivity,* Penner.

JP 203 abcd. Ionized Gas Theory. *6 units (2-0-4); any term. Prerequisite: Ph 112 or Ch 226 a or JP 201 a or equivalent.* The course will consist of the following subjects with one term being devoted to each subject: (1) Particle interactions: elastic, inelastic and recombination collisions involving neutral atoms, electrons and + ions studied in sufficient detail for accurate evaluation of bulk kinetic and thermodynamic properties of ionized gases. (2) Bulk properties: Application of kinetic theory, statistical thermodynamics and collision parameters developed in (1) above to bulk properties of ionized gases such as equilibrium composition, electrical conductivity, ambipolar diffusion rate and others. (3) Surface phenomena: Particle and bulk interactions between an ionized gas and a bounding surface, surface emission processes, electrical and thermal conduction between a hot ionized gas and a cold surface. (4) Discharges: Ionization in strong electric fields, electron and ion mobilities, glow discharges, arc discharges, engineering applications. Not offered every year. Instructors: Staff.

JP 211 ab. Gas Dynamics of Propulsion System Components. *6 units (2-0-4); any term. Prerequisites: JP 121 abc, Ae 101 abc or Hy 101 abc or equivalent.* This course will consist of the following subjects with one term being devoted to each subject: (1) Inlet diffusers: theory of diffusers for air breathing engines in supersonic and hypersonic flow, real fluid effects and losses, stability, diffuser problems in rarefied gases. (2) Nozzles: theory of three-dimensional flow in nozzles, separation and over-expansion, plug nozzles; chemical reactions and phase condensation; particle flow in nozzles. Not offered every year. Instructors: Marble, Zukoski.

JP 212 ab. Flame Theory and Combustion Technology. *6 units (2-0-4); any term. Prerequisites: JP 120 abc, Ae 101 abc or Hy 101 abc or equivalent.* This course will consist of the following subjects with one term being devoted to each subject: (1) Stationary flames: review of laminar flame and diffusion flame theory; combustion of solid propellants, spray burning; combustion in boundary layers, wakes, and laminar mixing regions; principles of ignition; turbulence and turbulent flames. (2) Unsteady flames: gas dynamic flow fields with flame discontinuities, structure of non-steady flames, stability of laminar flames; unsteady combustion of particles and droplets; flame holding, flame spreading; combustion chambers. Not offered every year. Instructors: Staff.

JP 221 abc. Rocket Trajectories and Orbital Mechanics. *6 units (2-0-4); any term. Prerequisite: AM 95 ab. (Students who have taken or are intending to take Ae 103 and Ae 203 should consult the instructor.)* This course will consist of the following subjects with one term being devoted to each subject: (1) Ballistic trajectories: impulsive launching, optimization with finite burning time, gravity turn; re-entry, non-lifting and gliding. (2) Satellite orbits: motion in an inverse square law field; perturbations due to oblateness of the earth, radiation pressure, moon, sun, and aerodynamic drag. (3) Space vehicle trajectories: transfer ellipses, minimum energy estimates, motion in the Earth-Moon system, powered flight. Not offered every year. Instructors: Staff.

JP 230 abcd. Power Generation and Propulsion in Space. *6 units (3-0-3); any term. Prerequisite: JP 121 abc (some previous knowledge of Electromagnetic Theory and Modern Physics is advisable).* (The aim of this course is to provide the background for understanding the current status and problems of space propulsion systems. The emphasis will change from year to year and the various terms are independent.) This course will consist of the following subjects with one term being devoted to each subject: (1) Power generation for space systems: general power requirements for space systems, turbogenerator systems with solar or nuclear power sources, radioisotope power supply, silicon solar cell, and thermoelectric systems; heat rejection and condensation processes. (2) Plasma propulsion and power extraction: plasma properties and magnetohydrodynamic flow fundamentals; steady, wave guide, and pulsed types of plasma accelerators, limitations on performance. (3) Ion propulsion: ion sources, ion accelerators, and beam neutralization; limitations on performance. (4) Nuclear propulsion: principles of the nuclear heat transfer rocket, propellant feed systems, cooling, and materials limitations; the gaseous fission rocket. Not offered every year. Instructor: Marble.

JP 240 a. Heat Transfer in Propulsion Systems—Radiative Heat Transfer. *9 units (3-0-6); any term. Prerequisite: AM 95 ab.* Black body radiation laws; spectral absorption coefficients; spectral emissivities and absorptivities for gases, liquids, and solids. The fundamental equations for radiative transfer. Mean absorption coefficients. Methods of solution of representative integro-differential equations arising in radiative transfer calculations. Non-dimensional parameters in transfer processes involving radiative exchange. Radiative transfer in shock waves, solid propellant burning, etc. Not offered every year.

JP 240 b. Heat Transfer in Propulsion Systems—Conductive and Convective Heat Transfer. *9 units (3-0-6); any term. Prerequisite: Hy 101 abc or ME 118 abc or equivalent.* Exact and approximate integral solutions of unsteady heat conduction problems, applications to solid propellant rocket motors; convective heat transfer to rocket chambers and nozzles, regenerative cooling of liquid propellant motors. Not offered every year. Instructor: Rannie.

JP 250 abc. Fluid Mechanics of Axial Turbomachines. *6 units (2-0-4); any term. Prerequisite: Hy 101 abc or equivalent.* This course will consist of the following subjects with one term being devoted to each subject: (1) Cascade theory: potential flow through two-dimensional cascades, real fluid effects, and evaluation of performance. (2) Axisymmetrical flow: flow through an actuator disc in an annular duct, linearized perturbations of strong vorticity fields, single and multiple blade rows of finite axial length, effect of varying duct height, and compressibility effects. (3) Three-dimensional real fluid effects: secondary flow, propagating stall, blade tip clearance flow. Not offered every year. Instructors: Marble, Rannie.

JP 270. Special Topics in Propulsion. *6 units (2-0-4).* The topics covered will vary from year to year. Instructors: Staff.

JP 280. Research in Jet Propulsion. *Units to be arranged.* Theoretical and experimental investigations of problems associated with propulsion and related fields. Instructors: Staff.

JP 290 abc. Advanced Seminar in Jet Propulsion. *1 unit (1-0-0); each term.* Seminar on current research problems in propulsion and related fields. Instructors: Staff.

LANGUAGES

UNDERGRADUATE SUBJECTS

L 1 abc. Elementary French. *10 units (3-1-6); first, second, third terms.* A course in grammar, pronunciation, and reading that will provide the student with a vocabulary and with a knowledge of grammatical structure sufficient to enable him to read at sight French scientific prose of average difficulty. Accuracy and facility will be insisted upon in the final tests of proficiency in this subject. One session in the language laboratory will be scheduled each week. Students who have had French in the secondary school should not register for this subject without consulting with the department of languages. Instructors: Stern, A. Mandel.

L 5. French Literature.* *9 units (3-0-6); second term. Senior Elective. Prerequisite: L 1 ab, or the equivalent.* The reading of selected classical and modern literature, accompanied by lectures on the development of French literature. Elective and offered when there is sufficient demand. Instructors: Bowerman, Stern.

L 32 abc. Introductory Scientific German. *10 units; first term (3-1-6), second term (3-1-6); third term (4-0-6).* A course in grammar, pronunciation, and reading that will provide the student with the ability to read scientific literature of average difficulty. In the first two terms, the essentials of grammar are covered, supplemented by a weekly drill in the language laboratory and selections from an elementary scientific reader. The third term is devoted to the reading of scientific literature of graduated difficulty. Students who have had German in the secondary school or junior college should not register for this course without consulting the staff in languages. Instructor: Bowerman.

L 33 abc. Introductory Literary German. *10 units (3-1-6); first, second, third terms.* A study of the fundamentals of grammar and pronunciation, culminating in the reading of several short literary works by modern German writers. Although primary emphasis is upon the reading goal, some stress is also placed upon the oral use of the language by both instructor and students. Classroom work is supplemented by an hour of language laboratory drill weekly. Students who have had German in the secondary school or junior college should not register for this course without consulting the staff in languages. Instructor: Wayne.

L 35. Scientific German. *10 units (0-0-10); first term. Prerequisite: L 32 abc, or equivalent.* This is a continuation of L 32 abc, with special emphasis on the translation of scientific material in the student's field. Instructor: Bowerman.

L 39 abc. Reading in French or German. *Units to be determined for the individual by the department.* Reading in scientific or literary French or German under the direction of the department.

L 40. German Literature.* *9 units (3-0-6): third term. Senior Elective. Prerequisite: L 35, or L 32 abc with above average grades.* The reading of selected classical and modern literature, accompanied by lectures on the development of German literature. Instructor: Stern.

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

L 50 abc. Elementary Russian. *10 units (4-0-6); first, second, third terms.* A course in pronunciation, grammar, and reading that is intended to enable a beginner to read technical prose in his field of study. Students are expected to become familiar with a basic scientific vocabulary. Articles from current Russian scientific periodicals are used in the second and third terms. Instructors: Kosloff, Novins.

L 51 abc. Intermediate Russian. *10 units (4-0-6); first, second, third terms. Prerequisite: L 50 abc or the equivalent.* A continued study of the Russian language with increased emphasis on conversation. The reading of selected classical and modern literature. Discussions in Russian. Continuation of reading and translation of scientific material. Instructor: Kosloff.

ADVANCED SUBJECTS

L 105. Same as L 5. For graduate students.

L 140. Same as L 40. For graduate students.

MATERIALS SCIENCE

UNDERGRADUATE SUBJECTS

MS 5 abc. Principles of Engineering Materials. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ch 1 abc, Ph 2 abc, AM 97 a.* The purpose of this course is to acquaint the student with the principles underlying the properties of solid materials. The electronic structure of atoms, the types of bonds between atoms in molecules and crystals, crystal structure and its determination by X-ray diffraction, and the band theory of crystalline solids are discussed. Topics in the physical properties of solids include: Electrical and thermal conductivity; the dielectric properties of insulators; diamagnetism, paramagnetism, ferromagnetism, and antiferromagnetism; specific heat; thermoelectric effects. An introduction to statistical thermodynamics is given. Rate processes such as diffusion and phase transformations in solids are discussed briefly. Elastic and plastic deformation of crystals, the concept of dislocations, properties, and interactions of dislocations are studied and applied to discussions of mechanical properties of polycrystalline aggregates, influence of grain size, alloying and phase dispersion, and high temperature creep and fracture. Instructors: Buffington (MS 5 b), Wood (MS 5 a, c).

MS 10. Engineering Physical Metallurgy. *9 units (2-1-6); first term. Prerequisite: MS 5 ab, or ME 3.* A study of the properties of ferrous and non-ferrous metals and alloys with respect to their application in engineering; the principles of the treatment of ferrous and non-ferrous alloys for a proper understanding by engineers for application of alloys in fabrication and design. Four laboratory sessions during the term correlate properties and heat treatment with the microstructures of alloys. Text: *Physical Metallurgy for Engineers,* Clark and Varney. Instructors: Clark, Buffington.

MS 11. Metallography Laboratory. *9 units (0-6-3); second term. Prerequisite: MS 10.* The technique of metallographic laboratory practice including microscopy, preparation of specimens, etching reagents and their use, photomicrography. The study of the microstructure of ferrous and non-ferrous metals and alloys for different conditions of treatment. Text: *Principles of Metallographic Laboratory Practice,* Kehl. Instructors: Clark, Buffington.

ADVANCED SUBJECTS

MS 100. Advanced Work in Physical Metallurgy. The staff in physical metallurgy will arrange special courses or problems to meet the needs of fifth-year students or qualified undergraduate students.

MS 102. Pyrometry. *9 units (1-6-2); third term. Prerequisite: Ph 2 abc.* Study of the principles of thermometry and the theory underlying instruments that are used to measure temperatures. Experiments will be conducted with a variety of such instruments to illustrate their applications and limitations. Instructors: Staff.

MS 103 ab. Physical Metallurgy Laboratory. *9 units (0-9-0); first term. 6 units (0-6-0); second term. Prerequisite: MS 11.* Experimental studies concerned with the structures and properties of metals and alloys associated with heat treatment and recrystallization phenomena. Studies of hardenability characteristics of steel with respect to prediction by thermodynamic considerations. The determination of grain size of metals and alloys in relation to properties. Instructor: Clark.

MS 105. Mechanical Behavior of Metals. *6 units (2-0-4); first term. Prerequisites: AM 97 abc, MS 5 abc.* A study of the mechanical behavior of metals for engineering applications. Elastic behavior of antistropic 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 112 ab. Advanced Physical Metallurgy. *9 units (3-0-6); second and third terms. Prerequisites: MS 5 ab or MS 120, MS 115 a.* Ternary phase diagrams; order-disorder transformations; solid-state diffusion; theory of gas-metal reactions; advanced consideration of magnetic properties; effects of radiation on materials. Instructor: Buffington.

MS 115 ab. Crystal Structure and Properties of Metals and Alloys. *9 units (3-0-6); first and second terms. Prerequisite: MS 5.* Physics of X-rays, elementary crystal structure, symmetry operations, symmetry classes, space groups. Stereographic projections. Reciprocal lattice. Von Laue and Debye-Scherrer methods of crystal structure analysis. Use of the diffractometer and intensity measurements. The texture of plastically deformed metals. Electron and neutron diffraction. Relationships between the structure of metals, solid solutions and intermetallic compounds and their physical properties. Text: *Elements of X-ray Diffraction, Cullity and Atomic Theory for Students in Metallurgy,* Hume-Rothery. Instructor: Duwez.

MS 116. X-Ray Metallography Laboratory I. *9 units (0-6-3); third term. Prerequisite: MS 115 a.* Experiments on X-ray emission spectra and absorption edges. Determination of crystal structures by the Von Laue and Debye-Scherrer methods. Use of the X-ray spectrometer. Study of preferred orientation in cold worked metals. Application of X-ray diffraction methods to the study of phase diagrams. Instructor: Duwez.

MS 120. Physics of Solids. *9 units (3-0-6); first term. Prerequisite: AM 95 ab or equivalent.* Introduction to wave mechanics; band theory of solids; physical properties of solids. Those who have received credit for MS 5 ab cannot receive credit for MS 120, since there exists some duplication of material. Additional study in physics of solids can be arranged under MS 100. Instructor: Buffington.

MS 135. Radioisotopes Laboratory. *9 units (0-9-0); third term. Prerequisites: AM 103 a, MS 112 a.* Experiments illustrating the use of radioisotopes in the field of physical metallurgy. Typical examples are studies of solid state diffusion and the determination of chemical inhomogeneities in metals and alloys. Instructor: Buffington.

MS 150 abc. Principles of Polymer Science. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 95 ab, or equivalent.* During the first term the following topics are discussed: types of polymeric substances–definition and classifications; chemical structure of monomers; methods of synthesis of polymers; principles of condensation polymerization–kinetics and molecular weight distribution; theory of gelation; principles of free radical polymerization–kinetics and molecular weight distribution, various techniques of molecular weight determination–viscosity, light scattering, osmometry; statistical thermodynamics of polymer solutions.

During the second term, the following topics are discussed: dimensions of polymer chains; diffusion and viscosity theory: molecular friction factor, segmental motion and glass temperature, free volume; conformation of crystalline polymers, kinetics and thermodynamics of growth of crystallites, effect of stretching on crystallinity.

During the third term, the following topics are discussed: rubber elasticity; molecular theory of viscoelasticity á la Rouse, Bueche, and Zimm; tensile strength of rubbers; properties of polymeric glasses; flaws, cracks, and crazing in plastics; theory of flow and extrusion of molten polymers.

Text: *Physical Properties of Polymers,* F. Beuche, Interscience (1962). All needed thermodynamic relations are derived in the course. Offered in alternate years, beginning 1965-66. Instructor: Blatz.

MS 200. Advanced Work in Physical Metallurgy. The staff in physical metallurgy will arrange special courses or problems to meet the needs of students beyond the fifth year.

MS 205 a. Theory of Crystal Dislocations. *9 units (3-0-6); second term. Prerequisites: AM 110 a, MS 115 a (may be taken concurrently).* The concept of a dislocation, special types and general dislocations. Dislocation motion and plastic deformation. The force on a dislocation, and the stress field and energy of a dislocation. Interactions of a dislocation with the crystal lattice, other dislocations, surfaces, and point defects. Text: *Dislocations in Crystals,* Read. Instructor: Wood.

MS 205 b. Dislocations and the Mechanical Properties of Crystalline Solids. *9 units (3-0-6); third term. Prerequisites: MS 205 a.* Current theories of plastic yielding, strain hardening, alloy hardening, anelasticity, twinning, fracture, creep, and fatigue are discussed. Experimental techniques used for the observation of crystalline defects are discussed including etch pitting, X-ray diffraction, electron transmission and diffraction, and field ion microscopy. Texts: *Mechanical Properties of Metals,* McLean, and selected readings from current literature. Instructor: Vreeland.

MS 217. X-Ray Metallography Laboratory II. *9 units (0-6-3); any term. Prerequisite: MS 116.* An advanced laboratory course for students carrying out research involving the use of X-ray diffraction techniques. Methods of X-ray diffraction requiring the use of single crystals, rotating crystal and Weisenberg methods. Accurate measurements of diffracted intensities. Quantitative analysis of phases in alloys. Special problems will be assigned, depending on the student's field of interest. Instructor: Duwez.

MS 225. Industrial Physics Metallurgy. *9 units (0-6-3); any term. Prerequisites: MS 103, MS 116.* Application of the principles of physical metallurgy and the techniques of metallographic laboratory practice to the solution of problems concerning the causes of failure of commercial parts. Typical cases are used as problems to be solved by the student and presented and discussed before the class and staff in the form of reports. Instructor: Clark.

MS 250 abc. Advanced Topics in Physical Metallurgy. *6 units (2-0-4); first, second, and third terms.* The content of this course will vary from year to year. Topics of current interest will be chosen according to the interests of students and staff. Visiting professors may present portions of this course from time to time. Instructors: Staff.

MS 300. Thesis Research.

MATHEMATICS

UNDERGRADUATE SUBJECTS

Ma 1 abc. Freshman Mathematics. *12 units (4-0-8); first, second, third terms. Prerequisites: High school algebra and trigonometry.* An introduction to the calculus; vector alegbra; analytic geometry; infinite series. Professor in charge: Fuller.

Ma 1.5 abc. Advanced Placement in Mathematics. *12 units (4-0-8); three terms.* This course is restricted to entering freshmen who are given advanced placement in mathematics. The concepts of the calculus are reviewed and the course covers the materials of Ma 1 abc and Ma 2 abc. Students who complete this course are given full credit for Ma 1 and Ma 2.

Ma 2 abc. Sophomore Mathematics. *12 units (4-0-8); first, second, third terms.* A continuation of the freshman mathematics course including: linear algebra; matrices and determinants; an extension of the calculus to functions of several variables; introduction to probability; differential equations. Professor in charge: Dade.

Ma 5 abc. Introduction to Abstract Algebra. *9 units (3-0-6); three terms.* Groups, rings, fields, and vector spaces are presented as axiomatic systems. The structure of these systems is studied, making use of the techniques of automorphisms, homomorphisms, linear transformations, subsystems, direct products, and representation theory. Many examples are treated in detail. Instructors: Dilworth, Spiegel, Halpern, Knuth.

Ma 31. Introduction to the Constructive Theory of Functions. *9 units (3-0-6); first term. Prerequisite: Ma 1 abc.* Polynomial approximation. The Weierstrass theorem and the Bernstein polynomials. Extremal properties of the Chebyshev polynomials. Markoff's theorems. Classical orthogonal polynomials. Applications to interpolation and approximation integration. Instructor: J. Todd.

Ma 91. Special Course. *9 units (3-0-6); third term.* Each year, during the third term, a course will be given in one of the following topics:

(a) Some field of number theory. (Given in 1959-60.)
(b) Some field of algebra or logic. (Given in 1965-66.) Instructor: Crawley.
(c) Some field of analysis. (Given in 1964-65.)
(d) Game Theory. (Given in 1960-61.)

Ma 92 abc. Senior Thesis. *9 units (0-0-9); three terms. Prerequisite: Approval of advisor.* Open only to seniors who are qualified to pursue independent reading and research. The work must begin in the first term and will be supervised by a member of the staff. Students will consult periodically with their supervisor, and will submit a thesis at the end of the year.

Ma 98. Reading. *3 units or more by arrangement.* Occasionally a reading course under the supervision of an instructor will be offered. Topics, hours, and units by arrangement. Only qualified students will be admitted after consultation with the instructor in charge of the course.

ADVANCED SUBJECTS

[A] The following courses are open to undergraduate and graduate students. Notice that some courses are given on an alternating basis.

Ma 102. Differential Geometry. *9 units (3-0-6); first term.* Selected topics in metrical differential geometry. Not offered in 1965-66. Given in 1966-67 and alternate years.

Ma 103. Algebraic Geometry. *9 units (3-0-6); second term. Prerequisite: Ma 5 abc.* A study of the relations between geometric objects (varieties) and the algebraic structures attached to them. Given in 1965-66 and alternate years. Instructor: Hall.

Ma 104. Projective Geometry. *9 units (3-0-6); second term. Prerequisite: Ma 5 abc.* Foundation of projective geometry. Theorems of Desargues and Pappus. Introduction of coordinates. Selected topics on properties of incidence and order, and various systems of coordinates. Not offered in 1965-66. Given in 1966-67 and alternate years.

Ma 108 abc. Advanced Calculus. *12 units (4-0-8); three terms. Prerequisite: Ma 2.* In this course, a sequel to Ma 2, more advanced techniques and applications of calculus are treated. Point set topology is the point of departure for the theory of convergence, and applications are made to implicit functions, partial differentiations, infinite series and infinite products of real and complex numbers. Other topics treated include: uniform convergence of sequences of functions; functions defined by integrals; Fourier series and integrals; analytic functions of a complex variable. Instructors: Krieger, Holbrook, Seever, Phillips.

Ma 109. Delta Functions and Generalized Functions. *9 units (3-0-6); first term.* Introduction to operational calculus and to delta functions. Applications to ordinary and partial differential equations. Given in 1965-66 and alternate years. Instructor: Phillips.

Ma 112. Elementary Statistics. *9 units (3-0-6); first and repeated in second term. Prerequisites: Ma 1, Ma 2.* This course is intended for anyone interested in the application of statistics to science and engineering. The topics treated will include the preparation and systematization of experimental data, the fundamental statistical concepts; population, sample, mean and dispersion, curve fitting and least squares, significance tests and problems of statistical estimation. Instructors: Garsia, Dilworth.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 5 abc or equivalent.* The predicate calculus and functional calculi of first order are presented and problems in the foundations of mathematics are studied. Included are Boolean algebra, theorems of Gödel, axiomatic set theory, and theory of cardinal and ordinal numbers. Instructor: Thompson.

Ma 118 abc. Functions of a Complex Variable. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Review of the basic concepts of the theory of analytic functions (Cauchy's theorem, singularities, residues, contour integration, analytic continuation). Further topics selected from: entire functions, conformal mapping, differential equations, special functions, applications of complex variable analysis. Instructor: Garsia.

Ma 120 abc. Abstract Algebra. *9 units (3-0-6); three terms. Prerequisite: Ma 5.* Abstract development of the basic structure theorems of groups, commutative and non-commutative rings, lattices, and fields. Instructor: Crawley.

Ma 121 ab. Combinatorial Analysis. *9 units (3-0-6); first and second terms. Prerequisite: Ma 5.* Elementary and advanced theory of permutations and combinations. Theory of partitions. Theorems on choice including Ramsey's theorem, the Hall-König theorem. Existence and construction of block designs with reference to statistical design of experiment, linear programming, and finite geometrics. Not offered in 1965-66.

Ma 137. Introduction to Lebesgue Integrals. *9 units (3-0-6); first term. Prerequisite: Ma 108 or equivalent.* Sets, topology, metric spaces. Functions of bounded variation. Lebesgue integrals of functions of one or two real variables. Fourier integrals. L^2 spaces. Linear functionals on Hilbert spaces and Banach spaces. This is an introductory course designed as a preparation for graduate courses in analysis and probability theory. Instructors: DePrima, Dean.

Ma 142 ab. Introduction to Partial Differential Equations. *9 units (3-0-6); second and third terms. Prerequisite: Ma 137 or equivalent.* Topics will include the following: Equations of the first order. Linear equations of the second order. Boundary value and eigenvalue problems for elliptic equations. Initial value and initial boundary value problems for parabolic and hyperbolic equations. Applications to problems of mathematical physics. Given in 1965-66 and alternate years. Instructor: Cohen.

Ma 143 ab. Functional Analysis and Integral Equations. *9 units (3-0-6); second and third terms. Prerequisites: Ma 108 and Ma 137 or equivalent.* This course is a continuation of Ma 137 and provides an introduction to methods of functional analysis. L^p spaces and their conjugates. Stieltjes integrals. The Riesz representation theorem. Daniell integrals. The Radon-Nikodym theorem. Linear operators on Banach spaces. Spectral theory of compact operators. Integral equations with applications to potential theory and to the Sturm-Liouville problem. Given in 1965-66 and alternate years. Instructor: Seever.

Ma 144 ab. Probability. *9 units (3-0-6); second and third terms. Prerequisite: Ma 137 or equivalent.* Basic concepts of probability, limit theorems, random walks, Markow chains, stochastic processes with applications. Instructor: Krieger.

Ma 150 abc. Combinatorial Topology. *9 units (3-0-6); three terms.* Introduction to combinatorial topology. The course covers homology and co-homology theory with applications to fixed point theorems and homotopy theory. Selected topics from the theory of fibre bundles. Not offered in 1965-66. Given in 1966-67 and alternate years.

Ma 160 abc. Number Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 108 abc or equivalent.* The first term, Ma 160 a, is a review of the elementary theory of numbers including congruences, numerical functions, elementary theory of primes, quadratic residues. The second and third terms, Ma 160 bc, include topics selected from: zeta functions, distribution of primes, elliptic modular functions, asymptotic theory of partitions, geometry of numbers, foundation of ideal theory in algebraic number fields, theory of units, valuations and local theory, discriminants, differents. Given in 1965-66 and alternate years. Instructor: Apostol.

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. Given in 1965-66 and alternate years. Instructor: Knuth.

Ma 190 abc. Elementary Seminar. *9 units; three terms.* This seminar is restricted to first year graduate students and is combined with independent reading. The topics will vary from year to year. Instructors: Dean, DePrima.

[B] The following courses are open primarily to graduate students. Notice that some courses are given on an alternating basis.

Ma 205 abc. Numerical Analysis. *9 units (3-0-6); three terms. Prerequisite: AMa 105 or equivalent.* Discussion of areas of current interest in numerical analysis and related mathematics; such as: matrix inversion and decomposition, ordinary differential equations, partial differential equations, integral equations, conformal mapping. discrete problems, linear programming and game theory, approximation theory, applications of functional analysis, theory of machines, theory of programming, estimates for characteristic value of matrices.

Each quarter will be treated as a separate unit. Where appropriate, accompanying laboratory periods will be arranged as a separate reading course. Instructor: Lancaster.

Ma 216 abc. Advanced Mathematical Logic. *9 units (3-0-6); three terms.* The propositional and predicate calculus. Gödel's completeness theorem. Recursive function theory and applications: Gödel's incompleteness theorem, undecidability. A treatment of the von Neumann-Bernays-Gödel set theory. Discussion of the axiom of choice, continuum hypothesis and inaccessible sets. Not offered in 1965-66.

Ma 222 abc. Group Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 120 or permission of instructor.* An introduction to the basic properties of finite and infinite groups. Theorems on homomorphisms, the theory of abelian groups, permutation groups, free groups, automorphisms. The Sylow theorems. Study of solvable, supersolvable, and nilpotent groups. A large part of the second term will be devoted to the theory of group representation, and will include applications to theoretical physics. Given in 1965-66 and alternate years. Instructor: Hall.

Ma 223 ab. Matrix Theory. *9 units (3-0-6); second and third terms. Prerequisite: Ma 120 or equivalent.* Algebraic, arithmetic and analytic aspects of matrix theory. Instructor: O. Todd.

Ma 224 abc. Lattice Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 120 or permission of instructor.* Systematic development of the theory of Boolean algebras, distributive, modular, and semi-modular lattices. Includes the study of lattice congruences, decomposition theory, and the structure of free lattices. Not offered in 1965-66. Given in 1966-67 and alternate years.

Ma 237 abc. Real Variable Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 137 or equivalent.* The axiom of choice and its relation to the other axioms of set theory. Measure theory; the theory of integration; and related topics such as differentiation of set functions, Banach function spaces, and ergodic theory. Topological linear spaces, introduction to Banach algebras, the Stone-Weierstrass theorem. Given in 1965-66. Instructor: Luxemburg.

Ma 238 abc. Advanced Complex Variable Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 108, Ma 118 a or equivalent.* In this course the knowledge of basic parts of the classical theory of analytic functions is assumed, and special topics are presented introducing topological and group-theoretical considerations, and relations to functional analysis. The topics will be selected from: linear spaces of analytic functions, conformal mapping, algebraic functions, Riemann surfaces, functions of several complex variables, singular integral equations. Not offered in 1965-66.

Ma 243 abc. Introduction to Functional Analysis. *9 units (3-0-6); three terms. Prerequisite: Ma 137 or equivalent.* Discussion of the theory of normed linear spaces; the closed graph theorem; the Riesz-Schauder theory; topics in Hilbert space; Banach algebras. Not offered in 1965-66.

Ma 244 ab. Advanced Probability. *9 units (3-0-6); first and second terms. Prerequisites: Ma 137 and Ma 144 or equivalent.* An exposition of probability theory in general sample spaces. Topics will include the following: modes of convergence of random variables, sequences of independent random variables, the central limit theorem, infinitely divisible distributions, conditional expectation, ergodic theory and the role of entropy in ergodic theory (and information theory). Not offered in 1965-66.

Ma 290. Reading. Occasionally advanced work is given by a reading course under the direction of an instructor. Hours and units by arrangement.

[C] The following courses and seminars are intended for advanced graduate students. They are research courses and seminars, offered according to demand, and covering selected topics of current interest. The courses offered, and the topics covered will be announced at the beginning of each term.

Ma 305 abc. Seminar in Numerical Analysis. *6 units. Three terms.*

Ma 320 ab. Special topics in Algebra. *9 units. Three terms.*

Ma 324 abc. Seminar in Matrix Theory. *Units to be arranged. Three terms.*

Ma 325 abc. Seminar in Algebra. *6 units. Three terms.*

Ma 340 abc. Special topics in Analysis. *9 units. Three terms.*

Ma 345 abc. Seminar in Analysis. *6 units. Three terms.*

Ma 350 ab. Special topics in Geometry. *9 units. First and second terms.*

Ma 355 abc. Seminar in Geometry. *6 units. Three terms.*

Ma 360 abc. Special topics in Number Theory. *9 units. Three terms.*

Ma. 365 abc. Seminar in Number Theory. *6 units. Three terms.*

Ma 390. Research. *Units by arrangement.*

Ma 392. Research Conference. *2 units.*

For courses in Applied Mathematics see separate section.

Mechanical Engineering

Undergraduate Subjects

ME 1. Introduction to Design. *9 units (0-9-0); second, or third term. Prerequisite: Gr 1.* This course supplements first-year graphics with more advanced applications of graphical methods to spatial delineation and design. The following subjects are introduced through a series of coordinated lecture discussions and laboratory problems: descriptive geometry in analysis and design; useful mechanisms; displacement, velocity and acceleration in machines and systems; creative synthesis;

human and economic factors as they affect design. Emphasis is placed on an imaginative yet rational approach to new problems and upon the development of the individual student's ability to recognize fundamental principles and logically plan his development work. Instructors: Welch, Morelli.

ME 3. Materials and Processes. *9 units (3-0-6); second term. Prerequisites: Ph 1 ab, Ch 1 abc.* A study of the materials of engineering and of the processes by which these materials are made and fabricated. The fields of usefulness and the limitations of alloys and other engineering materials are studied, and also the fields of usefulness and limitations of the various methods of fabrication and of processing machines. The student is not only made acquainted with the technique of processes but with their relative importance industrially and with the competition for survival which these materials and processes continually undergo. Text: *Engineering Materials and Processes,* Clark. Instructors: Buffington, Clark.

ME 5 abc. Design. *9 units (2-6-1); first, second, and third terms. Prerequisite: AM 95 ab or concurrently.* The purpose of this course is to develop creative ability and engineering judgment through work in design and engineering analysis. Existing devices are analyzed to determine their characteristics and the possibilities for improving their performance or economy and to evaluate them in comparison with competitive devices. Practice in the creation or synthesis of new devices is given by problems in the design of machines to perform specified functions. The fundamental principles of scientific and engineering knowledge and appropriate mathematical techniques are employed to accomplish the analysis and designs. Text: *Design and Production,* Kent. Instructors: Morelli, Auksmann.

ME 17 abc. Thermodynamics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* An introduction to the laws governing the properties of matter in equilibrium and some aspects of nonequilibrium behavior. Definition and scales of temperature. The laws of classical thermodynamics. Thermodynamic potentials, Maxwell's relations, calculation of thermal properties and applications to various homogeneous systems. First order changes of phase and the Clausius-Clapeyron equation. Analyses of energy conversion cycles. General conditions for thermodynamic equilibrium, extremum properties of the thermodynamic potentials, and the thermodynamic inequalities. Chemical potential, mixtures of gases and vapors, solutions, basic chemical thermodynamics. Elementary statistical mechanics, ensembles, and statistical thermodynamics. Introduction to nonequilibrium thermodynamics, thermoelectric effects, and problems of heat conduction in solids. Some aspects of the kinetic theory of gases, calculation of transport properties by mean-free-path methods and simplified forms of the Boltzmann equation. Limited discussion of energy transfer in fluid form. Instructor: Liepmann.

ME 19 abc. Fluid Mechanics and Gas Dynamics. *9 units (3-0-6); first, second, and 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. Flow and wave phenomena in open conduits. Theory and practice of some turbomachines such as fans, pumps, compressors, and turbines. Convective transfer of heat. Availability of mechanical, chemical, nuclear, and solar energy sources. Brief discussion and comparison of some types of systems for power. Instructor: Acosta.

ME 55. Adaptive Design. *9 units (3-6-0); first term.* This course presents the standard calculations necessary for the application and adaptation of materials and components to produce useful machines and structures. The properties and behavior of engineering materials to industrial environments are discussed. The purposes of standard components are explained. Some attention is given to dangerous situations and material combinations. Instructor: Morelli.

ADVANCED SUBJECTS

ME 100. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses or problems to meet the needs of fifth-year students or qualified undergraduate students.

ME 101 abc. Advanced Design. *9 units (1-6-2); first, second, and third terms. Prerequisite: ME 5 abc or equivalent.* Creative design and analysis of machines and engineering systems is developed at an advanced level. Laboratory problems are given in terms of the need for accomplishing specified end results in the presence of broadly defined environments. Investigations are made of environmental conditions to develop quantitative specifications for the required designs. Searches are made for the possible alternate designs and these are compared and evaluated. Preferred designs are developed in sufficient detail to determine operational characteristics, material specifications, general manufacturing requirements and costs. Instructors: Morelli, Auksmann.

ME 118 abc. Advanced Thermodynamics and Energy Transfer. *9 units (3-0-6); first, second, and third terms. Prerequisites: ME 17 abc, ME 19 abc, or equivalent.* Equilibrium of chemical systems including dilute solutions, elements of non-equilibrium thermodynamics, basic concepts of statistical mechanics. Special problems in heat conduction involving non-isotropic media, moving sources, and changes of phase. Exact solutions of heat transfer problems in laminar flow for compressible and incompressible fluids. Problems in turbulent flow and the application of Reynolds analogy. Principles of mass transfer and problems involving the simultaneous transfer of heat and mass. Theory of black body radiation and radiation characteristics of solids and gases. Instructors: Sabersky, Acosta.

ME 126. Fluid Mechanics and Heat Transfer Laboratory. *9 units (0-6-3); third term. Prerequisites: ME 17 abc, ME 19 ab, or equivalent. Students with other background shall obtain instructor's permission.* Introduction to some of the basic measurements and phenomena in fluid mechanics and heat transfer. The students will become acquainted with the use of hot wire equipment, thermocouples, thermistors, velocity probes, as well as with electrical and hydraulic analogues. The experiments in which these instruments will be used will include, for example, the flow over a flat plate, free and forced convention heat transfer, boiling heat transfer, solid state energy conversion phenomena, free surface and supersonic flows. Instructors: Sabersky, Zukoski.

ME 127. High Frequency Measurements in Fluids and Solids. *9 units (2-6-1); second term. Prerequisite: AM 95 ab.* The course will treat the theory and application of modern instrumentation to dynamic problems in fluid mechanics and elasticity which will be selected to provide familiarity with a wide range of electronic devices, transducers, and high-speed photoelastic and schlieren photographic techniques. The theory of optical masers and experimental work with them will be included. Instructor: Ellis.

ME 200. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses on problems to meet the needs of students beyond the fifth year.

ME 300. Thesis Research.

Many advanced courses in the field of Mechanical Engineering may be found listed in other engineering options such as:

Applied Mechanics, page 283.
Hydraulics, page 325.
Jet Propulsion, page 328.
Materials Science, page 333.

Music

Mu 1 abc. Music History and Analysis. *5 units (2-0-3).* The development of Western music studied through the analysis of historically significant compositions. Musical notation, melodic techniques, harmonic and polyphonic forms will be studied in relation to stylistic use during the principal periods of music history. An understanding of the musical score will be emphasized by means of correlated studies in analysis and record listening. Instructor: Ochse.

Paleontology

(See under Geological Sciences)

Philosophy and Psychology

Undergraduate Subjects

Pl 1. Introduction to Philosophy.* *9 units (3-0-6). Senior Elective.* A study of a selected number of major historical philosophical systems by way of readings in the sources. Priority is given to philosophical traditions which are still existent and influential in the contemporary world. Instructor: Bures.

Pl 2. Symbolic Logic.* *9 units (3-0-6). Senior Elective.* A study of the logic of elementary propositions, the logic of general propositions, the logic of relations and the logic of classes. The emphasis is on applied logic. Translation of sentences into logical notation and methods of assessing the validity and invalidity of arguments form the main themes. Instructor: Bures.

Pl 3. Contemporary European Philosophy.* *9 units (3-0-6). Senior Elective.* A critical analysis of the main trends in contemporary European philosophy, especially in France, Germany, Italy, and Spain. The course will include neo-Kantianism, neo-Hegelianism, Bergsonism, Logical-Positivism, Phenomenology, neo-Thomism, and Existentialism, in their influence on the whole of modern culture. Instructor: Stern.

Pl 4. Human Nature and Ethics.* *9 units (3-0-6). Senior Elective.* A study of ethical values in relation to human nature and culture. Conceptions of human nature provide bases for study of human value systems. All phases of human inquiry which bear on human nature are considered. Instructor: Bures.

Pl 6 a. The Psychology of Behavioral Processes.* *9 units (3-0-6). Senior Elective; first term.* A study of the individual, social and cultural factors that contribute to the development of human behavior and human interaction. Both theoretical and empirical formulations will be used in the analysis of the content and process of behavior, especially as it occurs within the student's experiential field. Instructor: Weir.

Pl 6 b. The Psychology of Personality Development.* *9 units (3-0-6). Senior Elective; second term.* A study of psychological development from birth to maturity. Attention is paid to stages of development, roles, emotional and motivational patterns. A posi-

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

tive conception of growth and creativity and factors inhibiting growth are emphasized in terms of a basic vocabulary. Instructor: Bures.

Pl 7. Human Relations. *7 units (3-0-4); third term.* An introduction to the principles and practices of interpersonal relationships. Individual and group interactions are analyzed using current theories of personality organization, motivation and group dynamics. Lectures, laboratory and field trips are employed to investigate the nature of social sensitivity, leadership, communication and group development. Instructors: Ferguson, Weir.

Pl 13. Reading in Philosophy. *Units to be determined for the individual by the department. Elective in any term.* Reading in philosophy, supplementary to, but not substituted for, courses listed; supervised by members of the department.

ADVANCED SUBJECTS

Pl 100 abc. Philosophy of Science.* *9 units (2-0-7). A full-year sequence. Senior Elective.* A study of the relationships between science and philosophy. The three terms respectively concentrate on: language and logic; logical analysis of some basic problems in the philosophy of science such as measurement, causality, probability, induction, space, time, reality; human nature, science and society. Instructor: Bures.

Pl 101 abc. History of Thought. *9 units (2-0-7).A full-year sequence.* A study of the basic ideas of Western Civilization in their historical development. The making of the modern mind as revealed in the development of philosophy and in the relations between philosophy and science, art and religion. The history of ideas in relation to the social and political backgrounds from which they came.

Pl 102 abc. Philosophy and Literature.* *9 units (2-0-7). A full-year sequence. Senior Elective.* A philosophical analysis and interpretation of literature as an art and as a vehicle of philosophical thought, exemplified in great works of world literature, beginning with Homer and the pre-Socratic poems on nature and ending with the literature of Existentialism and Surrealism. The course includes a study of the main philosophical theories of the different forms of literary expression (tragedy, comedy, poetry, the novel) and the reading of original works or translations. Instructor: Stern.

Pl 113. Reading in Philosophy. Same as Pl 13 but for graduate credit.

IS 250 abc. Mathematical Linguistics. *9 units (3-0-6).* (See page 328.)

Physics

UNDERGRADUATE SUBJECTS

Ph 1 abc. Kinematics, Particle Mechanics, and Electric Forces. *12 units (4-3-5); first, second, and third terms. Prerequisites: High school physics, algebra, and trigonometry.* The first year of a two-year course in Introductory Classical and Modern Physics. The course work consists of two general lectures each week, in which the main topics of the course are presented, and two class recitations in which more specific questions are treated, largely through the solution of problems. A weekly three-

*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

hour laboratory provides working familiarity with physical principles and measurement techniques. Topics covered in the first year include kinematics, the Lorentz transformation, nonrelativistic and relativistic particle mechanics, electric and magnetic forces, planetary motion, harmonic motion, geometrical optics, interference, diffraction, and scattering of radiation, kinetic theory, thermodynamics, and black body radiation. Instructors: Lauritsen, Leighton, Strong, Sutton, Vogt, and Assistants.

Ph 2 abc. Electricity, Fields, and Atomic Structure. *12 units (4-3-5); first, second, and third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or their equivalent.* The second year of a two-year course in Introductory Classical and Modern Physics. The course is organized along the same lines as Ph 1 abc. Topics covered in the second year include electricity and magnetism (with emphasis upon the field concept), Maxwell's equations, electromagnetic potentials, free waves and cavity resonators; elasticity; fluid flow; atomic structure. Instructors: Pine, Neher, Neugebauer, Peck, and Assistants.

Ph 77 ab. Experimental Physics Laboratory. *6 units; first and second terms.* A two-term laboratory course open to senior physics majors. The purpose of the course is to familiarize the student with laboratory equipment and procedures that are used in the research laboratory. The experiments are designed to illustrate fundamental physical phenomena, such as Compton scattering, nuclear and paramagnetic resonance, the photoelectric effect, the interaction of charged particles with matter, etc. Instructors: Kavanagh, Whaling.

ADVANCED SUBJECTS

Ph 106 abc. Topics in Classical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 2 abc, Ma 2 abc.* An intermediate course in the application of the basic principles of classical physics to a wide variety of subjects. It is intended that roughly half of the year will be devoted to mechanics, and half to electromagnetism. Topics to be covered include the Lagrangian and Hamiltonian formulations of mechanics, small oscillations and normal modes, boundary value problems, multipole expansions, and various applications of electromagnetic theory. Graduate students majoring in physics or astronomy will be given only 6 units credit for this course. Instructors: Bahcall, van Putten.

Ph 112 abc. Atomic and Nuclear Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 106 abc and Ph 125 abc, or equivalents.* A lecture and problem course on the experimental and theoretical foundations of contemporary atomic and nuclear physics. The first term includes a study of atomic and molecular structure and spectroscopy, and a discussion of classical and quantum statistical mechanics with applications. The second term includes a discussion of the structure of crystals, the band theory of solids with application to insulators, conductors, and semiconductors, and the properties of matter at low temperatures. Topics discussed in the third term include nuclear forces and the nuclear two-body problem, the shell and collective models of nuclear structure, nuclear reactions in the laboratory and in astrophysics, and the classification of the elementary particles. Texts: *Principles of Modern Physics,* Leighton; references from other textbooks and current periodicals. Instructor: Barnes.

Ph 115 ab. Geometrical and Physical Optics. *9 units (3-0-6); first and second terms. Prerequisite: Ph 2 abc.* An intermediate lecture and problem course dealing with the fundamental principles and applications of geometrical optics, interference, diffraction and other topics of physical optics. Given in alternate years. Not offered in 1965-66.

Ph 125 abc. Quantum Mechanics. *9 units (4-0-5); first, second, and third terms. Prerequisites: Ph 2 abc, Ma 2 abc. It is recommended that AM 95 abc or Ma 108 abc or the equivalent be taken concurrently.* A fundamental course in non-relativistic quantum mechanics aimed at understanding physical phenomena at the atomic level and introducing the mathematical techniques of calculation. The subject matter will include the Schrödinger equation, stationary states, the theory of angular momentum and spin, stationary and time-dependent perturbation theory, variational method, classical approximation, Zeeman effect, atomic structure, scattering, and quantum statistics. Graduate students majoring in physics will be given only 6 units for this course. Instructors: Christy, Frautschi, Mathews.

Ph 129 abc. Methods of Mathematical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 106 abc or the equivalent (may be taken concurrently), and some knowledge of complex variables.* Aimed at developing familiarity with the mathematical tools useful in physics, the course discusses practical methods of summing series, integrating, and solving differential equations, including numerical methods. The special functions (Bessel, Elliptic, Gamma, etc.) arising in physics are described, as well as Fourier series and transforms, partial differential equations, orthogonal functions, eigenvalues, calculus of variations, integral equations, matrices and tensors, and non-commutative algebra. The emphasis is toward applications, with special attention to approximate methods of solution. Instructor: Walker.

Ph 171. Reading and Independent Study. Occasionally, advanced work involving reading, special problems, or independent study is carried out under the supervision of an instructor. Units in accordance with work accomplished. Approval of the instructor and of the student's Departmental Advisor or Registration Representative must be obtained before registering.

Ph 172. Experimental Research in Physics. *Units in accordance with the work accomplished.* Approval of the student's research supervisor and of his Departmental Advisor or Registration Representative must be obtained before registering.

Ph 173. Theoretical Research in Physics. *Units in accordance with the work accomplished.* Approval of the student's research supervisor and of his Departmental Advisor or Registration Representative must be obtained before registering.

Ph 201 abc. Analytical Mechanics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 108 abc; Ph 129 ab is desirable.* A problem and lecture course dealing with the various formulations of the laws of motion of systems of particles and rigid bodies, and with both exact and approximate solutions of the resulting equations. Topics considered include Lagrange's and Hamilton's equations, canonical transformations, the dynamics of axially symmetric rigid bodies, and vibrations about equilibrium and steady motion. Additional topics will be selected from such subjects as elasticity, hydrodynamics, non-linear vibrations, dynamics of particles in accelerators, potential theory, and hydromagnetics. Not offered in 1965-66.

Ph 203 abc. Nuclear Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 112 abc and Ph 125 abc.* A problem and lecture course in nuclear physics concerning the use of available experimental and theoretical methods for the study of nuclear structure. Special emphasis will be placed upon understanding both the apparatus and the theoretical interpretation of those experiments that have led to the adoption of the currently fashionable models for nuclei and for nuclear reactions. Among the topics covered will be included: the properties of nuclei and nuclear excited states, nuclear reaction mechanisms, modes of nuclear decay, and the acceleration and detection of nuclear particles. Instructor: Tombrello.

Ph 204. Low Temperature Physics. *9 units (3-0-6); second term. Prerequisite: Ph 112 abc.* Introductory exposition of the subject of cryogenics. General coverage of topics includes (1) liquid helium II, (2) superconductivity, and (3) adiabatic demagnetization and nuclear alignment. Emphasis to be based on correlating behavior of matter at low temperatures with existing theoretical interpretations. Instructor: Mercereau.

Ph 205 abc. Principles of Quantum Mechanics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 125 abc, Ph 112 abc or equivalents; Ph 129 abc concurrently.* A fundamental treatment of quantum mechanics including stationary states of one and many particle systems; exclusion principle; approximation methods; transition problems; scattering theory; angular momentum; introduction to the quantum theory of radiation; application of these methods to atomic, molecular, and nuclear problems. Instructor: Dashen.

Ph 209 abc. Electromagnetism and Electron Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 106 abc.* Electromagnetic fields in vacuum and in matter; classical electron theory, retarded potentials, radiation, dispersion, and absorption; theories of the electric and magnetic properties of materials; selected topics in wave propagation; special relativity. Instructor: Davis.

Ph 213 ab. Nuclear Astrophysics. *9 units (3-0-6); first and second terms.* A lecture or reading course in the applications of nuclear physics to astronomy. The first term reviews the fundamental properties and structure of nuclei. The experimental evidence on nuclear cross sections is extensively analyzed in terms of current theories of nuclear reactions. The second term covers energy generation and element synthesis in stars, supernovae, and the massive condensations in quasars and extended radio sources. Nuclear evidence on the origin of the solar system is also discussed. Offered in 1965-66 as a lecture course for graduates or undergraduates. Instructor: Fowler.

Ph 216 abc. Introduction to Plasma Physics. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 106 abc or equivalent.* An introduction to the principles of plasma physics. Topics presented will include: Orbits of charged particles in electric, magnetic, and gravitational fields; elementary processes in the production and decay of ionized gases; continuum magnetohydrodynamics and elementary stability theory; transport processes such as conductivity and diffusion; waves, oscillations, and radiation in plasmas. Examples from physics, engineering, and astrophysics will be discussed. Instructor: Gould.

Ph 217. Spectroscopy. *9 units (3-0-6); third term. Prerequisite: Ph 112 ab or the equivalent.* Atomic line spectra. Experimental techniques of excitation and observation of the spectra of atoms and ions. A discussion of observed spectra, including complex spectra, in terms of atomic structure theory. Given in alternate years. Not offered in 1965-66.

Ph 218 ab. Electronic Circuits and their Application to Physical Research. *9 units (3-0-6); first and second terms. Permission of the instructor is required in order to register for this course.* A course on electronic circuits with primary emphasis on basic factors entering into the design and use of electronic instruments for physical research. Topics considered will include the theory of response of linear networks to transient signals, linear and nonlinear properties of electron tubes and practical circuit components, basic passive and active circuit combinations, cascade systems, amplifiers, feedback in linear and nonlinear systems, statistical signals, noise, and practical construction. Particular examples will be taken from commonly used research instruments. Given in alternate years. Offered in 1965-66. Instructor: Tollestrup.

Ph 220. Introduction to Solid State Physics. *9 units (3-0-6); third term. Prerequisite: Ph 125 abc. Recommended: Ph 112 abc concurrently.* An introduction to the experimental and theoretical foundations of solid state physics and its relation to other domains of physics. Topics presented will include: The dynamics of lattices and their association with physical properties of solids; crystal structures; the electric and magnetic properties of bulk matter, including ferromagnetism; band theory of solids; theory of conductors and semiconductors; optical spectra of crystals; nuclear hyperfine interactions in solids; scattering of slow neutrons from crystals; lattice defects. Instructor: Mössbauer.

Ph 227 abc. Thermodynamics, Statistical Mechanics, and Kinetic Theory. *9 units (3-0-6); first, second and third terms. Prerequisites: Ph 106 abc, Ph 125 abc, or the equivalent.* The fundamental concepts and laws of thermodynamics. Entropy and other characteristic functions. Nernst's theorem. Kinetic theory of gases. Classical and quantum statistical mechanics. The relation between statistical mechanics and thermodynamics. Illustrative applications of thermodynamics and statistical mechanics. Not offered in 1965-66.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 205 or equivalent.* Relativistic quantum mechanics, Feynman diagrams, quantum electrodynamics, field theory formalism, dispersion relations, theories of strong and weak interactions. Instructor: Zachariasen.

Ph 231 abc. High Energy Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 125 abc or equivalent, Ph 112 abc (may be taken concurrently).* A course covering the properties of the elementary particles and their interactions, especially at high energies. Topics discussed include the classification of the particles and their properties, strangeness theory, pion nucleon and nucleon-nucleon interactions, photoproduction of pions, high energy electron scattering, high energy electromagnetic interactions, production of strange particles, hyperfragments. Instructor: Zweig.

Ph 234 abc. Topics in Theoretical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 205 or equivalent.* The content of this course will vary from year to year. Topics presented will include: General methods in quantum mechanics such as operator calculus, group theory and its application; theory of meson and electromagnetic fields; atomic and molecular structure; theory of solids; theoretical nuclear physics.

Ph 236 ab. Relativity Theory. *9 units (3-0-6); first and second terms.* The incompatibility of Newtonian relativity and Maxwell's electromagnetism; survey of the classic ether experiments, and the transformation equations of Lorentz. Einstein's derivation of these, based on the Postulates of Relativity. Minkowski's discovery of the Riemannian geometry of space-time. Tensor analysis applied to the differential geometry of space-time, and the covariant expression of relativistic physics. The relativistic generalization of the law of inertia to include gravitation. Not offered in 1965-66.

Ph 237 abc. Theoretical Nuclear Physics. *6 units (2-0-4); first, second, and third terms. Prerequisite: Ph 205 or equivalent.* The course covers an introduction to the theory of nuclear structure, with emphasis on nuclear models such as the shell and unified models. Inelastic nuclear processes at low energies will also be discussed. Not offered in 1965-66.

Ph 238 abc. Seminar on Theoretical Physics. *4 units; first, second, and third terms.* Recent developments in theoretical physics for specialists in mathematical physics. In charge: Christy, Davis, Feynman, Frautschi, Gell-Mann, Mathews, Zachariasen.

Ph 240 abc. Current Theoretical Problems in Particle Physics. *6 units (2-0-4); first, second and third terms. Prerequisite: Ph 230 abc or equivalent.* Emphasis on symmetries. Discussion and argument are encouraged. Instructor: Gell-Mann.

Ph 241. Research Conference in Physics. *4 units; first, second, and third terms.* Meets once a week for a report and discussion of the work appearing in the literature and that in progress in the laboratory. Advanced students in physics and members of the physics staff take part. In charge: Anderson, Christy.

Ph 300. Research in Physics. *Units in accordance with work accomplished.* Ph 300 is elected in place of Ph 172 when the student has progressed to the point where his research leads directly toward the thesis of the degree of Doctor of Philosophy. Approval of the student's research supervisor and of his Departmental Advisor or Registration Representative must be obtained before registering.

PSYCHOLOGY

(See under Philosophy)

RUSSIAN

(See under Languages)

Section VII

DEGREES CONFERRED JUNE 11, 1965

Doctor of Philosophy

Kenneth Hoyt Adams (Materials Science). *B.S., California Institute of Technology, 1959; M.S., 1960.* Thesis: Dislocation Mobility and Density in Zinc Single Crystals.

Charles Bruce Archambeau (Geophysics). *B.S., University of Minnesota, 1955; M.S., 1959.* Thesis: Elastodynamic Source Theory.

George S. Argyropoulos (Engineering Science, Physics and Economics). *Dipl. in M.E.* and *E.E., National Technical University of Athens, 1960; M.S., California Institute of Technology, 1961.* Thesis: Anistropies and Interactions in Shear Flow of Macromolecular Suspensions.

John Fredrich Asmus (Electrical Engineering and Physics). *B.S., California Institute of Technology, 1958; M.S., 1959.* Thesis: Analysis of Perturbed Confocal Resonators.

Luis Baez-Duarte (Mathematics). *B.S., California Institute of Technology, 1959.* Thesis: Pointwise Abelian Ergodic Theorems.

James Maxwell Bardeen (Physics). *A.B., Harvard College, 1960.* Thesis: Stability and Dynamics of Spherically Symmetric Masses in General Relativity.

Leonard Daniel Baumert (Mathematics). *B.A., University of California (Los Angeles), 1952; M.A., 1959.* Thesis: Extreme Copositive Quadratic Forms.

Douglas Stanley Beder (Physics). *B.Sc., McGill University, 1961.* Thesis: Two Studies of Dynamical Calculations in Two-Meson Systems.

George Wood Beeler, Jr. (Electrical Engineering). *B.S.E., Princeton University, 1960; M.S., California Institute of Technology, 1961.* Thesis: Stochastic Processes in the Human Eye Movement Control System.

James M. Bell (Civil Engineering). *B.S., Colorado State College of Agriculture and Mechanic Arts, 1954; M.S., California Institute of Technology, 1955.* Thesis: Stress-Strain Characteristics of Cohesionless Granular Materials Subjected to Statically Applied Homogeneous Loads in an Open System.

Glenn LeRoy Berge (Astronomy). *B.A., Luther College, 1960; M.S., California Institute of Technology, 1962.* Thesis: An Interferometric Study of Jupiter's Decimeter Radio Emission.

Thomas Mark Bieniewski (Physics). *B.S., University of Detroit, 1958; M.S., California Institute of Technology, 1960.* Thesis: The Measurements of Oscillator Strengths in the Presence of Resonance Self-Broadening.

Robert Harold Bond (Electrical Engineering and Physics). *B.S., Colorado State University, 1958; M.S., California Institute of Technology, 1959.* Thesis: Directed Electron Velocity Distributions in Rare Gas Discharges Using Guard-Ring Probes.

Carl James Buczek (Electrical Engineering and Physics). *B.E.E., Rensselaer Polytechnic Institute, 1956; M.S., California Institute of Technology, 1959.* Thesis: Spontaneously Radiating Atoms in Cavity Fields.

Roger William Caputi (Chemistry). *B.S., California Institute of Technology, 1957.* Thesis: Studies of Liquid Mercury and Liquid Mercury-Gallium Systems by X-Ray Diffraction.

Chang-Chih Chao (Engineering Science). *B.S., National Taiwan University, 1956; M.S., Virginia Polytechnic Institute, 1960.* Thesis: A Study of CsCl Type Intermediate Phases Involving Rare Earth Elements.

Phillip John Chase (Mathematics). *B.A., The College of Wooster, 1961.* Thesis: Sublattices of Partition Lattices.

Arthur Noble Chester (Physics). *B.S., University of Texas, 1961.* Thesis: Regge Poles in Field Theories and Elementarity.

Armando Cisternas (Geophysics and Mathematics). *Min. Eng., University of Chile, 1957; M.S., California Institute of Technology, 1960.* Thesis: I. The Radiation of Elastic Waves from a Spherical Cavity in a Half Space. II. Precision Determination of Focal Depths and Epicenters of Earthquakes.

Donald Henry Close (Electrical Engineering and Physics). *B.S., University of Kansas, 1960; M.S., California Institute of Technology, 1962.* Thesis: Nonlinear Effects in Traveling Wave Laser Amplifiers.

Jules Bernard Cohen (Civil Engineering). *B.C.E., City College of New York, 1955; M.S., University of Colorado, 1958.* Thesis: Effects of Ionizing Radiation on Aqueous Solutions of the Detergent Alkylbenzenesulfonate and Several Lower Homologs.

Terrill Alan Cool (Mechanical Engineering and Physics). *B.S., University of California (Los Angeles), 1961; M.S., California Institute of Technology, 1962.* Thesis: Recombination, Ionization, and Nonequilibrium Electrical Conductivity in Seeded Plasmas.

Ronald Yvon Cusson (Physics and Mathematics). *B.Sc., University of Montreal, 1960.* Thesis: A Study of the Elastic and Inelastic Scattering of Alpha Particles by Li^7.

Lee Walker Davison (Applied Mechanics). *B.S., University of Idaho, 1959; M.S., New York University, 1961.* Thesis: Propagation of Finite Amplitude Waves in Elastic Solids.

David Tilton Denhardt (Biophysics and Physics). *B.A., Swarthmore College, 1960.* Thesis: A Biophysical Study of Bacteriophage ø X-174 Replication.

Robert Dewey de Pencier (Mechanical Engineering). *B.Sc., Queen's University (Ontario), 1959; M.S., California Institute of Technology, 1960.* Thesis: Genesis of a Machine; A Production Paper Cutter.

Nicholas Anthony Derzko (Mathematics and Physics). *B.Sc., University of Toronto, 1962.* Thesis: Wave Limits and Generalized Hilbert Transforms.

Theodore Neil Divine (Astronomy and Physics). *S.B., Massachusetts Institute of Technology, 1959; M.S., University of Michigan, 1960.* Thesis: Structure and Evolution of Model Helium Stars.

David James Duchamp (Chemistry). *B.S., University of Southwestern Louisiana, 1961.* Thesis: I. The Crystal Structure of Trimesic Acid. II. Topics in Crystallographic Calculations.

David Ray Dyroff (Chemistry and Chemical Engineering). *B.S., University of Illinois, 1962.* Thesis: The Crystal Structure of Sodium Triphosphate Hexahydrate.

Philip Filner (Biochemistry). *B.A., Johns Hopkins University, 1960.* Thesis: Studies on Exponential Cultures of Plant Cells.

Michael Hamilton Fisch (Chemistry). *A.B., Columbia College, 1960.* Thesis: The Photochemistry of Santonin in Aprotic Solvent: I. Photo-products. II. Mechanism.

James Norman Foster (Chemistry). *B.A., Occidental College, 1959.* Thesis: I. The Electrochemistry of Certain Metal Cations in Pyrophosphate Media. II. A Theoretical Study of Chronopotentiometry and Chronoamperometry at Unshielded Electrodes. III. Determination of Cobalt by Constant Current Coulometry.

Robert Peter Frosch (Chemistry). *B.S., Union College, 1959.* Thesis: I. The Emission and Absorption Spectra of Some Simple Molecules Trapped in Solid Rare Gases. II. Theory of Electronic Relaxation in the Solid Phase.

George Donald Garlick (Geochemistry). *B.Sc., University of Witwatersrand, 1956; M.S., California Institute of Technology, 1961.* Thesis: Oxygen Isotope Ratios in Coexisting Minerals of Metamorphic Rocks.

Michael Saunders Gazzaniga (Psychobiology and Immunology). *A.B., Dartmouth College, 1961.* Thesis: Some Effects of Cerebral Commissurotomy on Monkey and Man.

Robert Joseph Gerbracht (Physics). *B.A., Reed College, 1960.* Thesis: A Multi-Channel Double Bootstrap for Rho and K^*.

William Andrew Goddard III (Engineering Science and Physics). *B.S., University of California (Los Angeles), 1960.* Thesis: An Improved Many-Electron Theory for Atoms and Molecules Using Eigenfunctions of Total Spin.

Dennis Jerome Graue (Chemical Engineering). *B.S., University of Colorado, 1961; M.S., California Institute of Technology, 1962.* Thesis: I. A Numerical Method for Smoothing Thermodynamic Data. II. Diffusion Coefficients in Binary Hydrocarbon Liquids. III. Correlation of Diffusion Coefficients of Liquid Hydrocarbons.

O. Hayes Griffith (Chemistry). *A.B., University of California (Riverside), 1960.* Thesis: Electron Spin Resonance of Several Molecules in the Solid State.

Donald Eugene Groom (Physics and Astronomy). *A.B., Princeton University, 1956.* Thesis: A Polarization at 90° in $K^+\Lambda$ Photoproduction.

Robert Duane Hanson (Civil Engineering). *B.S., University of Minnesota, 1957; M.S.C.E., 1958.* Thesis: Post-Elastic Dynamic Response of Mild Steel Structures.

William Morgan Hardham (Chemistry). *B.S., Pennsylvania State University, 1961.* Thesis: Some Photochemistry of Maleic Anhydride: the Addition to Benzene and the Dimerization.

Robert Henry Hertel (Electrical Engineering and Physics). *S.B., Massachusetts Institute of Technology, 1958; M.S., California Institute of Technology, 1959.* Thesis: An Experimental Study of the Hydromagnetic Waveguide.

John Arthur Rankin Holbrook (Mathematics). *B.Sc., Queen's University (Ontario), 1961; M.A., 1962.* Thesis: The Egoroff Property and Related Properties in the Theory of Riesz Spaces.

John Leonard Honsaker (Physics). *B.S., California Institute of Technology, 1955.* Thesis: Investigation of the $Li^6(p,n)Be^6$ Reaction by the Neutron Threshold Technique.

Roger LeBaron Hooke (Geology and Hydraulics). *A.B., Harvard College, 1961.* Thesis: Alluvial Fans.

Kwang-chou Hwang (Chemical Engineering). *B.S., Taiwan University, 1956; M.S., California Institute of Technology, 1961.* Thesis: A Mathematical Study of the Transient Behavior of a Fixed-Bed Catalytic Reactor.

Li-San Hwang (Civil Engineering). *B.S., National Taiwan University, 1958; M.S., Michigan State University, 1962.* Thesis: Flow Resistance of Dunes in Alluvial Streams.

Ronald H. Jensen (Chemistry). *B.S., Lawrence College, 1960.* Thesis: Complexes of Silver (I) with Nucleic Acids.

Jack Randolph Jokipii (Physics). *B.S., University of Michigan, 1961.* Thesis: Two Topics in the Physics of the Solar Wind: I. A Model of Fermi Acceleration at Shock Fronts. II. Effects of Diffusion on the Composition of the Solar Corona and Solar Wind.

Gordon Ernest Keller (Mathematics). *B.A., Houghton College, 1960; M.A., University of Buffalo, 1962.* Thesis: Groups with Only the Identity Fixing Three Letters.

Arnold James Kelly (Mechanical Engineering). *M.E., Stevens Institute of Technology, 1955; M.S., University of California (Los Angeles), 1958.* Thesis: Atom-Atom Ionization Mechanisms and Cross Sections in Noble Gases and Noble Gas Mixtures.

Leon Frank Keyser (Chemistry). *B.S., University of Notre Dame, 1959.* Thesis: I. Infrared Spectra of Monomeric and Polymeric HCl and DCl in Solid Krypton and Xenon. II. Infrared Spectra of NH_2 and ND_2 Produced by Photolysis and X-Radiolysis of Ammonia in Solid Krypton. III. Ultraviolet Spectra of CH Produced by X-Radiolysis of Methane in Solid Argon.

Karl Kent Knapp (Mechanical Engineering). *B.S., California Institute of Technology, 1959; M.S., 1960.* Thesis: An Experimental Investigation of Free Convection Heat Transfer to Carbon Dioxide in the Region of Its Critical Point.

Joel Ivan Krugler (Physics). *B.E.E., The Cooper Union, 1959.* Thesis: Spin Absorption in Triplet Exciton Systems.

Joel Kwok (Chemistry and Physics). *B.S., University of California, 1959.* Thesis: I. Spectroscopic Observations of Discrete Sites in Simple Liquids. II. Infrared Intensity Perturbations of Hydrogen Halide Fundamentals in Liquid Xenon. III. Molecular Motion of HCl in Solid Rare Gas Matrices.

Joseph Buckley Lambert (Chemistry). *B.S., Yale University, 1962.* Thesis: I. Conformational Properties of Cyclobutanes. II. Nitrogen-15 Magnetic Resonance Spectroscopy.

Angelo Anthony Lamola (Chemistry). *S.B., Massachusetts Institute of Technology, 1961.* Thesis: I. Radiationless Transitions in Organic Systems: Determination of Intersystem Crossing in Fluid Solution. II. Intramolecular Energy Transfer Between Non-Conjugated Chromophores in Some Model Compounds.

James Daniel Larson (Physics). *S.B., Massachusetts Institute of Technology, 1957; M.S., California Institute of Technology, 1959.* Thesis: Gamma Radiation from the Alpha Particle Bombardment of C^{12}.

Arnold Vincent Lesikar (Physics). *B.A., Rice University, 1958.* Thesis: Magnetic Hyperfine Interactions of Sm^{149} in Ferromagnetic $SmAl_2$.

Milton Irwin Levenberg (Chemistry and Physics). *B.S., Illinois Institute of Technology, 1958.* Thesis I. Preliminary Studies of the Chain-Transfer Constant of Methylferrocene. II. Protonation of Metallocenes. III. An Analysis of the N.M.R. Spectra of Substituted Ferrocenes. IV. Experimental and Theoretical Studies of the Charge Distribution on the Ferrocenyl Carbinyl Carbonium Ion.

Gerald Richard Liebling (Chemistry and Physics). *B.S., Polytechnic Institute of Brooklyn, 1959.* Thesis: I. Study of Molecular Orbital Degeneracy in C_5H_5. II. The Crystal and Molecular Structure of Cyclopentadiene.

Ericson John List (Applied Mechanics and Mathematics). *B.E. (Hons), University of Auckland, 1961; B.Sc., 1962; M.E., 1962.* Thesis: The Stability and Mixing of a Density-Stratified Horizontal Flow in a Saturated Porous Medium.

Robert Shing-Hei Liu (Chemistry). *B.S., Howard Payne College, 1961.* Thesis. Photosensitized Reactions of Conjugated Dienes.

Robert James Macek (Physics). *B.S., South Dakota State College, 1958.* Thesis: A Search for the Process $K^+ \pi^+ + \pi^\circ + \gamma$

Rajeshwar Kumar Malhotra (Applied Mechanics and Mathematics). *I.Sc., Ewing Christian College (Allahabad, India), 1956; B.S., Oregon State College, 1959; M.S., Cornell University, 1961.* Thesis: Free and Forced Oscillations of a Class of Self-Excited Oscillators.

J. Howard Marshall III (Physics). *B.S., California Institute of Technology, 1957.* Thesis: $K^+ \Lambda$ Photoproduction from Hydrogen Near 90° in the Center of Mass.

Sami Faiz Masri (Mechanical Engineering). *B.S., University of Texas, 1960; M.S., 1961; M.S., California Institute of Technology, 1962.* Thesis: Analytical Experimental Studies of Impact Dampers.

Paul G. Mikolaj (Chemical Engineering). *B.Ch.E., Fenn College, 1958; M.S., University of Rochester, 1960.* Thesis: An X-Ray Diffraction Study of the Structure of Fluid Argon.

Robert Loomis Millette (Biochemistry and Chemistry). *B.S., Oregon State College, 1954; M.S., 1959.* Thesis: Hemoglobin Synthesis in the Maturing Reticulocyte.

Charles Gray Montgomery (Physics). *B.A., Yale University, 1959; M.S., California Institute of Technology, 1961.* Thesis: One-Dimensional Excitons in Organic Molecular Crystals.

Milton Edward Morrison (Chemical Engineering). *B.S., Iowa State University, 1961; M.S., California Institute of Technology, 1962.* Thesis: I. The Rate and Mechanism of the Air Oxidation of Parts-per-Million Concentrations of Nitric Oxide. II. The Quantitative Determination of Parts-per-Million Quantities of Nitrogen Dioxide in Nitrogen, Oxygen, and up to 75 p.p.m. of Nitric Oxide by Electron-Capture Detection in Gas Chromatography.

Werner Alfred Mukatis (Chemistry). *B.S., Northwestern University, 1960.* Thesis: Variation of the Conformation of the Active Site of Alpha-Chymotrypsin: I. Hydrogen Ion Concentration Studies. II. Electrolyte Concentration Studies.

Eugene Byrd Nebeker (Chemical Engineering and Nuclear Engineering). *B.S., Stanford University, 1959; M.S., California Institute of Technology, 1960.* Thesis: Thermodynamic Study of Coupled Chemical Reactions.

George Carroll Nieman (Chemistry). *B.S., Carnegie Institute of Technology, 1961.* Thesis: Triplet Exciton Phenomena in Benzene Crystals.

Maurice Joseph Nugent, Jr. (Chemistry and Economics). *B.A., University of Colorado, 1961.* Thesis: I. Beta-Ferrocenylalkyl Carbonium Ions. II. The Stereospecific Syntheses of the *Exo* and *Endo* Isomers of Alpha-Hydroxymethyl-l, $_2$-Tetramethylene-ferrocene.

Robert Francis Pawula (Electrical Engineering). *B.S., Illinois Institute of Technology, 1960; M.S., Massachusetts Institute of Technology, 1961.* Thesis: Generalizations and Extensions of the Fokker-Planck-Kolmogorov Equations.

Jerry Clifford Peck (Aeronautics and Mathematics). *B.S., California Institute of Technology, 1957; M.S., 1958; Ae.E., 1959.* Thesis: Plane-Strain Diffraction of Transient Elastic Waves by a Circular Cavity.

Roger L. Peterson (Chemistry). *B.S., Northwestern University, 1960.* Thesis: The Alpha-Chymotrypsin-Catalyzed Hydrolyses of Derivatives of N-Acetyl-L-phenylalanine Methyl Ester and Methyl Hippurate.

Kenneth L. Servis (Chemistry). *B.S. Purdue University, 1961.* Thesis: I. The Formolysis of Allycarbinyl Tosylates. II. Studies of Fluoroalkadienes by Nuclear Magnetic Resonance Spectroscopy. III. The Dissociation Constants of Methyl Alkyl Ketone Cyanohydrins.

Robert Victor Sharp (Geology and Paleontology). *B.S., California Institute of Technology, 1956; M.S., 1961.* Thesis: Geology of the San Jacinto Fault Zone in the Peninsular Ranges of Southern California.

Neil Rolfson Sheeley, Jr. (Physics). *B.S., California Institute of Technology, 1960.* Thesis: Measurements of Solar Magnetic Fields.

Frank Thomas Snively (Physics and Economics). *B.S., Antioch College, 1959; M.S., California Institute of Technology, 1961.* Thesis: Mössbauer Effect Investigations of the Magnetic Properties of Single Crystal Thulium Ethylsulphate.

Zoltán Géza Soos (Chemistry and Physics). *A.B., Harvard College, 1962.* Thesis: I. Theory of the Linear Heisenberg Antiferromagnet. II. Phonon Effects in Triplet Exciton Theory.

Walter Albert Specht, Jr. (Electrical Engineering and Physics). *B.S., California Institute of Technology, 1957.* Thesis: I. Modes in Spherical-Mirror Resonators. II. Dominant Mode Calculations in Output-Coupled Infinite Strip Mirror Resonators.

Jerold Lindsay Swedlow (Aeronautics). *B.S., California Institute of Technology, 1957; M.S., Stanford University, 1960.* Thesis: The Thickness Effect and Plastic Flow in Cracked Plates.

Harry Warren Townes (Mechanical Engineering). *B.S., Brown University, 1959; M.S., California Institute of Technology, 1960.* Thesis: Flow Over a Rough Surface.

Laurence Munro Trafton (Astronomy and Physics). *B.S., California Institute of Technology, 1960; M.S., 1961.* Thesis: A Study of the Energy Balance in the Atmospheres of the Major Planets.

Charles William Van Atta (Aeronautics). *B.S.E., University of Michigan, 1957; M.S.E., 1958.* Thesis: Spiral Turbulence in Circular Couette Flow.

Giulio Venezian (Engineering Science). *B. Eng. Phys., McGill University, 1960.* Thesis: I. Fluid Flow in a Precessing Spherical Cavity. II. Electromagnetic Radiation from an Expanding Sphere in a Magnetic Field.

Richard Bernard Wade (Mechanical Engineering). *B.Sc. Eng., University of Natal, 1958; M.Sc.Eng., 1960.* Thesis: Investigations on Cavitating Hydrofoils.

Donald Harris Webb (Physics and Mathematics). *B.S., Michigan State College, 1953; M.S., University of California (Los Angeles), 1955.* Thesis: Multiple-Transition Effects in Superconducting Tin Whisker Crystals.

Donald Martin Wiberg (Mechanical Engineering). *B.S., California Institute of Technology, 1959; M.S., 1960.* Thesis: Optimal Feedback Control of Spatial Xenon Oscillations in a Nuclear Reactor.

John Fergus Wilkinson (Mathematics and Economics). *B.S., California Institute of Technology, 1961.* Thesis: A Coloring Problem Related to König's Theorem.

James Sai Wing Wong (Mathematics). *B.S., Baylor University, 1960.* Thesis: Generalizations to the Converse of Contraction Mapping Principle.

Joe William Woodward (Chemical Engineering). *B.S., Texas Agricultural and Mechanical College, 1960; M.S., California Institute of Technology, 1961.* Thesis: A Study of the Effects of Dislocation Density and Crystal Orientation on the Kinetics of the Catalyzed Oxidation of Ethylene over a Single Crystal of Silver.

Jain-Ming Wu (Aeronautics). *B.S., National Taiwan University, 1955; M.S., California Institute of Technology, 1959.* Thesis: A Satellite Theory and Its Applications.

Engineer's Degree

AERONAUTICAL ENGINEER

Nazeer Ahmed. *B.E., University of Mysore, 1961; M.S., California Institute of Technology, 1962.*

Glen Walter Hostetler, Lt., U.S.N. *B.S., University of Idaho, 1955; M.S., Chrysler Institute of Engineering, 1957; Ae.E., United States Naval Postgraduate School, 1964.*

Jark Chong Lau. *Dipl., Royal Melbourne Technical College, 1957; M.S., California Institute of Technology, 1963.*

Robert Edward Spitzer, *B.S., University of Illinois, 1961; M.S., 1962.*

MECHANICAL ENGINEER

Jean-Michel Calle. *Dipl. Ing., Ecole Centrale des Arts et Manufactures (Paris), 1963; M.S., California Institute of Technology, 1964.*

Wayne Robert Cooper, Flight Lt., R.C.A.F. *B.Sc., University of Saskatchewan, 1961; M.S., California Institute of Technology, 1964.*

Marlyn Tony Jakub. *B.S., Carnegie Institute of Technology, 1958; M.S., California Institute of Technology, 1962.*

Richard Franklin Smisek. *B.S., California Institute of Technology, 1956; M.S., 1958.*

Master of Science

AERONAUTICS

Terry Allen Abell. *B.S., United States Naval Academy, 1963.*

Philip Robert Austin. *B.AeE., University of Detroit, 1959.*

Scott Williams Beckwith. *B.S., Texas A&M University, 1964.*

Elton Dean Bellinger. *B.S.E., University of Michigan, 1964.*

Jose Chirivella Casanova. *Ing., Escuela Tecnica Superior de Ingenieros Aeronauticos (Madrid), 1964.*

Philippe Raymond Chalier. *Ing., Ecole Centrale des Arts et Manufactures (Paris), 1964.*

Man-Cheong Cheung. *B.S., Taiwan Provincial Cheng Kung University, 1964.*

Antonio Crespo. *Ing., Escuela Tecnica Superior de Ingenieros Aeronauticos (Madrid), 1964.*

Michael James Gilliom. *B.S., United States Air Force Academy, 1964.*

Guy Paul Lengellé. *Ing., Ecole Nationale Superieure des Arts et Metiers (Paris), 1964.*

Momtaz Nosshi Mansour. *B.AeE., Cairo University, 1962.*

Carlos Navarro. *Ing., Escuela Tecnica Superior de Ingenieros Aeronauticos (Madrid), 1964.*

Nick Demetrios Panagiotacopulos. *Dipl., University of Athens, 1957; Dipl., Training Center for Experimental Aerodynamics (Belgium), 1961.*

Hugo de Oliveira Piva. *B.AeE., Instituto Tecnologico de Aeronautica (Brazil), 1958.*

James Robert Rose. *B.A.Sc., University of Toronto, 1964.*

Samir Dimitri Sayegh. *B.S., Centre d'Etudes Mathematiques et Physiques (Lebanon), 1961; Ing., Ecole Nationale Superieure de l'Aeronautique (Paris), 1963.*

John Vernon Schafer, Jr. *B.S., United States Military Academy, 1957.*

Richard A. Seebach. *B.M.E., Syracuse University, 1964.*

Arthur Torosian. *B.S., University of Illinois, 1958.*

Sachio Uehara. *B.S., University of Tokyo, 1956.*

Philippe Vidal. *Ing., Ecole Nationale Superieure des Arts et Metiers (Paris), 1964.*

APPLIED MATHEMATICS

John Gillespie Hartnett. *B.S.E., Princeton University, 1964.*

APPLIED MECHANICS

Richard J. Evershed. *B.S., Rochester Institute of Technology, 1963.*

Jean François Noël Guermonprez. *Ing., Ecole Nationale Superieure de Mecanique et d'Aerotechnique (Poitiers), 1964.*

John Kent Koester. *B.S., University of Notre Dame, 1964.*

Sheng-rong Lin. *B.S., National Taiwan University, 1961; M.S., 1964.*

Hidehiko Mori. *B.E., Waseda University (Tokyo), 1963.*

Timothy Owen Murray. *B.A., Rice University, 1963; B.S.M.E., 1964.*

Louis Edmond Rostand. *B.S., Polytechnic Institute of Brooklyn, 1964.*

Matias J. Turteltaub. *Ing., University of Chile, 1961.*

I-Min Yang. *B.S., National Taiwan University, 1958; M.S., 1964.*

ASTRONOMY

Virginia Louise Trimble. *B.A., University of California (Los Angeles), 1964.*

BIOLOGY

Richard Jay Laurent Bondar. *B.Sc., McGill University, 1962.*

CHEMICAL ENGINEERING

Raymond Paul Cej. *B.E., Royal Military College of Canada (Kingston), 1964.*
Inder Singh Cheema. *Pet.E., Colorado School of Mines, 1963.*
Joseph Francis Cullen. *B.S., California Institute of Technology, 1964.*
Allyn Merrill Davis. *B.S., Clarkson College of Technology, 1964.*
Satish Vithal Desai. *B.Tech., Indian Institute of Technology (Bombay), 1964.*
Terry Eugene Ernest. *B.S., California Institute of Technology, 1963.*
Stephen Chester Smelser. *B.S., University of Michigan, 1964.*
William George Smith. *B.S., California Institute of Technology, 1964.*
Richard King Teague. *B.S., Washington University (St. Louis), 1963.*

CHEMISTRY

Dana Lincoln Roth. *B.S., University of California (Los Angeles), 1962.*

CIVIL ENGINEERING

Gerassimos George Aperghis. *B.A., Cambridge University, 1964.*
Assadour Hagop Hadjian. *B.S., American University of Beirut (Lebanon), 1959; M.S., Illinois Institute of Technology, 1963.*
Robert Harry Harris. *B.S., West Virginia University, 1963.*
Lawrence Donald Hofmeister. *B.S., Carnegie Institute of Technology, 1964.*
Hugh Michael McAlear. *B.S., Valparaiso University, 1964.*
Michael Louis Neeser. *B.S., University of Idaho, 1964.*
Albert Bernard Pincince. *B.S., Northeastern University, 1963.*
Ignacio Rodriguez-Iturbe. *Eng., Universidad Del Zulia (Venezuela), 1963.*
Stephen Ilott Taylor. *B.A.Sc., University of British Columbia (Vancouver), 1963.*
Ansel Frederick Thompson, Jr. *B.S., Pennsylvania State University, 1963.*
Nien-chien Tsai. *B.S., National Taiwan University, 1961.*
Joe Clarence Willis. *B.S., Mississippi State University, 1960.*
Chen-shyong Young. *B.S., National Taiwan University, 1961; M.S., 1964*

ELECTRICAL ENGINEERING

Bernard Abel Aimelet. *Ing., Ecole Nationale Superieure de l'Aeronautique (Paris), 1964.*
Raymond Arrathoon. *B.E.E., Cornell University, 1964.*
Gerald Richard Ash. *B.S., Rutgers University, 1964.*
Paul David Batelaan. *B.S., California State Polytechnic College, 1964.*
Thomas Robert Bierma. *B.S.E., University of Michigan, 1964.*
Milton Mow-Tack Chang. *B.S., University of Illinois, 1964.*

Pierre-Yves Michel Comte. *Ing., Ecole Nationale Superieure des Telecommunications (Paris), 1964.*

Wayne Franklin Covington. *B.S., California Institute of Technology, 1964.*

Clark Allan Crane. *B.S., United States Air Force Academy, 1964.*

Peter Nicholas Demopoulos. *B.S., University of California (Los Angeles), 1964.*

Claude Jean Durand. *Ing., Ecole Centrale des Arts et Manufactures (Paris), 1964.*

Clarence Sigmund Fuzak, Jr. *B.S., California Institute of Technology, 1964.*

Richard Rutherford Green. *B.S., California Institute of Technology, 1964.*

John Franklin Gunn. *B.S., Tufts University, 1964.*

Howard Elliot Harry, Jr. *B.S., California Institute of Technology, 1964.*

Alden Barry Johnson, *B.S., University of Denver, 1964.*

James Thomas Kindle. *B.S., Rutgers University, 1964.*

Richard Ira Klein. *B.E.E., Cornell University, 1964.*

Michel Andre Lagorce. *Ing., Ecole Nationale Superieure de l'Aeronautique (Paris), 1964.*

Jean-Pierre Laussade. *Ing., Ecole Superieure d'Electricite (Paris), 1964.*

Pat Chiu Leung. *B.S., University of Pennsylvania, 1964.*

John Michael Julius Madey. *B.S., California Institute of Technology, 1964.*

Dominique René Jacques Marchand. *Ing., Ecole Superieure d'Electricite (Malakoff), 1964.*

Thomas Conley McGill, Jr. *B.S., Lamar State College of Technology, 1964.*

Roger Leon Minear. *B.S., California Institute of Technology, 1964.*

Theodore Wallace Parry. *B.S., Northrop Institute of Technology, 1963.*

David Lawrence Randall. *B.S.E., University of Michigan, 1963.*

David Allen Rennels. *B.S., Rose Polytechnic Institute, 1964.*

Robert R. R. Rodite. *B.S., Lafayette College, 1964.*

Valentin Rodriguez. *B.E.E., Catholic University of America, 1964.*

Jack Raymond Slager. *B.S., California Institute of Technology, 1963.*

James W. Surhigh. *B.S., Wayne State University, 1964.*

Athanassios D. Varvatsis. *Dipl., Natl. Technical University of Athens, 1960.*

ENGINEERING SCIENCE

James Johnson Duderstadt. *B.E., Yale University, 1964.*

Henrik Gustaf Gronroos. *Ing., Finland Institute of Technology, 1958.*

Roger Allison Haas. *B.E.S., University of Florida, 1964.*

Alexander Chen-Che Liang. *B.S.E., University of Michigan, 1963.*

John Thomas McCrickerd. *S.B., Massachusetts Institute of Technology, 1964.*

Roger Selig Schlueter. *B.S., Purdue University, 1964.*

Steven James Sharp. *B.S., Southern Methodist University, 1964.*

Felix Shek Ho Wong. *B.S., Purdue University, 1964.*

GEOLOGY

Bruce Alan Carter.

MATERIALS SCIENCE

Steven Jonathan Goldner. *B.S., California Institute of Technology, 1964.*

Chung Hsiung Lin. *B.S., National Taiwan University, 1963.*

Martin Eric Weiner. *B.S., California Institute of Technology, 1964.*

MATHEMATICS

Harold Charles Kurtz. *B.S., California Institute of Technology, 1962.*

MECHANICAL ENGINEERING

Albert Charles Angelovich. *B.S., Worcester Polytechnic Institute, 1964.*
N. Ebbe Banstorp. *Ing., Royal Institute of Technology (Stockholm), 1963.*
Thomas Richard Brussat. *B.S., University of Wisconsin, 1964.*
Robert William Conn. *B.Ch.E., Pratt Institute, 1964.*
Raymond Kay DeLong. *B.S., Kansas State University, 1962.*
James Thomas Early. *S.B., Massachusetts Institute of Technology, 1964.*
Jay Laurence Finkelstein. *B.A., Rice University, 1960; B.S., 1961.*
Robert Ridgeway Gilpin. *B.Sc., University of Alberta, 1964.*
Douglas Edwin Griffin. *B.S., University of Alberta, 1964.*
Denis R. Hayner. *B.S., Michigan College of Mining and Technology, 1961.*
Harry Douglas Hunter. *B.Sc., University of Alberta, 1964.*
William Masaru Matsukado. *B.S., University of Hawaii, 1964.*
Daniel Curtis Paxton, Jr. *B.S., California Institute of Technology, 1964.*
Terry Neil Rahmeier. *B.S., University of Pennsylvania, 1964.*
Bernard Claude Solelhac. *Ing., Ecole Centrale des Arts et Manufactures (Paris), 1964.*
Alvah Thomas Strickland. *B.S., Washington State University, 1964.*
David Owen Swint. *B.S., University of Texas, 1960.*
Mohan Vachani. *B.Sc., Lucknow University, 1959; B.Tech., Indian Institute of Technology, 1963.*
Richard William Weeks II. *B.S., Swarthmore College, 1964.*
Michel Wehrey. *Ing., Ecoles Nationales d'Ingenieurs Arts et Metiers (Paris), 1964.*
Robert Orville Winkler. *B.S., Bucknell University, 1964.*
David Ken Yoshikawa. *B.S., University of California (Berkeley), 1962.*

PHYSICS

Martin G. Delson. *B.S., Queens College (New York), 1962.*
Melinda Ann Groom. *A.B., Bryn Mawr College, 1961.*
David Louis Kreinick, *B.A., Brandeis University, 1963.*
Harold Theodore Larson. *B.A., California State College (Los Angeles), 1963.*
Michael James Mahon. *B.S., St. Louis University, 1963.*
Thomas Charles Rindfleisch. *B.S., Purdue University, 1962.*
Phillip Howard Roberts, Jr. *B.S., University of Kansas, 1963.*
Edmund J. Weber. *B.E., McGill University, 1963.*

Bachelor of Science

Students whose names appear in boldface type are being graduated with honor in accordance with a vote of the Faculty.

Michael Stephen Ball, Sarasota, Florida. *Engineering.*
Robert Joseph Barro, Los Angeles, California. *Physics.*
Michael I. Baskes, Chicago, Illinois. *Engineering.*
Edward Stephen Bauer, Pasadena, California. *Engineering.*
John Harden Beamer, Toronto, Ontario. *Chemical Engineering.*
James Grant Blackinton, Englewood, Colorado. *Engineering.*
Vernon LeRoy Bliss, Bakersfield, California. *Biology.*
Edward Mark Bloomberg, Swampscott, Massachusetts. *Mathematics.*
Donald Lawrence Blumenthal, Boston, Massachusetts. *Engineering.*
Steven Lloyd Blumsack, Garden Grove, California. *Mathematics.*
George Conrad Brackett, Carbondale, Illinois. *Physics.*
Russell Martin Brill, San Francisco, California. *Physics.*
Steven Elliot Brown, Little Neck, New York. *Mathematics.*
Walter Kendall Brown, Des Moines, Iowa. *Physics.*
Robert Clifton Burket, Sacramento, California. *Geology.*
Randall Curtis Cassada, Jr., San Antonio, Texas. *Biology.*
I-Lok Chang, Wooster, Ohio. *Mathematics.*
Thomas Shelby Chapman III, Lakewood, Colorado. *Chemistry.*
John D. Chidley, Butte, Montana. *Chemical Engineering.*
Donald Ray Chivens, Pasadena, California. *Engineering.*
Stanley A. Christman, San Francisco, California. *Chemical Engineering.*
Peter King Clark, Charleston, West Virginia. *Physics.*
Glenn Gary Clinard, Great Falls, Montana. *Engineering.*
D. Louis Corl, El Sobrante, California. *Physics.*
Michael Joseph Cosgrove, Phoenix, Arizona. *Engineering.*
James Hansen Crabtree, Redlands, California. *Chemistry.*
James Christopher Dalton, Corning, New York. *Chemistry.*
Kris Davidson, Harlem, Montana. *Physics.*
Roger Carl Davisson, Pueblo, Colorado. *Engineering.*
Walter Jordan Deal, Jr., Slidell, Louisiana. *Chemistry.*
Leland Allen DePriest, Mesa, Arizona. *Engineering.*
John Crockett Diebel, South Pasadena, California. *Engineering.*
Barry William Dinius, Seattle, Washington. *Engineering.*
Nicholas I-Tsing Djeu, Buenos Aires, Argentina. *Physics.*
James Farnum Eder, Jr., Canoga Park, California. *Biology.*
Martin B. Einhorn, Dayton, Ohio. *Physics.*
Wladislaw Vladislavovitch Ellis, Glendale, California. *Biology.*
James M. Espinosa, Mexico, D.F., Mexico. *Physics.*
Richard Charles Essenberg, Sacramento, California. *Chemistry.*
Jon Kenner Evans, Las Vegas, Nevada. *Geology.*
David White Faulconer, Rochester, Minnesota. *Engineering.*

Gary Owen Fitzpatrick, Eureka, California. *Physics.*
Lewis Martin Fraas, Manhattan Beach, California. *Physics.*
W. Phelps Freeborn, New Hope, Pennsylvania. *Geology.*
Richard Skipp Frenk, Vandenberg Air Force Base, California. *Engineering.*
Stephen Hopkins Garrison, Manila, Philippines. *Engineering.*
Robert Edward Gillon, Fairfield, Connecticut. *Geology.*
Mark Gingold, Syracuse, New York. *Mathematics.*
Barry Lee Goldberg, Beverly Hills, California. *Mathematics.*
Gerald Dale Gowen, Portland, Oregon. *Chemical Engineering.*
Burton William Graves, Alhambra, California. *Engineering.*
Donald Webb Green, Phoenix, Arizona. *Biology.*
Thomas Kennedy Greenfield, Bulawayo, Rhodesia. *Astronomy.*
Lawrence Hinman Hall, South Pasadena, California. *Chemistry.*
Steven David Hall, Brecksville, Ohio. *Geology.*
John Barrett Long Harkness, La Porte, Texas. *Chemical Engineering.*
William Edward Hawks, Elko, Nevada. *Engineering.*
Roger Walden Hendrix, Walnut Creek, California. *Biology.*
William David Hixson, San Angelo, Texas. *Engineering.*
John Myrom Holte, Mount Vernon, Washington. *Mathematics.*
Richard Arthur House II, Albuquerque, New Mexico. *Physics.*
John N. C. Hsu, Flushing, New York. *Chemistry.*
Manuel Andrés Huerta, Habana, Cuba. *Engineering.*
Ronald Ernest Hutton, Baldwin Park, California. *Physics.*
Martin Isler, New York, New York. *Mathematics.*
David D. Jackson, Pasadena, California. *Physics.*
David Dixon Jarvis, Santa Monica, California. *Engineering.*
Robert Theodore Jenkins, Houston, Texas. *Engineering.*
Paul Douglas Josephson, Omaha, Nebraska. *Physics.*
Steven Kenneth Kauffmann, Mexico, D.F., Mexico. *Physics.*
James Robert Kercher, San Pedro, California. *Physics.*
Paul Craig Kochendorfer, Portland, Oregon. *Engineering.*
Kenneth Kunen, Mount Vernon, New York. *Mathematics.*
Edgar Kuplis, Longview, Washington. *Engineering.*
Richard Neil Lane, Bethesda, Maryland. *Mathematics.*
Amos Levin, Ramat-Gan, Israel. *Engineering.*
Robert David Levin, Denver, Colorado. *Chemistry.*
Del Eugene Levy, Melba, Idaho. *Engineering.*
Steven Ross Lipshie, Van Nuys, California. *Geology.*
Kenneth Raymond Ludwig, Berkeley, California. *Chemistry.*
Hugh Bardeen Maynard, Littleton, Colorado. *Mathematics.*
Rainer Franz McCown, San Jose, California. *Engineering.*
Dennis Lloyd McCreary, North Hollywood, California. *Chemistry.*
Charles Hosewell McGruder, Bristol, Pennsylvania. *Astronomy.*
Dallas J. Meggitt, Scottsdale, Arizona. *Engineering.*
Thomas More Menzies, Santa Barbara, California. *Engineering.*

Charles King Michener, Idaho Falls, Idaho. *Engineering.*
John Randolph Miller, Annandale, Virginia. *Physics.*
Michael Norman Misheloff, Los Angeles, California. *Physics.*
Harold D. Moeller, Hinsdale, Illinois. *Engineering.*
Stephen Elliott Morse, Houston, Texas. *Physics.*
Kenneth Kiyoshi Murata, Sacramento, California. *Physics.*
John Nady, San Francisco, California. *Engineering.*
Francis S. Nakamoto, Kahului, Maui, Hawaii. *Engineering.*
Lee Neidengard, Palos Verdes Estates, California. *Biology.*
Jerry Earl Nelson, San Fernando, California. *Physics.*
Arthur Edwin Niell, Lubbock, Texas. *Physics.*
Dennis Lowell Oberg, Minneapolis, Minnesota. *Physics.*
Lawrence Kermit Oliver, Walker, Minnesota. *Chemistry.*
Maynard Victor Olson, Healdsburg, California. *Chemistry.*
William Peter O'Neill, Butte, Montana. *Engineering.*
Dimitri A. Papanastassiou, Athens, Greece. *Physics.*
Gerhard Hans Parker, Paso Robles, California. *Engineering.*
Carlton Hutton Paul III, Scottsdale, Arizona. *Biology.*
DeWitt Allen Payne, Santa Ana, California. *Chemistry.*
Warren Joseph Peascoe, San Pedro, California. *Chemistry.*
William Michael Pence, El Cajon, California. *Engineering.*
David Thomas Price, Blue Lake, California. *Mathematics.*
Thomas Antone Pucik, Portland, Oregon. *Physics.*
J. Niles Puckett, Jr., Phoenix, Arizona. *Engineering.*
Ronald S. Remmel, Milwaukee, Wisconsin. *Physics.*
George Andrew Repasy, La Habra, California. *Engineering.*
Robert Richard Roberts, Arcadia, Indiana. *Mathematics.*
Michael Morris Rosbash, Newton, Massachusetts. *Chemistry.*
Freeman Harding Rose, Jr., Casa Grande, Arizona. *Engineering.*
Hanan Rosenthal, New York, New York. *Physics.*
Stephen Alan Ross, Brookline, Massachusetts. *Physics.*
Jeffrey Paul Royer, Vandalia, Ohio. *Physics.*
Peter Michael Ryan, Quincy, Massachusetts. *Mathematics.*
Wayne Howard Ryback, La Grange Park, Illinois. *Chemistry.*
Benjamin Arden Saltzer, Los Angeles, California. *Engineering.*
William Franklin Satterthwaite, Wellesley, Massachusetts. *Mathematics.*
Gary Walter Scott, Topeka, Kansas. *Chemistry.*
Michael McCreary Scott, Gainesville, Florida. *Physics.*
Robert Benson Scott, Hamilton, Montana. *Engineering.*
Walter Alvin Scott, Baker, Oregon. *Biology.*
Samuel Murray Sherman, Pittsburgh, Pennsylvania. *Biology.*
Harry James Simpson, Jr., Sullivan, Missouri. *Chemistry.*
John Charles Simpson, Jr., Alexandria, Virginia. *Chemical Engineering.*
Terry Regg Simpson, Billings, Montana. *Physics.*
Victor Leon Sirelson, Tujunga, California. *Mathematics.*

Frank James Slaby, Pasadena, California. *Biology.*
Charles Monck Smythe, Tulare, California. *Astronomy.*
William Glen Spring, Los Angeles, California. *Engineering.*
Benjamin Stackler, Chicago, Illinois. *Physics.*
Melvin M. Stephens II, Independence, Missouri. *Chemistry.*
Edwin Paul Swatek III, Sewickley, Pennsylvania. *Chemistry.*
Robert Mahlon Sweet, Mt. Morris, Illinois. *Chemistry.*
Gary Edgar Thompson, Inglewood, California. *Physics.*
John J. Turechek, Fresno, California. *Physics.*
Richard Alan Vogel, Miami, Florida. *Mathematics.*
Arden Bruce Walters, Pasadena, California. *Chemical Engineering.*
Stuart Steve Watson, Houston, Texas. *Chemistry.*
Oliver Laurence Weaver, Birmingham, Alabama. *Physics.*
Rodger Fairfax Whitlock, Hyattsville, Maryland. *Chemistry.*
Anthony Brackett Williams, Walpole, Massachusetts. *Geology.*
Jefferson K. Wise, Long Beach, California. *Engineering.*
James Fong Yee, Hughes, Arkansas. *Engineering.*
Akira Yoshida, Richmond Hill, New York. *Physics.*
William Robin Zame, Coral Gables, Florida. *Mathematics.*

HONORS AND AWARDS

Honor Standing

The undergraduate students listed below have been awarded honor standing for the current year, on the basis of excellence of their academic records for the year 1964-65.

No honor standing has been granted for the class of 1968. Under present Institute policy, grades in all freshman courses are only "P," indicating passed, or "F," indicating failed.

CLASS OF 1966

Austin, James Warren
Austin, Jared Asher
Aschbacher, Michael George
Bergman, Rodney Kent
Bigelow, Richard Henry
Chase, Clement Grasham
Chu, David
Colglazier, Elmer William, Jr.
Comly, Jack Clifton
Creutz, Michael John
Davis, Walter Ziesche, Jr.
Dembart, Benjamin
Elliott, Steven Paul
Galley, Stuart Wilber
Holford, Alden Douglas
Lynch, Raymond Paul
Ma, Ernest Seu-Keung
Mayer, Frederick Insley
Melton, Lynn Ayres
Miller, William Patrick, Jr.
Nielsen, Richard Carl
Pearlman, Jay S.
Perry, Edward Harris
Powell, Howard Thomas
Pressing, Jeffrey Lynn
Putterman, Seth Jay
Sawicki, Charles Anthony
Scandella, Carl John
Shultz, Frederick Waters
Silver, Richard Neil
Solomon, Sean Carl
Stanley, Richard Peter
Stephens, Timothy Lee
Stolfa, David Lewis
Trijonis, John Charles
Tucker, John R.
Tymczyszyn, Joseph Paul
Uyeda, Norman Minoru
Walter, John Peyton

CLASS OF 1967

Beale, James Thomas
Beeson, Michael James
Buckholtz, Thomas Joel
Cooper, Benjamin Grosvenor
Dillehay, Larry Edward
Eardley, Douglas Michael
Erickson, Daniel Edwin
Eyler, John Robert
Goldberg, Joel
Hendrickson, Terrill Willard
Jennings, Gray
Lamb, Frederick Keithley
Landy, Richard Allen
Langton, Stacy Guy
Lippa, Erik Alexander
MacKay, Andrew Dougal
Mandell, Myron Jay
Manke, Joseph Walter
McQuillan, Charles Edwin
Metlay, Daniel Stefan
Miller, William Booth
Moore, Reagan Wentworth
Nordsieck, Kenneth Hugh
Osheroff, Douglas Dean
Pearson, James Edward
Poythress, Vern Sheridan
Robel, Michael Cornelius
Schor, Robert Hyllel
Sheng, Ping
Van Essen, David Clinton
White, Dennis Edward
Young, Eric Daniel

American Institute of Aeronautics and Astronautics Award

Awarded to the student member of the AIAA attaining the best scholastic record in engineering or the physical sciences.

JAMES ROBERT ROSE

Don Baxter, Inc. Prizes

Awarded to the undergraduate students who during the year have carried out the best original researches in chemistry.

First prize: HARRY JAMES SIMPSON, JR.

Second prizes: MELVIN M. STEPHENS II, ROBERT MAHLON SWEET

Honorable mention: MAYNARD VICTOR OLSON, GARY WALTER SCOTT

E. T. Bell Mathematics Prize

Awarded annually to one or more juniors or seniors for outstanding original research in mathematics.

RICHARD PETER STANLEY
MICHAEL GEORGE ASCHBACHER

Conger Peace Prizes

Established in 1912 by the late Everett D. Conger, D.D., for the promotion of interest in the movement toward universal peace, and for the furtherance of public speaking.

First prize: KERMIT RUDOLPH KUBITZ

Second prize: FRED K. LAMB

Eastman Kodak Scientific Awards in Chemistry

Awarded to doctoral students on the basis of outstanding contributions and progress either in graduate studies and research or in teaching.

First prize: JOSEPH BUCKLEY LAMBERT

Honorable Mention: DAVID JAMES DUCHAMP, WILLIAM GEORGE HERKSTROETER, BALDOMERO MARQUEZ OLIVERA

George W. Green Memorial Award

Awarded to the undergraduate student who, in the opinion of the Division Chairmen, has shown outstanding ability and achievement in the field of creative scholarship.

FREDERICK INSLEY MAYER

Honeywell Award

Established by Honeywell, Inc. for presentation to a senior student for outstanding individual performance in undergraduate engineering and science.

GLENN GARY CLINARD

Frederic W. Hinrichs, Jr., Memorial Award

Awarded to the senior who, in the opinion of the Undergraduate Deans, has throughout his years at the Institute made the greatest contributions to the welfare of the student body and whose qualities of leadership, character and responsibility have been outstanding.

Not given this year

David Joseph Macpherson Prize

Awarded annually to the graduating senior in engineering who best exemplifies excellence in scholarship.

MANUEL ANDRES HUERTA

Mary A. Earle McKinney Prizes

First prize: STEVEN PAUL ELLIOTT

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TERRILL RICHARD WARREN

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