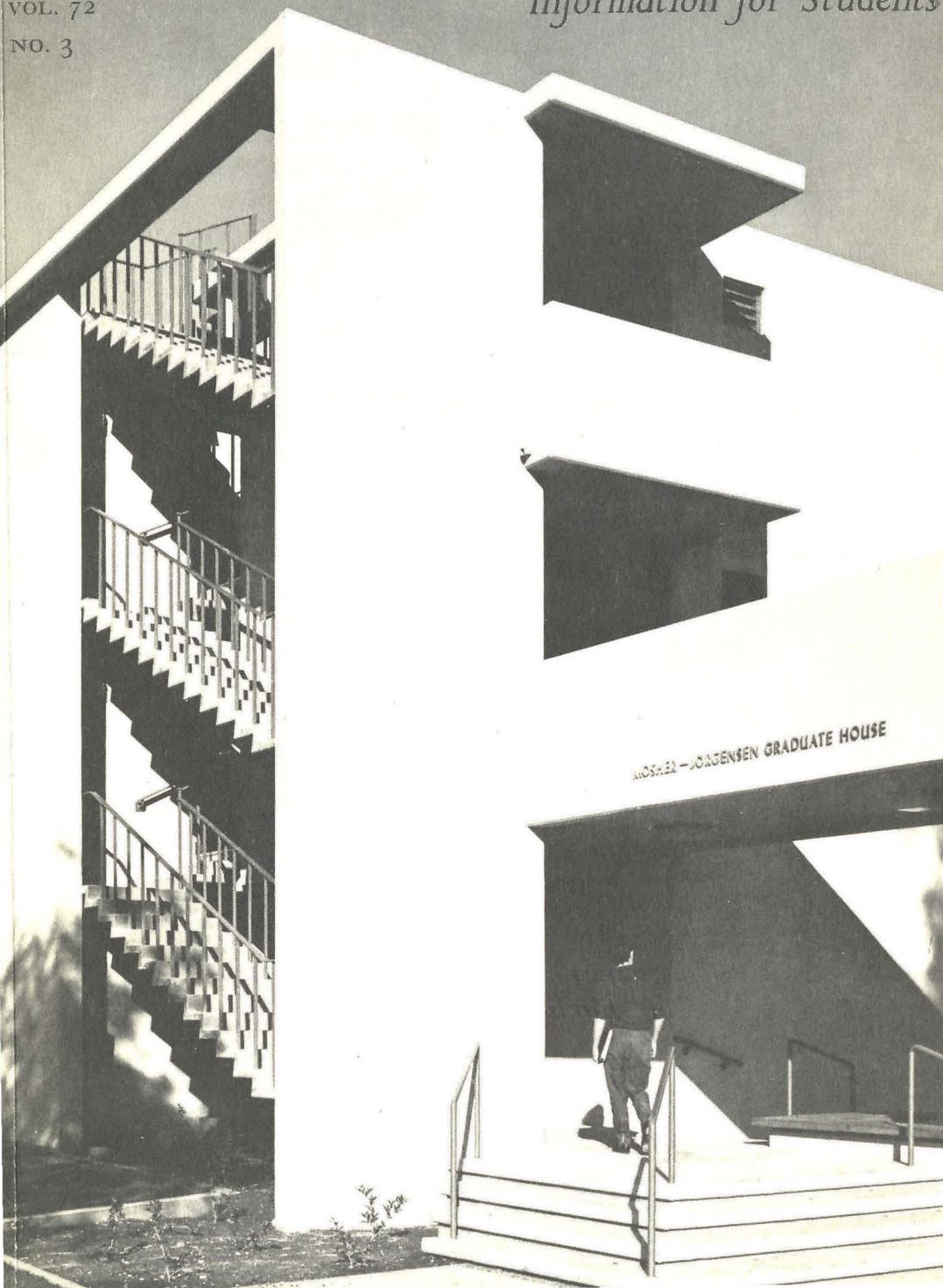


# BULLETIN OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

VOL. 72  
NO. 3

*Information for Students*



MOSHER-JØRGENSEN GRADUATE HOUSE

# 1963

| SEPTEMBER |    |    |    |    |    |    | OCTOBER |    |    |    |    |    |    | NOVEMBER |    |    |    |    |    |    | DECEMBER |    |    |    |    |    |    |   |   |
|-----------|----|----|----|----|----|----|---------|----|----|----|----|----|----|----------|----|----|----|----|----|----|----------|----|----|----|----|----|----|---|---|
| SU        | MO | TU | WE | TH | FR | SA | SU      | MO | TU | WE | TH | FR | SA | SU       | MO | TU | WE | TH | FR | SA | SU       | MO | TU | WE | TH | FR | SA |   |   |
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| 15        | 16 | 17 | 18 | 19 | 20 | 21 | 13      | 14 | 15 | 16 | 17 | 18 | 19 | 10       | 11 | 12 | 13 | 14 | 15 | 16 | 15       | 16 | 17 | 18 | 19 | 20 | 21 |   |   |
| 22        | 23 | 24 | 25 | 26 | 27 | 28 | 20      | 21 | 22 | 23 | 24 | 25 | 26 | 17       | 18 | 19 | 20 | 21 | 22 | 23 | 22       | 23 | 24 | 25 | 26 | 27 | 28 |   |   |
| 29        | 30 |    |    |    |    |    | 27      | 28 | 29 | 30 | 31 |    |    | 24       | 25 | 26 | 27 | 28 | 29 | 30 | 29       | 30 | 31 |    |    |    |    |   |   |

# 1964

| JANUARY   |    |    |    |    |    |    | FEBRUARY |    |    |    |    |    |    | MARCH    |    |    |    |    |    |    | APRIL    |    |    |    |    |    |    |   |  |  |
|-----------|----|----|----|----|----|----|----------|----|----|----|----|----|----|----------|----|----|----|----|----|----|----------|----|----|----|----|----|----|---|--|--|
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| 5         | 6  | 7  | 8  | 9  | 10 | 11 | 2        | 3  | 4  | 5  | 6  | 7  | 8  | 9        | 10 | 11 | 12 | 13 | 14 | 5  | 6        | 7  | 8  | 9  | 10 | 11 |    |   |  |  |
| 12        | 13 | 14 | 15 | 16 | 17 | 18 | 9        | 10 | 11 | 12 | 13 | 14 | 15 | 16       | 17 | 18 | 19 | 20 | 21 | 12 | 13       | 14 | 15 | 16 | 17 | 18 |    |   |  |  |
| 19        | 20 | 21 | 22 | 23 | 24 | 25 | 16       | 17 | 18 | 19 | 20 | 21 | 22 | 23       | 24 | 25 | 26 | 27 | 28 | 19 | 20       | 21 | 22 | 23 | 24 | 25 |    |   |  |  |
| 26        | 27 | 28 | 29 | 30 | 31 |    | 23       | 24 | 25 | 26 | 27 | 28 | 29 | 29       | 30 | 31 |    |    |    | 26 | 27       | 28 | 29 | 30 |    |    |    |   |  |  |
| MAY       |    |    |    |    |    |    | JUNE     |    |    |    |    |    |    | JULY     |    |    |    |    |    |    | AUGUST   |    |    |    |    |    |    |   |  |  |
| SU        | MO | TU | WE | TH | FR | SA | SU       | MO | TU | WE | TH | FR | SA | SU       | MO | TU | WE | TH | FR | SA | SU       | MO | TU | WE | TH | FR | SA |   |  |  |
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| 10        | 11 | 12 | 13 | 14 | 15 | 16 | 14       | 15 | 16 | 17 | 18 | 19 | 20 | 12       | 13 | 14 | 15 | 16 | 17 | 18 | 9        | 10 | 11 | 12 | 13 | 14 | 15 |   |  |  |
| 17        | 18 | 19 | 20 | 21 | 22 | 23 | 21       | 22 | 23 | 24 | 25 | 26 | 27 | 19       | 20 | 21 | 22 | 23 | 24 | 25 | 16       | 17 | 18 | 19 | 20 | 21 | 22 |   |  |  |
| 24        | 25 | 26 | 27 | 28 | 29 | 30 | 28       | 29 | 30 |    |    |    |    | 26       | 27 | 28 | 29 | 30 | 31 |    | 23       | 24 | 25 | 26 | 27 | 28 | 29 |   |  |  |
| SEPTEMBER |    |    |    |    |    |    | OCTOBER  |    |    |    |    |    |    | NOVEMBER |    |    |    |    |    |    | DECEMBER |    |    |    |    |    |    |   |  |  |
| SU        | MO | TU | WE | TH | FR | SA | SU       | MO | TU | WE | TH | FR | SA | SU       | MO | TU | WE | TH | FR | SA | SU       | MO | TU | WE | TH | FR | SA |   |  |  |
|           | 1  | 2  | 3  | 4  | 5  |    |          | 1  | 2  | 3  | 1  | 2  | 3  |          |    | 1  | 2  | 3  | 4  | 5  | 6        | 7  |    | 1  | 2  | 3  | 4  | 5 |  |  |
| 6         | 7  | 8  | 9  | 10 | 11 | 12 | 4        | 5  | 6  | 7  | 8  | 9  | 10 | 8        | 9  | 10 | 11 | 12 | 13 | 14 | 6        | 7  | 8  | 9  | 10 | 11 | 12 |   |  |  |
| 13        | 14 | 15 | 16 | 17 | 18 | 19 | 11       | 12 | 13 | 14 | 15 | 16 | 17 | 15       | 16 | 17 | 18 | 19 | 20 | 21 | 13       | 14 | 15 | 16 | 17 | 18 | 19 |   |  |  |
| 20        | 21 | 22 | 23 | 24 | 25 | 26 | 18       | 19 | 20 | 21 | 22 | 23 | 24 | 22       | 23 | 24 | 25 | 26 | 27 | 28 | 20       | 21 | 22 | 23 | 24 | 25 | 26 |   |  |  |
| 27        | 28 | 29 | 30 |    |    |    | 25       | 26 | 27 | 28 | 29 | 30 | 31 | 29       | 30 |    |    |    |    |    | 27       | 28 | 29 | 30 | 31 |    |    |   |  |  |

## BULLETIN OF THE CALIFORNIA

INSTITUTE OF TECHNOLOGY

1201 EAST CALIFORNIA BOULEVARD

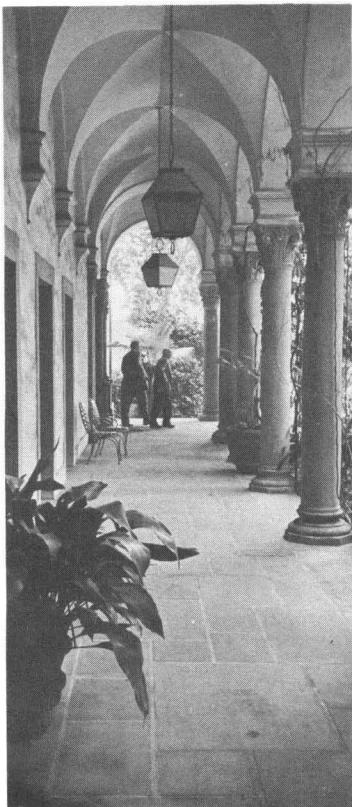
PASADENA, CALIFORNIA

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INFORMATION  
FOR  
STUDENTS  
1963-1964



CALIFORNIA INSTITUTE  
OF TECHNOLOGY

PASADENA • CALIFORNIA

SEPTEMBER 1963

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## ACADEMIC CALENDAR

1963-1964

| 1963            | FIRST TERM  |
|-----------------|---|
| September 26    | Registration of entering freshmen—8:00 a.m. to 12 noon.                                       |
| September 26    | Registration of undergraduate students transferring from other colleges—8:00 a.m. to 12 noon. |
| September 26-28 | Student Camp.   |
| September 30    | General Registration—8:30 a.m. to 3:30 p.m.   |
| September 30    | Undergraduate Academic Standards and Honors Committee—3:00 p.m.                               |
| October 1       | Beginning of instruction—8:00 a.m.  |
| October 18      | Last day for adding courses.  |
| October 19      | Examinations for the removal of conditions and incompletes.                                   |
| October 26      | Parents' Day.   |
| November 4-9    | Mid-Term Week.  |
| November 9      | MID-TERM.   |
| November 11     | Mid-Term deficiency notices due—9:00 a.m.   |
| November 15     | Last day for dropping courses.  |
| November 15     | French examination for admission to candidacy for degree of Doctor of Philosophy.             |
| November 19     | Freshman-Sophomore MUDEO—3:00 p.m.  |
| November 22     | German examination for admission to candidacy for degree of Doctor of Philosophy.             |
| November 25-29  | Pre-registration for second term, 1963-64.  |
| Nov. 28-Dec. 1  | Thanksgiving recess.  |
| November 28-29  | Thanksgiving holidays for employees.  |
| December 7      | Students' Day.  |
| December 14-20  | Final examinations—first term, 1963-64.   |
| December 21     | End of first term, 1963-64.   |
| Dec. 22-Jan. 5  | Christmas vacation.   |
| December 25     | Christmas holiday for employees.  |
| 1964            | SECOND TERM   |
| January 1       | New Year's holiday for employees.   |
| January 3       | Undergraduate Academic Standards and Honors Committee—9:00 a.m.                               |
| January 6       | General Registration—8:30 a.m. to 3:30 p.m.   |
| January 7       | Beginning of instruction—8:00 a.m.  |
| January 24      | Last day for adding courses.  |
| January 25      | Examinations for the removal of conditions and incompletes.                                   |
| February 3-8    | Mid-Term Week.  |
| February 8      | MID-TERM.   |
| February 10     | Mid-Term deficiency notices due—9:00 a.m.   |
| February 14     | Last day for dropping courses.  |
| February 14     | French examination for admission to candidacy for the degree of Doctor of Philosophy.         |
| February 21     | German examination for admission to candidacy for the degree of Doctor of Philosophy.         |
| February 24-28  | Pre-registration for third term, 1963-64.   |
| March 14-20     | Final examinations—second term, 1963-64.  |
| March 21        | End of second term, 1963-64.  |
| March 22-29     | Spring Recess.  |
| March 27        | Undergraduate Academic Standards and Honors Committee—9:00 a.m.                               |

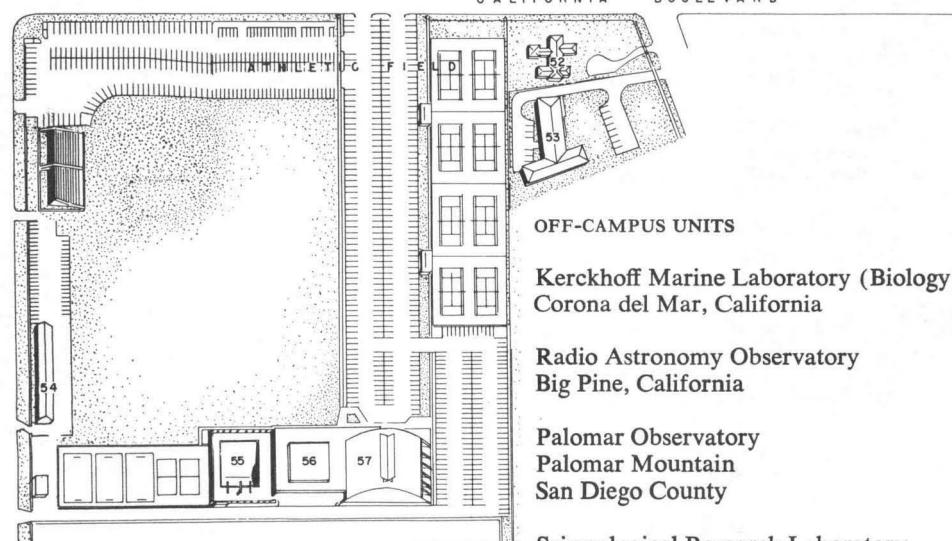
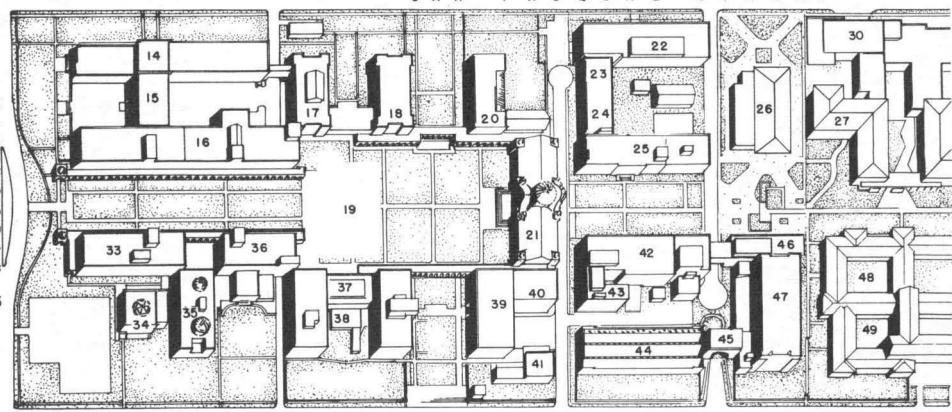
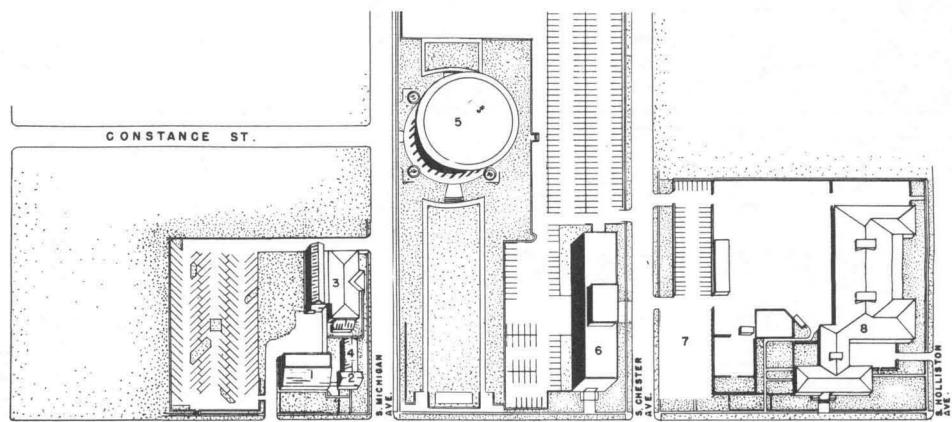
**1964****THIRD TERM**

|                |   |
|----------------|---|
| March 30       | General Registration—8:30 a.m. to 3:30 p.m.   |
| March 31       | Beginning of instruction—8:00 a.m.  |
| April 17       | Last day for adding courses.  |
| April 18       | Examinations for the removal of conditions and incompletes.   |
| April 27-May 2 | Mid-Term Week.  |
| May 2          | Last day for obtaining admission to candidacy for Engineers' degrees.                                 |
| May 2          | MID-TERM.   |
| May 4          | Mid-Term deficiency notices dues—9:00 a.m.  |
| May 8          | Last day for dropping courses.  |
| May 8          | French examination for admission to candidacy for the degree of Doctor of Philosophy.                 |
| May 8-9        | Examinations for admission to upper classes, September 1964.  |
| May 15         | German examination for admission to candidacy for the degree of Doctor of Philosophy.                 |
| May 15-June 15 | Summer Registration.  |
| May 18-22      | Pre-registration for first term, 1964-65.   |
| May 28         | Last day for final oral examinations and presenting of theses for the degree of Doctor of Philosophy. |
| May 28         | Last day for presenting theses for Engineers' degrees.  |
| May 30         | Memorial Day holiday (observed on Friday, May 29).  |
| May 30         | Memorial Day holiday for employees (observed on May 29).  |
| June 1-5       | Final examinations for senior and graduate students, third-term, 1963-64.                             |
| June 6-12      | Final examinations for undergraduate students, third-term, 1963-64.                                   |
| June 10        | Curriculum Committee—10:00 a.m.   |
| June 10        | Faculty Meeting—2:00 p.m.   |
| June 11        | Class Day.  |
| June 12        | Commencement.   |
| June 13        | End of third term, 1963-64.   |
| June 19        | Undergraduate Academic Standards and Honors Committee—9:00 a.m.                                       |
| July 4         | Independence Day holiday for employees (observed on July 3).  |

**1964****FIRST TERM, 1964-65**

|                 |  |
|-----------------|--|
| September 7     | Labor Day holiday for employees.   |
| September 24    | Registration of entering freshmen—8:00 a.m. to 12 noon.                                  |
| September 24    | Registration of undergraduate students transferring from other colleges—8:00 to 12 noon. |
| September 24-26 | Student Camp.  |
| September 28    | General Registration—8:30 a.m. to 3:30 p.m.  |
| September 29    | Beginning of instruction—8:00 a.m.   |

## CAMPUS · CALIFORNIA



## OFF-CAMPUS UNITS

Kerckhoff Marine Laboratory (Biology)  
Corona del Mar, California

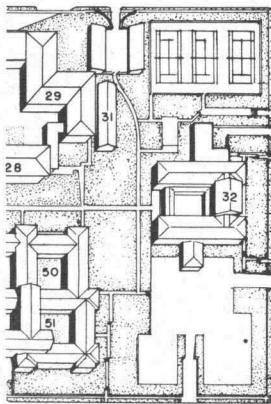
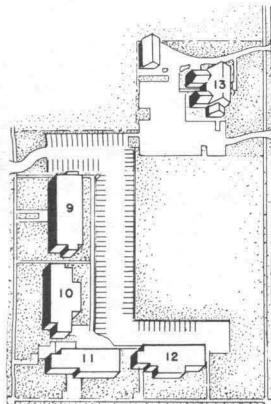
## Radio Astronomy Observatory Big Pine, California

Palomar Observatory  
Palomar Mountain  
San Diego County

Seismological Research Laboratory  
295 N. San Rafael Ave., Pasadena

**INFORMATION DESK, ROOM 25, THROOP HALL  
BUILDING NO. 21**

# INSTITUTE OF TECHNOLOGY



1. Campbell Laboratory (Plant Research)
2. Dolk Laboratory (Plant Physiology)
3. Earhart Laboratory (Plant Research)
4. Clark Laboratory (Plant Research)
5. Beckman Auditorium
6. Keck Laboratories (Engineering)
7. Booth Computing Center
8. Physical Plant (Administration and Shops)
9. Keck House
10. Mosher-Jorgensen House
11. Braun House
12. Marks House
13. Industrial Relations Center
14. Church Laboratory (Chemical Biology)
15. Alles Laboratory (Molecular Biology)
16. Kerckhoff Laboratory (Biological Sciences)
17. Crellin Laboratory (Chemistry)

18. Gates Laboratory (Chemistry)
19. Site of future Millikan Memorial Library
20. Dabney Hall (Humanities)
21. Throop Hall (Administration)
22. Spalding Laboratory (Chemical and Electrical Engineering)
23. Chemical Engineering Laboratory
24. Heating Plant
25. Thomas Laboratory (Civil and Mechanical Engineering)
26. Winnett Student Center
27. Page House
28. Lloyd House
29. Ruddock House
30. Chandler Dining Hall
31. Building T-4
32. Athenaeum
33. Mudd Laboratory (Geological Sciences)
34. Culbertson Hall
35. Robinson Laboratory (Astrophysics)
36. Arms Laboratory (Geological Sciences)
37. Bridge Laboratory (Physics)
38. Cosmic Ray Laboratory
39. Sloan Laboratory (Mathematics & Physics)
40. Kellogg Radiation Laboratory (Nuclear Physics)
41. Graphic Arts, Receiving Room and Central Warehouse
42. Guggenheim Laboratory (Aeronautics)
43. Karman Laboratory (Fluid Mechanics and Jet Propulsion)
44. Central Engineering Machine Shop
45. Merrill Wind Tunnel
46. Firestone Laboratory (Flight Sciences)
47. Synchrotron Laboratory
48. Fleming House
49. Dabney House
50. Ricketts House
51. Blacker House
52. Arden House
53. Young Health Center
54. Building T-1: (Air Force ROTC)
55. Alumni Swimming Pool
56. Locker Rooms
57. Brown Gymnasium



# Section I

## CALIFORNIA INSTITUTE OF TECHNOLOGY

### OFFICERS AND FACULTY

#### BOARD OF TRUSTEES

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|                       |       |                                     |
|-----------------------|-------|-------------------------------------|
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(Arranged in order of seniority of service with dates of first election)

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| Norman Chandler (1941)          | ..... | Los Angeles      |
| Lee A. DuBridge (1947)          | ..... | Pasadena         |
| Edward R. Valentine (1948)      | ..... | San Marino       |
| Leonard S. Lyon (1950)          | ..... | Los Angeles      |
| Harry J. Volk (1950)            | ..... | Los Angeles      |
| Arnold O. Beckman (1953)        | ..... | Corona del Mar   |
| Charles S. Jones (1953)         | ..... | Pasadena         |
| John E. Barber (1954)           | ..... | Pasadena         |
| Lawrence A. Williams (1954)     | ..... | San Marino       |
| *Robert L. Minckler (1954)      | ..... | Pasadena         |
| Howard G. Vesper (1954)         | ..... | Oakland          |
| Shannon Crandall, Jr. (1955)    | ..... | Pasadena         |
| F. Marion Banks (1955)          | ..... | Pasadena         |
| Herbert L. Hahn (1955)          | ..... | Pasadena         |
| Richard R. Von Hagen (1955)     | ..... | Encino           |
| Earle M. Jorgensen (1957)       | ..... | Los Angeles      |
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| Lindley C. Morton (1959)        | ..... | Pasadena         |
| John G. Braun (1959)            | ..... | Pasadena         |
| Thomas V. Jones (1960)          | ..... | Los Angeles      |
| Seeley G. Mudd (1960)           | ..... | San Marino       |
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| John S. Griffith (1962)         | ..... | Pasadena         |
| William Clayton (1963)          | ..... | Pasadena         |
| Henry Dreyfuss (1963)           | ..... | South Pasadena   |

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| P. G. Winnett (1939, 1961)      | ..... | Los Angeles   |
| Elbridge H. Stuart (1950, 1962) | ..... | Bel Air       |

<sup>a</sup>Died August 6, 1963

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| Robert B. Gilmore                  | John E. Pomfret      |
| *Jesse L. Greenstein               | *Ernest E. Sechler   |
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\*Selected by the membership of the Athenaeum

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| Norman H. Horowitz                    |
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## GEOLOGY

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| Jesse L. Greenstein                |
| Earle M. Jorgensen                 |
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| <i>Director of News Bureau</i> . . . . .   | Graham G. Berry       |
| <i>Editor of Engineering and Science</i> . . . . .                               | Edward Hutchings, Jr. |
| <i>Executive Director of Industrial Associates</i> . . . . .                     | Emory L. Ellis        |
| <i>Master of Student Houses</i> . . . . .  | Robert A. Huttenback  |
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\*On leave of absence, 1963-64.

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**1963-64**

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*Vice-Chairman: D. S. Clark*

*Secretary: H. C. Martel*

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| <i>Term Expires</i>      | <i>Term Expires</i>        | <i>Term Expires</i>  |
|--------------------------|----------------------------|----------------------|
| <i>June 30, 1964</i>     | <i>June 30, 1965</i>       | <i>June 30, 1966</i> |
| R. B. Corey              | R. F. Christy              | H. Borsook           |
| D. C. Elliot             | W. H. Corcoran             | A. J. Haagen-Smit    |
| M. S. Plesset            | M. Hall, Jr.               | J. Mathews           |
| R. L. Walker             | D. E. Hudson               | H. V. Neher          |
| W. Whaling               | W. B. Kamb                 | C. J. Pings          |
| C. H. Wilts <sup>1</sup> | C. G. Niemann <sup>2</sup> | T. Vreeland          |

Ex officio: L. A. DuBridge, C. D. Anderson, F. C. Lindvall, R. D. Owen, J. D. Roberts, R. P. Sharp, H. D. Smith, R. F. Bacher, H. F. Bohnenblust, P. C. Eaton, L. W. Jones, F. Strong.

<sup>1</sup>Serving in the absence of R. W. Gould

<sup>2</sup>Serving in the absence of J. Waser

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| <i>Term Expires June 30, 1964</i> | <i>Term Expires June 30, 1965</i> |
|-----------------------------------|-----------------------------------|
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| R. D. Owen*                       | E. E. Sechler*                    |

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RELATIONS WITH SECONDARY SCHOOLS—*R. M. Sutton, A. J. Acosta, P. J. Blatz, N. R. Davidson, A. J. Haagen-Smit, L. W. Jones, C. Newton, M. A. Nicolet, R. F. Scott, H. P. Taylor, Jr.*

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UNDERGRADUATE STUDENT HOUSES—*D. S. Clark, P. C. Eaton, R. B. Gilmore, R. A. Huttenback, J. H. Richards, R. P. Sharp, F. Strong, T. Vreeland, Jr., W. Whaling.*

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STAFF OF INSTRUCTION AND RESEARCH  
SUMMARY

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Ray D. Owen, *Chairman*

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| George E. MacGinitie, M.A. ....         | <i>Biology</i>                                 |
| Alfred H. Sturtevant, Ph.D., D.Sc. .... | <i>Thomas Hunt Morgan Professor of Biology</i> |

## PROFESSORS

|  |   |
|--|---|
| James F. Bonner, Ph.D.* ....             | <i>Biology</i>                          |
| Henry Borsook, Ph.D., M.D. ....          | <i>Biochemistry</i>                     |
| Max Delbrück, Ph.D. ....                 | <i>Biology</i>                          |
| William J. Dreyer, Ph.D. ....            | <i>Biology</i>                          |
| Sterling Emerson, Ph.D. ....             | <i>Genetics</i>                         |
| Arie J. Haagen-Smit, Ph.D. ....          | <i>Bio-Organic Chemistry</i>            |
| Alan J. Hodge, Ph.D. ....                | <i>Biology</i>                          |
| Norman H. Horowitz, Ph.D. ....           | <i>Biology</i>                          |
| Anton Lang, Ph.D. ....                   | <i>Biology</i>                          |
| Edward B. Lewis, Ph.D. ....              | <i>Biology</i>                          |
| Herschel K. Mitchell, Ph.D. ....         | <i>Biology</i>                          |
| Ray D. Owen, Ph.D., Sc.D. ....           | <i>Biology</i>                          |
| Robert L. Sinsheimer, Ph.D. ....         | <i>Biophysics</i>                       |
| Roger W. Sperry, Ph.D. ....              | <i>Hixon Professor of Psychobiology</i> |
| Albert Tyler, Ph.D. ....                 | <i>Biology</i>                          |
| Anthonie van Harreveld, Ph.D., M.D. .... | <i>Physiology</i>                       |
| Cornelis A. G. Wiersma, Ph.D. ....       | <i>Biology</i>                          |

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| William S. Stewart, Ph.D. .... | <i>Biology</i>    |
| Jean J. Weigle, Ph.D. ....     | <i>Biophysics</i> |

## ASSOCIATE PROFESSORS

|                               |   |
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| Giuseppe Attardi, M.D. ....   | <i>Biology</i>                            |
| Charles J. Brokaw, Ph.D. .... | <i>Biology</i>                            |
| Robert S. Edgar, Ph.D. ....   | <i>Biology</i>                            |
| Derek H. Fender, Ph.D. ....   | <i>Biology and Electrical Engineering</i> |

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| Henry Hellmers, <sup>1</sup> Ph.D. .... | <i>Biology</i>                            |
| Geoffrey L. Keighley, Ph.D. ....        | <i>Biology</i>                            |
| Heinz Schuster, Ph.D. ....              | <i>Biology</i>                            |
| David M. Vowles, Ph.D. ....             | <i>Biology and Electrical Engineering</i> |

## INSTRUCTOR

|                              |                |
|------------------------------|----------------|
| Edward A. Carusi, Ph.D. .... | <i>Biology</i> |
|------------------------------|----------------|

<sup>\*</sup>On leave of absence, 1963-64<sup>1</sup>U.S. Forest Service

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| David Griffin <sup>1</sup> , Ph.D.          | Manfred D. E. Ruddat, Ph.D.                  |
| Ferenc Guba, Ph.D.                          | Kenneth G. M. Skene <sup>1</sup> , Ph.D.     |
| Burton S. Guttman <sup>3</sup> , Ph.D.      | Alan B. Stone, Ph.D.*                        |
| Hiroshi Harada, Ph.D.                       | Clare C. C. Yu-Sun <sup>3</sup> , Ph.D.      |
| Anne M. Haywood, M.D.                       | Thomas W. Thompson, Ph.D.*                   |
| Erich Heftmann <sup>7</sup> , Ph.D.         | Hector Timourian, Ph.D.                      |
| R. W. Henry <sup>3</sup> , Ph.D.            | Cornelius H. Vanderwolf, Ph.D.               |
| Harry R. Highkin <sup>8</sup> , Ph.D.       | Jacomijntje Van Hof, M.D.                    |
| P. C. Huang, Ph.D.                          | Marius Van Hof, M.D.                         |
| R. C. Huang, Ph.D.                          | Christoph Von Campenhausen, Ph.D.            |
| Richard P. Huemer <sup>1</sup> , M.D.       | J. A. D. Zeevaart, Ph.D.                     |
| Beal B. Hyde, Ph.D.                         |  |

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| Dennis Barrett, A.B.        | Michael Fried, B.A.        |
| Thomas L. Benjamin, B.A.    | Michael S. Gazzaniga, A.B. |
| Richard J. L. Bondar, B.Sc. | Ellen R. Glowacki, B.A.    |
| James B. Boyd, B.A.         | Stuart F. Goldstein, B.A.  |
| Thomas A. Cole, B.A.        | Charles R. Hamilton, B.S.  |
| David T. Denhardt, B.A.     | Roy W. Harding, Jr., B.S.  |
| Paul C. Denny, B.A.         | Loren E. Hatlen, B.A.      |
| Larre N. Egbert, M.S.       | Robert L. Heath, M.S.      |

[THESE FOOTNOTES PERTAIN TO PAGES 17 AND 18]

<sup>1</sup>In residence, 1962-63<sup>2</sup>U.S. Public Health Service Fellow<sup>3</sup>Massachusetts Institute of Technology<sup>4</sup>National Science Foundation Fellow<sup>4</sup>Rockefeller Foundation Fellow<sup>5</sup>Immaculate Heart College<sup>6</sup>Commonwealth Scientific and Industrial Research Organization<sup>7</sup>U.S. Public Health Service<sup>8</sup>San Fernando Valley State College<sup>9</sup>University of California at Los Angeles<sup>10</sup>American Cancer Society Fellow

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| Laszlo Zechmeister, Dr.Ing. .... | Organic Chemistry    |

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| Dan H. Campbell, Ph.D., Sc.D. ....   | Immunochemistry                               |
| William H. Corcoran, Ph.D. ....  | Chemical Engineering                          |
| Robert B. Corey, Ph.D. ....  | Structural Chemistry                          |
| Norman Davidson, Ph.D. ....  | Chemistry                                     |
| Sheldon K. Friedlander, Ph.D. ....   | Chemical Engineering and Environmental Health |
| George S. Hammond, Ph.D. ....  | Organic Chemistry                             |
| Aron Kuppermann, Ph.D. ....  | Chemical Physics                              |
| Harden M. McConnell, Ph.D. ....  | Chemistry and Physics                         |
| Carl G. Niemann, Ph.D. ....  | Organic Chemistry                             |
| Linus Pauling, Ph.D., Sc.D., L.H.D., U.J.D., Dr. h.c., D.F.A., L.L.D., Nobel Laureate .... | Chemistry                                     |
| John D. Roberts, Ph.D., Dr. rer. nat. h.c. ....  | Organic Chemistry                             |
| G. Wilse Robinson, Ph.D. ....  | Physical Chemistry                            |
| Bruce H. Sage, Ph.D., Eng.D. ....  | Chemical Engineering                          |
| J. Holmes Sturdivant, Ph.D. ....   | Chemistry                                     |
| Ernest H. Swift, Ph.D., LL.D. ....   | Analytical Chemistry                          |
| Jürg Waser,* Ph.D. ....  | Chemistry                                     |
| Don M. Yost, Ph.D. ....  | Inorganic Chemistry                           |

## RESEARCH ASSOCIATES

|                                 |                    |
|---------------------------------|--------------------|
| Edwin R. Buchman, D.Phil. ....  | Organic Chemistry  |
| Edward W. Hughes, Ph.D. ....    | Physical Chemistry |
| Joseph B. Koepfli, D.Phil. .... | Chemistry          |
| Seeley G. Mudd, M.D. ....       | Medical Chemistry  |
| Walter A. Schroeder, Ph.D. .... | Chemistry          |
| Jerome R. Vinograd, Ph.D. ....  | Chemistry          |
| Oliver R. Wulf,** Ph.D. ....    | Physical Chemistry |

## VISITING ASSOCIATES

|                                 |                      |
|---------------------------------|----------------------|
| Ronald F. Brown, Ph.D. ....     | Chemistry            |
| Kenneth G. Denbigh*** ....      | Chemical Engineering |
| Frank B. Mallory,† Ph.D. ....   | Chemistry            |
| Maurice E. Mathisen, Ph.D. .... | Chemistry            |
| Robert D. Vold, Ph.D. ....      | Chemistry            |

## ASSOCIATE PROFESSORS

|                                  |                      |
|----------------------------------|----------------------|
| Fred C. Anson,* Ph.D. ....       | Analytical Chemistry |
| Richard E. Dickerson, Ph.D. .... | Physical Chemistry   |
| Paul A. Longwell,†† Ph.D. ....   | Chemical Engineering |
| Cornelius J. Pings, Ph.D. ....   | Chemical Engineering |
| John H. Richards, Ph.D. ....     | Organic Chemistry    |

\*On leave of absence.

\*\*Member U.S. Weather Bureau.

\*\*\*In residence 1962-63.

†John Simon Guggenheim Memorial Foundation Fellow.

††Part-time.

## SENIOR RESEARCH FELLOWS

|                              |                      |
|------------------------------|----------------------|
| Marjorie C. Caserio, Ph.D.   | Chemistry            |
| Justine S. Garvey, Ph.D.     | Chemistry            |
| Richard E. Marsh, Ph.D.      | Chemistry            |
| H. Hollis Reamer, M.S.       | Chemical Engineering |
| Heinrich Rinderknecht, Ph.D. | Chemistry            |
| Sten Samson, Fil.Lic.        | Chemistry            |
| Kenneth N. F. Shaw, Ph.D.    | Chemistry            |

## ASSISTANT PROFESSORS

|                             |                      |
|-----------------------------|----------------------|
| Sunney I. C.-H. Chan, Ph.D. | Chemical Physics     |
| George Neal Richter, Ph.D.  | Chemical Engineering |
| Robert G. Rinker, Ph.D.     | Chemical Engineering |
| William P. Schaefer, Ph.D.  | Chemistry            |
| Richard C. Seagrave, Ph.D.  | Chemical Engineering |

## ARTHUR AMOS NOYES RESEARCH INSTRUCTORS

|                          |           |
|--------------------------|-----------|
| Morris Brown, Ph.D.      | Chemistry |
| Russell M. Pitzer, Ph.D. | Chemistry |

## RESEARCH FELLOWS

|   |  |
|---|--|
| Gustav Albrecht, Ph.D.                  | Willem J. A. Maaskant, Ph.D.           |
| Alfred A. Amkraut <sup>1</sup> , Ph.D.  | Adalbert Maercker, Ph.D.               |
| Donald R. Babin, Ph.D.                  | Brian S. Malone, Ph.D.                 |
| Hector Belmares-Sarabia, Ph.D.          | Frances G. Mark,* Ph.D.                |
| Gerhard Binsch, Ph.D.                   | Jack Foster McConnell,* Ph.D.          |
| Stanko Borčić, Ph.D.                    | Robert A. Meyers, Ph.D.                |
| William H. Brown, Ph.D.                 | Uma Shankar Nandi, Ph.D.               |
| John Francis Catchpool, Ph.D.           | Rex A. Palmer, Ph.D.                   |
| Arthur Cherkin, Ph.D.                   | William T. Raynes, Ph.D.               |
| John R. Fox, Ph.D.                      | Egon E. Rickli, Ph.D.                  |
| Albert J. Fry, Ph.D.                    | Bryan W. Roberts <sup>1</sup> , Ph.D.  |
| Carlo Maria Gramaccioli, Ph.D.          | Richard Robson, D.Phil.                |
| Dieter Grünwedel, Dr. rer. nat.         | Wilfried Rombauts <sup>4</sup> , Ph.D. |
| Donald Halford, Ph.D.                   | Anil Kumar Saha, Ph.D.                 |
| Carole O. Hamilton, Ph.D.               | Takuya R. Sato, Ph.D.                  |
| Peter Hauk <sup>1</sup> , Ph.D.         | Ulrich Scheidegger, D.Sc.              |
| Alfred H. Kalantar <sup>2</sup> , Ph.D. | Brahama Datta Sharma, Ph.D.            |
| Gordon R. Johnston, Ph.D.               | Richard H. Stanford, Jr., Ph.D.        |
| Lois M. Kay, M.S.                       | Reinhard Steinmetz, Dr.rer.nat.        |
| Charles M. Knobler, Dr. Wis.-Nat.       | Ronald G. Sutherland, Ph.D.            |
| Alvin L. Kwigram <sup>3</sup> , Ph.D.   | Michal Witanowski, Ph.D.               |
| Jacob Lebowitz, Ph.D.                   | Chin-Hua Wu, Ph.D.                     |
| Günter Maass, Ph.D.                     | Emile Zuckerkandl, Ph.D.               |

## GRADUATE FELLOWS AND ASSISTANTS, 1962-63

|                          |                          |
|--------------------------|--------------------------|
| Harvie Andre, B.S.       | Thomas A. Beineke, B.S.  |
| John H. Arndt, Jr., B.S. | Charles M. Blair, B.A.   |
| Peter Baine, G.R.I.C.    | David A. Brueckner, B.S. |
| John R. Barker, B.Sc.    | Thomas E. Burke, B.A.    |

<sup>1</sup>NAS-NRC Fellow.<sup>2</sup>National Science Foundation Postdoctoral Fellow.<sup>3</sup>Arthur Amos Noyes Fellow.<sup>4</sup>Belgian-American Educational Foundation Fellow.

\*In residence 1962-63.

Roger W. Caputi, B.S.  
Shiou-Shan Chen, M.S.  
Charles R. Christensen, B.E.  
Harold R. Couch, M.S.  
Lelia M. Coyne, B.S.  
Robert F. Cuffel, M.S.  
Joseph J. Dannenberg, A.B.  
Charles D. DeBoer, B.S.  
Alan S. Dubin, Ch.E.  
David J. Duchamp, B.S.  
David R. Dyroff, B.S.  
Michael H. Fisch, A.B.  
James N. Foster, B.A.  
Charles J. Fritchie, Jr., B.S.  
Robert P. Frosch, B.S.  
William C. Galley, B.Sc.  
Terry R. Galloway, B.S.  
Edward S. Glazer, B.A.  
Lester S. Gorelic, B.S.  
Dennis J. Graue, M.S.  
O. Hayes Griffith, A.B.  
John J. Grocki, B.S.  
William M. Hardham, B.S.  
William G. Herkstroeter, B.A.  
Brian M. Hoffman, S.B.  
Walter R. Holmquist, B.S.  
Wallace I. Honeywell, B.S.  
Daniel J. F. Hoy, B.S.  
Johannes Huisman, M.S.  
Glen O. Hultgren, B.S.  
Kwang-Chou Hwang, M.S.  
Martin S. Itzkowitz, A.B.  
Ronald H. Jensen, B.S.  
Janet G. Jones, B.A.  
Noel D. Jones, B.S.  
David Kauffman, B.S.  
James W. Kessel, B.S.  
Leon F. Keyser, B.S.  
W. Bruce Kover, B.S.  
Joel Kwok, B.S.  
Joseph B. Lambert, B.S.  
William E. Lambert III, B.A.  
Angelo A. Lamola, B.S.  
Robert C. Leif, B.S.  
Gerald R. Liebling, B.S.  
Peter J. Lingane, A.B.  
Chung-Chiun Liu, M.S.  
Robert S. H. Liu, B.S.  
Chien-Shih Lu, M.S.  
Edward R. H. McDowell, M.S.  
Arthur W. Merkl, B.S.  
Robert M. Metzger, B.S.  
Paul G. Mikolaj, M.S.  
Darwin P. Moradiellos, B.S.  
Milton E. Morrison, M.S.  
Robert G. Mortimer, M.S.  
Werner A. Mukatis, B.S.  
Eugene B. Nebeker, M.S.  
Gary L. Neil, B.S.  
George C. Nieman, B.S.  
Maurice J. Nugent, Jr., B.A.  
Heiko H. Ohlenbusch, B.S.  
Baldomero M. Olivera, Jr., B.S.  
Edwin S. Olson, B.A.  
Dinshaw J. Patel, B.Sc.  
Roger L. Peterson, B.S.  
Leonard W. Piszkiewicz, B.S.  
James R. Rapp, A.B.  
Sergio E. Rodriguez, M.S.  
Allan J. Rosen, A.B.  
Dana L. Roth, B.S.  
Jack Saltiel, B.A.  
Kenneth L. Servis, B.S.  
Usha B. Shah, B.S.  
Sang Chul Shim, B.S.  
Harris J. Silverstone, A.B.  
Zoltán G. Šoos, B.A.  
Edmund E. Spaeth, B.S.  
Peter R. Sumner, B.S.  
Donal D. Thomas, B.S.  
Dino S. Tinti, B.A.  
Nicholas J. Turro, Jr., B.A.  
Harris E. Ulery, B.A.  
Donald H. Valentine, Jr., B.A.  
Harold P. Waits, B.S.  
Yui-Loong Wang, M.S.  
Ned C. Webb, B.A.  
George M. Whitesides, B.A.  
Thomas H. Wirth, A.B.  
David E. Wood, B.S.  
Joe W. Woodward, M.S.

## DIVISION OF ENGINEERING AND APPLIED SCIENCE

Frederick C. Lindvall, *Chairman*Clark B. Millikan, *Director, Graduate Aeronautical Laboratories*

## PROFESSORS EMERITI

|                           |                                      |
|---------------------------|--------------------------------------|
| Frederick Converse, B.S.  | Soil Mechanics                       |
| Robert L. Daugherty, M.E. | Mechanical and Hydraulic Engineering |
| Aladar Hollander, M.E.    | Mechanical Engineering               |
| R. Martel, S.B.           | Structural Engineering               |
| William W. Michael, B.S.  | Civil Engineering                    |
| Royal W. Sorensen, D.Sc.  | Electrical Engineering               |

## PROFESSORS

|                               |   |
|-------------------------------|---|
| Norman H. Brooks, Ph.D.       | Civil Engineering                             |
| Thomas K. Caughey, Ph.D.      | Applied Mechanics                             |
| Donald S. Clark, Ph.D.        | Physical Metallurgy                           |
| Julian D. Cole, Ph.D.         | Aeronautics                                   |
| Charles E. Crede, M.S.        | Mechanical Engineering and Applied Mechanics  |
| Charles R. DePrima, Ph.D.     | Applied Mechanics                             |
| Pol E. Duwez, D.Sc.           | Materials Science                             |
| Sheldon K. Friedlander, Ph.D. | Chemical and Environmental Health Engineering |
| Yuan-Cheng Fung, Ph.D.        | Aeronautics                                   |
| Roy W. Gould*, Ph.D.          | Electrical Engineering and Physics            |
| George W. Housner, Ph.D.      | Civil Engineering and Applied Mechanics       |
| Donald E. Hudson, Ph.D.       | Mechanical Engineering and Applied Mechanics  |
| Arthur L. Klein, Ph.D.        | Aeronautics                                   |
| Paco A. Lagerstrom, Ph.D.     | Aeronautics                                   |
| Robert V. Langmuir, Ph.D.     | Electrical Engineering                        |
| Lester Lees, M.S.             | Aeronautics                                   |
| Hans W. Liepmann, Ph.D.       | Aeronautics                                   |
| Frederick C. Lindvall, Ph.D.  | Electrical and Mechanical Engineering         |
| Gilbert D. McCann, Ph.D.      | Electrical Engineering                        |
| Jack E. McKee, Sc.D.          | Environmental Health Engineering              |
| Frank E. Marble, Ph.D.        | Jet Propulsion and Mechanical Engineering     |
| Julius Miklowitz, Ph.D.       | Applied Mechanics                             |
| Clark B. Millikan, Ph.D.      | Aeronautics                                   |
| Dino A. Morelli, Ph.D.        | Engineering Design                            |
| Charles H. Papas, Ph.D.       | Electrical Engineering                        |
| William H. Pickering,* Ph.D.  | Electrical Engineering                        |
| Milton S. Plesset, Ph.D.      | Engineering Science                           |
| W. Duncan Rannie, Ph.D.       | Robert H. Goddard Professor of Jet Propulsion |
| Anatol Roshko, Ph.D.          | Aeronautics                                   |
| Rolf Sabersky, Ph.D.          | Mechanical Engineering                        |
| Ernest E. Sechler, Ph.D.      | Aeronautics                                   |
| Homer J. Stewart, Ph.D.       | Aeronautics                                   |
| Vito A. Vanoni, Ph.D.         | Hydraulics                                    |
| J. Harold Wayland, Ph.D.      | Engineering Science                           |
| Gerald Whitham, Ph.D.         | Aeronautics and Mathematics                   |
| Max L. Williams, Ph.D.        | Aeronautics                                   |
| Charles H. Wilts, Ph.D.       | Electrical Engineering                        |
| David S. Wood, Ph.D.          | Materials Science                             |
| Theodore Y. Wu, Ph.D.         | Applied Mechanics                             |

## VISITING PROFESSOR

William Chester, Ph.D. .... Aeronautics

\*On leave of absence, 1963-64

## RESEARCH ASSOCIATES

|                                |                        |
|--------------------------------|------------------------|
| Simon Ramo, Ph.D. ....         | Electrical Engineering |
| Dean E. Wooldridge, Ph.D. .... | Engineering            |

## ASSOCIATES

|                       |                   |
|-----------------------|-------------------|
| George W. Downs ..... | Engineering       |
| Henry Dreyfuss .....  | Industrial Design |

## ASSOCIATE PROFESSORS

|                                    |                                    |
|------------------------------------|------------------------------------|
| Allan J. Acosta, Ph.D. ....        | Mechanical Engineering             |
| Francis S. Buffington, Sc.D. ....  | Materials Science                  |
| Donald E. Coles,* Ph.D. ....       | Aeronautics                        |
| Albert T. Ellis, Ph.D. ....        | Applied Mechanics                  |
| Derek H. Fender, Ph.D. ....        | Biology and Electrical Engineering |
| Joel N. Franklin, Ph.D. ....       | Applied Mechanics                  |
| Nicholas George, Ph.D. ....        | Electrical Engineering             |
| James K. Knowles, Ph.D. ....       | Applied Mechanics                  |
| Toshi Kubota, Ph.D. ....           | Aeronautics                        |
| Harold Lurie, Ph.D. ....           | Engineering Science                |
| Caleb W. McCormick, Jr., M.S. .... | Civil Engineering                  |
| Hardy C. Martel, Ph.D. ....        | Electrical Engineering             |
| Carver A. Mead, Ph.D. ....         | Electrical Engineering             |
| Robert D. Middlebrook, Ph.D. ....  | Electrical Engineering             |
| Wheeler J. North, Ph.D. ....       | Environmental Health Engineering   |
| Ronald F. Scott, Sc.D. ....        | Civil Engineering                  |
| Ronald F. Soohoo, Ph.D. ....       | Electrical Engineering             |
| Thad Vreeland, Jr., Ph.D. ....     | Materials Science                  |
| David F. Welch, I.D. ....          | Engineering Design                 |
| Edward E. Zukoski, Ph.D. ....      | Jet Propulsion                     |

## VISITING ASSOCIATES

|                                |                        |
|--------------------------------|------------------------|
| F. H. Abernathy, Ph.D. ....    | Aeronautics            |
| D. B. Narasimhaiah, M.Sc. .... | Civil Engineering      |
| Merrill P. Spencer, M.D. ....  | Engineering            |
| Edward J. Wellman, Ph.D. ....  | Mechanical Engineering |

## SENIOR RESEARCH FELLOWS

|                                    |                                    |
|------------------------------------|------------------------------------|
| Paul J. Blatz, Ph.D. ....          | Materials Science                  |
| Sheldon Cherry, Ph.D. ....         | Civil Engineering                  |
| Kamalaksha Das Gupta, Ph.D. ....   | Materials Science                  |
| Wallace G. Frasher, Jr., M.D. .... | Engineering Science                |
| Ludwig Hartmann, Ph.D. ....        | Environmental Health Engineering   |
| Floyd B. Humphrey, Ph.D. ....      | Electrical Engineering             |
| Saul Kaplan, Ph.D. ....            | Aeronautics                        |
| Hao-Wen Liu, Ph.D. ....            | Aeronautics                        |
| Sitaram Rao Valluri, Ph.D. ....    | Aeronautics                        |
| David M. Vowles, Ph.D. ....        | Biology and Electrical Engineering |
| Minoru Takahashi, D.Sc. ....       | Electrical Engineering             |

## SENIOR LECTURER

|                             |             |
|-----------------------------|-------------|
| Melvin Gerstein, Ph.D. .... | Engineering |
|-----------------------------|-------------|

\*On leave of absence, 1963-64.

## ASSISTANT PROFESSORS

|  |                        |
|--|------------------------|
| Charles D. Babcock, Jr., Ph.D.         | Aeronautics            |
| David J. Braverman, Ph.D.              | Electrical Engineering |
| Fred E. C. Culick, Sc.D.               | Jet Propulsion         |
| Thomas L. Grettenberg, Ph.D.           | Electrical Engineering |
| Din-Yu Hsieh, Ph.D.                    | Engineering Science    |
| Peter S. B. Lissaman, M.S. (Part-time) | Aeronautics            |
| Kenneth Lock, Ph.D.                    | Electrical Engineering |
| Peter V. Mason, Ph.D.                  | Electrical Engineering |
| Marc-Aurele Nicolet, Ph.D.             | Electrical Engineering |
| Frederic Raichlen, Sc.D.               | Civil Engineering      |
| William R. Samples, Ph.D.              | Civil Engineering      |
| Jerome L. Shapiro, Ph.D.               | Applied Science        |
| Bradford Sturtevant, Ph.D.             | Aeronautics            |
| Raphael Sivan-Sussman, Ph.D.           | Electrical Engineering |
| Ronald H. Willens, Ph.D.               | Materials Science      |

## LECTURERS

|                        |                                  |
|------------------------|----------------------------------|
| Taras Kiceniuk, M.S.   | Engineering Design               |
| Harvey F. Ludwig, M.S. | Environmental Health Engineering |

## RESEARCH FELLOWS

|                            |                                  |
|----------------------------|----------------------------------|
| H. G. Ahlstrom, Ph.D.      | Aeronautics                      |
| Daniel K. Ai, Ph.D.        | Engineering                      |
| A. V. Anantaraman, Ph.D.   | Engineering                      |
| B. J. S. Barnard, Ph.D.    | Engineering                      |
| George Bienkowski, Ph.D.   | Aeronautics                      |
| Peter Daly, Ph.D.          | Electrical Engineering           |
| Charles W. Ferguson, B.S.  | Aeronautics                      |
| Andrew L. Gram III, Ph.D.  | Environmental Health Engineering |
| Marcos Intaglietta, Ph.D.  | Engineering Science              |
| Timothy Wu Kao, Ph.D.      | Engineering                      |
| Jirair K. Kevorkian, Ph.D. | Aeronautics                      |
| Wolfgang G. Knauss, Ph.D.  | Aeronautics                      |
| Takeshi Kunio, Ph.D.       | Aeronautics                      |
| Joseph L. Leray, D.Sc.     | Engineering Science              |
| Roddam Narasimha, Ph.D.    | Aeronautics                      |
| Barry L. Reeves, D.Sc.     | Aeronautics                      |
| John V. Robinson, Ph.D.    | Civil Engineering                |
| Louis V. Schmidt, Ph.D.    | Aeronautics                      |
| Andrew N. Schofield, Ph.D. | Soil Mechanics                   |
| Jacob Steinberg, Ph.D.     | Electrical Engineering           |
| Robert L. Street, Ph.D.    | Engineering                      |
| George C. Vlases, Ph.D.    | Aeronautics                      |
| Duen-pao Wang, Ph.D.       | Engineering                      |
| Anthony M. Watts, Ph.D.    | Aeronautics                      |
| Russell A. Westmann, Ph.D. | Aeronautics                      |
| Adam R. Zak, Ph.D.         | Aeronautics                      |

## DIVISION OF ENGINEERING AND APPLIED SCIENCE

## GRADUATE FELLOWS AND ASSISTANTS, 1962-63

|  |                                    |
|--|------------------------------------|
| Mahmoud Khairy Abd-el-Gawad, B.Sc.       | William Winston Evans, B.Sc.       |
| Ahmad Khalil Abu-Shumays, B.S.           | David Arthur Evensen, M.S.         |
| Kenneth Hoyt Adams, M.S.                 | Pierre Facon, Ing.                 |
| Harlow Garth Ahlstrom, M.S.              | William Thomas Fehlberg, B.S.E.    |
| Nazeer Ahmed, M.S.                       | Michael John Ferguson, B.A.Sc.     |
| Irwin Emanuel Alber, B.S.                | Hugo Breed Fischer, B.S.           |
| Robert James Arenz, M.S.                 | Efthymios Stefanos Folias, M.S.    |
| George S. Argyropoulos, M.S.             | Michael Eugene Fourney, M.S.       |
| John Theodore Armstrong, B.S.            | Edward George Gibson, M.S.         |
| John Fredrich Asmus, M.S.                | Lavelle Roger Gibson, B.S.         |
| Percy Max Augustus, B.S.                 | Philip Mwangi Githinji, M.S.       |
| Boris Auksmann, M.E.                     | William Andrew Goddard III, B.S.   |
| Donald Baganoff, M.S.                    | Jacques Godin, B.App.Sc.           |
| Richard George Batt, M.S.                | Harris Gold, M.S.M.E.              |
| Wayne Metcalf Beebe, M.S.                | Robert Goldstein, M.S.             |
| George Wood Beeler, Jr., M.S.            | Muvaffak Ilhan Gozaydin, M.S.      |
| Wilhelm Behrens, Dipl.Ing.               | Augustine Heard Gray, Jr., S.M.    |
| James Melvin Bell, M.S.                  | Louise Dillon Gray, M.S.           |
| Lon Edward Bell, B.S.                    | William Franklin Greenman, M.S.    |
| David Bernard Benson, B.S.               | William Paul Gruber, B.S.          |
| Charles Edgar Billings, S.M.             | Lawrence William Hallanger, M.S.   |
| Harry Spencer Blackiston, Jr., M.S.      | Anthony Michael John Hannon, B.E.  |
| David Jordan Blakemore, M.S.             | Robert Duane Hanson, M.S.C.E.      |
| Ronald David Boettcher, B.A.B.S.         | Kenneth Gunder Harstad, S.M.       |
| Robert William Bower, A.B.               | Kenneth Edwin Harwell, M.S.        |
| William Charles Boyle, M.S.              | Edward Hauptmann, M.S.             |
| Arthur Gerald Brady, B.Sc.               | Gilbert Arthur Hegemier, M.S.      |
| Ralph Eric Bredehorst, B.S.              | Malcolm Lee Heimer, B.S.E.E.       |
| Carl James Buczek, M.S.                  | William Lynderman Hendry, B.S.     |
| Klaus Victor Bury, B.A.Sc.               | Robert Henry Hertel, M.S.          |
| William Berrian Bush, B.S.               | Robert Hickling, M.A.              |
| David Chapman Cartwright, B.S.           | Jack Hubert Hill, M.S.             |
| Tsui Chiu Chan, M.S.                     | Leo Horowitz, B.S.                 |
| Chang-chih Chao, M.S.                    | John Raymond Hribar, M.S.          |
| Billie Mae Chu, M.A.                     | Paul Yu-fei Hu, M.S.               |
| Vicente Armando Citarella, B.S.          | Gordon Frierson Hughes, M.S.       |
| Peter Osgoode Clark, M.S.                | Li-San Hwang, M.S.                 |
| Don Paul Clausing, M.S.                  | Edmond Remy Iagolnitzer, Dipl.Ing. |
| Donald Henry Close, M.S.                 | Alexander Donald Jacobson, M.S.    |
| René Clément Collette, M.S.              | Marlyn Tony Jakub, M.S.            |
| Bruce Leroy Conroy, S.B.                 | David Fielding James, B.Sc.        |
| John Thomas Cookson, Jr., M.S.           | Paul Christian Jennings, M.S.      |
| Terrill Alan Cool, M.S.                  | Donald Frederick Jensen, B.S.      |
| James Edward Cordes, B.S. B.A.           | Arnold Richard Jones, B.S.E.E.     |
| Richard Clark Crewdson, B.S.             | Keishi Kawamo, B.E.                |
| Donald Leslie Cronin, M.S.               | Robert Kenneth Keenan, B.Sc.       |
| Steven Collins Crow, B.S.                | Vassiliios Kerdemelidis, M.S.      |
| Iain George Currie, M.A.Sc.              | Ronald Allan Kleban, M.S.          |
| Ted Herbert Davey, B.S.                  | John Michael Klineberg, M.S.       |
| Lee Walker Davison, M.S.                 | Gerhard Joachim Klose, M.S.        |
| Jacques de Barbeyrac Saint-Maurice, M.S. | Charles Robert Klotz, B.S.         |
| Everett Leon DeLano, Jr., B.S.           | Karl Kent Knapp, M.S.              |
| Robert Dewey de Pencier, M.S.            | Wolfgang Gustav Knauss, M.S.       |
| Alan Jerome DeVilbiss, M.S.              | Hon-Yim Ko, B.Sc.                  |
| C. Forbes Dewey, Jr., M.S.               | William L. Ko, M.S.                |
| Andrew Dienes, B.Eng.                    | Robert Ching-Yee Koh, M.S.         |
| Robert Charles Erdmann, M.S.             | Daniel Julius Krause, M.S.         |

## 26 Officers and Faculty

Logan Keith Kuiper, B.A.  
James Edward Lancaster, B.S.  
Raymond Walter Latham, M.S.  
Jark Chong Lau, Dipl.  
Joseph Po-keung Lau, B.Sc.  
Jen-shih Lee, B.S.  
Kelvin Shun Hung Lee, M.S.  
Richard Michael Leichus, B.S.  
Mark Levinson, M.S.  
Miguel Enrique Levy, B.S.  
George Waldimir Lewicki, M.S.  
John Eldon Lewis, B.S.  
Alfred George Liberman, M.S.  
Amabel Linan-Martinez, Ae.E.  
Ronald Keith Linde, M.S.  
Gerald Herbert Lindsey, M.S.  
Alan Lippert, M.S.  
Ericson John List, M.E.  
Joseph Tsu Chieh Liu, M.S.  
Anastasios Gerasimos Livitsanos, B.E.  
Helmut Karl Valentin Lotsch, M.S.  
Hans Ludewig, M.S.  
Huey-Lin Luo, M.S.  
Loren Daniel Lutes, M.Sc.  
Gordon Frank MacGinitie, M.S.  
Rajeshwar Kumar Malhotra, M.S.  
Peter John Mantle, D.C.Ae.  
Franklin Lester Marshall, B.S.  
Sami Faiz Masri, M.S.  
John Wallace Matthews, B.S.  
David James McCloskey, M.S.  
Malcolm McColl, M.S.  
Patrick Anthony McGovern, B.Sc.  
Francis Clay McMichael, M.S.  
Chiang Chung Mei, M.S.  
Osorio Chagas Meirelles, M.S.  
Stanley Brun Mellsen, M.S.  
Lauren Vail Merritt, B.S.  
Fernando Mexia-Algar, Ae.E.  
Heinz Dieter Middendorf, M.S.  
Kenneth Martin Mitzner, M.S.  
Donald Joseph Mokski, B.S.  
Donald Wayne Moon, M.S.  
Otto Moosburner, B.C.E.  
John Brian Murphy, B.S.E.E.  
John Fletcher Murphy, M.S.  
James Charles Murray, M.Sc.  
Elliott Robert Nagelberg, M.E.E.  
Paul Joel Nahin, B.S.  
Robert Ronald Natale, B.E.S.  
Niels Norby Nielsen, C.E.  
Frederick Reyes Norwood, B.S.  
Michael Edmond James O'Kelly, M.S.  
Mervyn Daniel Olson, B.A.Sc.  
Patrick Gerard O'Regan, M.S.  
Howard Oringer, B.E.  
Robert Reid Parmerter, M.S.  
Richard Walter Patch, M.S.  
Robert Francis Pawula, M.S.  
Jerry Clifford Peck, Ae.E.  
James Sibley Petty, M.S.  
Demetrius Philippou, M.S.  
Alfred Cyril Pinchak, M.S.E.  
Robert Leslie Poeschel, M.S.  
Raymond Felix Poggi, Ing.  
David Peter Pope, M.S.  
John William Porter, Jr., M.S.  
Om Parkash Puri, M.S.  
Jay C. Pyle, B.S.  
Bernard Charles Reardon, M.S.  
Ira Richer, M.S.  
Frank Ridolphi, B.S.  
Peter Paul Augustine Rispin, M.Sc.  
Harvey Lee Roberson, M.S.  
Richard Dale Rocke, M.S.  
George Robert Root, B.S.  
Charles Joseph Ruger, B.Ae.  
Viviane Claude Rupert, M.S.  
John Christian Russ, B.S.  
Louis Vincent Schmidt, Ae.E.  
Robert James Schneider, B.S.  
Dwight Clare Schroeder, B.S.  
Henry Gerard Schwartz, Jr., M.S.  
Steven Emanuel Schwarz, M.S.  
Richard Anthony Scott, M.Sc.  
William Lewis Shackleford, M.S.  
Alex Shumka, M.S.  
Boris Simpser-Dubovoy, C.E.  
Robert Edmund Singleton, M.S.  
Lionel Joseph Skidmore, M.S.  
Erik Jaak Hendrik Slachmuylders, M.S.  
Michael Elmer Slater, M.S.  
Richard Franklin Smisek, M.S.  
Jay Smith III, B.S.  
Jerome Allan Smith, B.S.E.  
Furman Yates Sorrell, Jr., M.S.  
Edmund Eugene Spaeth, B.S.  
Frank William Spaid, M.S.  
Walter Albert Specht, Jr., B.S.  
Robert Edward Spitzer, M.S.  
William Dean Squire, M.S.  
Gaetan Joseph St-Cyr, B.S.  
Alexander James Sutherland, M.E.  
Jerold Lindsay Swedlow, M.S.  
Christopher Kwong Wah Tam, B.Eng.  
Mitchell Thomas, Jr., M.S.  
Pin Tong, B.S.  
Harry Warren Townes, M.S.  
Richard Ripley Tracy, M.S.  
John Burgess Trenholme, M.S.  
Wai-Keung Tso, M.S.  
Chang-chyi Tsuei, B.S.  
Eliot Francis Tucker, B.S.  
Gary B. Turner, B.S.  
Thomas Janney Tyson, M.S.  
Ernesto Vallerani, Ing.  
Charles William Van Atta, M.S.E.  
Dwayne Robert Van Besien, B.S.E.E.  
Giulio Vitale Samuele Venezian,  
B.Eng.Phys.

Richard Bernard Wade, M.Sc.Eng.  
David John Wahl, B.S.  
Charles Chang-Ping Wang, M.S.  
Ronald Watson, M.S.  
Donald Martin Wiberg, M.S.  
Richard R. Williams, M.S.  
Clarence George Winterheimer, B.S.

Po Kee Wong, M.Sc.  
David Clark Wooten, M.S.  
Jain-Ming Wu, M.S.  
Ying-Chu Lin Wu, M.S.  
James Yoh, B.S.  
Gerold Yonas, B.E.Ph.  
Laurence Bei-yu Zung, B.Sc.

## DIVISION OF GEOLOGICAL SCIENCES

Robert P. Sharp, *Chairman*Frank Press, *Director of the Seismological Laboratory*

## PROFESSORS

|                               |                        |
|-------------------------------|------------------------|
| Hugo Benioff, Ph.D.           | Seismology             |
| Harrison S. Brown, Ph., LL.D. | Geochemistry           |
| Charles Hewitt Dix, Ph.D.*    | Geophysics             |
| Samuel Epstein, Ph.D.         | Geochemistry           |
| W. Barclay Kamb, Ph.D.        | Geology and Geophysics |
| Heinz A. Lowenstam, Ph.D.     | Paleoecology           |
| Frank Press, Ph.D.            | Geophysics             |
| Charles F. Richter, Ph.D.     | Seismology             |
| Robert P. Sharp, Ph.D.        | Geology                |
| Gerald J. Wasserburg, Ph.D.   | Geology and Geophysics |

## VISITING PROFESSOR

|                          |            |
|--------------------------|------------|
| Johannes Weertman, D.Sc. | Geophysics |
|--------------------------|------------|

## RESEARCH ASSOCIATES

|                            |              |
|----------------------------|--------------|
| Ian Campbell, Ph.D.        | Geology      |
| Leon Knopoff, Ph.D.        | Geophysics   |
| E. Ralph Lapwood, Ph.D.    | Geophysics   |
| Eugene M. Shoemaker, Ph.D. | Astrogeology |

## VISITING ASSOCIATE

|                      |         |
|----------------------|---------|
| John F. White, Ph.D. | Geology |
|----------------------|---------|

## ASSOCIATE PROFESSORS

|                          |                        |
|--------------------------|------------------------|
| Arden L. Albee, Ph.D.    | Geology                |
| Clarence R. Allen, Ph.D. | Geology and Geophysics |
| Arthur J. Boucot, Ph.D.  | Paleontology           |
| Bruce Murray, Ph.D.      | Planetary Science      |
| Leon T. Silver, Ph.D.    | Geology                |

## VISITING ASSOCIATE PROFESSOR

|                         |              |
|-------------------------|--------------|
| Wallace Broecker, Ph.D. | Geochemistry |
|-------------------------|--------------|

## SENIOR RESEARCH FELLOWS

|                            |              |
|----------------------------|--------------|
| Dang Dinh Ang, Ph.D.       | Geophysics   |
| Claire C. Patterson, Ph.D. | Geochemistry |

## ASSISTANT PROFESSORS

|                         |            |
|-------------------------|------------|
| Don L. Anderson, Ph.D.  | Geophysics |
| Egon T. Degens, Ph.D.   | Geology    |
| Stewart W. Smith, Ph.D. | Geophysics |
| Hugh P. Taylor, Ph.D.   | Geology    |

## RESEARCH FELLOWS

|                           |              |
|---------------------------|--------------|
| Ari Ben-Menahem, Ph.D.    | Geophysics   |
| Robert Burridge, Ph.D.    | Geophysics   |
| David G. Harkrider, Ph.D. | Geophysics   |
| John D. Hudson, Ph.D.     | Geology      |
| Iaakov Karez, Ph.D.       | Geology      |
| Robert L. Kovach, Ph.D.   | Geophysics   |
| Donald S. Miller, Ph.D.   | Geochemistry |

\*On leave of absence, 1963-64

|                            |                              |
|----------------------------|------------------------------|
| Stephen Mueller, D.Sc.     | <i>Geophysics</i>            |
| James R. O'Neil, Ph.D.     | <i>Geochemistry</i>          |
| Walter L. Pilant, Ph.D.    | <i>Geophysics</i>            |
| James M. Short, Ph.D.      | <i>Geochemistry</i>          |
| M. Nafi Toksoz, Ph.D.      | <i>Geophysics</i>            |
| Kenneth McCarn Towe, Ph.D. | <i>Geology</i>               |
| David G. Towell, Ph.D.     | <i>Geochemistry</i>          |
| Robert L. Wildey, Ph.D.    | <i>Astronomy and Geology</i> |
| Alfred M. Ziegler, Ph.D.   | <i>Paleontology</i>          |

## GRADUATE FELLOWS AND ASSISTANTS, 1962-63

|  |                                |
|--|--------------------------------|
| Hector M. Alvarez, Ing. Civil de Minas | Roger L. Hooke, B.A.           |
| Charles B. Archambeau, M.S.            | Abou-Bakr Khalil Ibrahim, M.S. |
| James Aronson, M.S.                    | Lane R. Johnson, M.S.          |
| Philip O. Banks, S.B.                  | Lisle T. Jory, B.Sc.           |
| John E. Beitzel, B.S.                  | S. Douglas McDowell, M.S.      |
| Shawn Biehler, M.S.                    | Thomas R. McGetchin, Sc.M.     |
| Robert R. Blandford, B.S.              | Laurent Meister, Eng.Geophy.   |
| William M. Chapple, B.S.               | Richard S. Naylor, B.S.        |
| Armando Cisternas, M.S.                | David J. Roddy, M.S.           |
| James A. Doutt, B.S.                   | Samuel M. Savin, B.A.          |
| Michael B. Duke, M.S.                  | Fred A. Schwab, B.A.           |
| John K. Gardner, M.S.                  | George A. Sellers, M.S.        |
| George Garlick, M.S.                   | Robert V. Sharp, M.S.          |
| James A. Grant, M.A.                   | Ta-liang Teng, B.S.            |
| David G. Harkrider, M.A.               | M. Nafi Toksoz, M.S.           |
| Charles Harper, S.M., M.S.             | John Watson, M.S.              |
| Thomas L. Henyey, B.A.                 | Kenneth Watson, M.S.           |
| Lincoln S. Hollister, B.A.             | Francis Taming 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.      | ..... | Industrial Relations     |
| Edwin S. Munger, Ph.D.    | ..... | Geography                |
| Rodman W. Paul, Ph.D.     | ..... | History                  |
| Hallett D. Smith, Ph.D.   | ..... | English                  |
| Roger Stanton, Ph.D.*     | ..... | English                  |
| Alfred Stern, Ph.D.       | ..... | Languages and Philosophy |
| Cushing Strout, Ph.D.     | ..... | History                  |
| Alan R. Sweezy, Ph.D.     | ..... | Economics                |
| Ray E. Untereiner, Ph.D.  | ..... | Economics                |

## ASSOCIATE PROFESSORS

|                           |       |            |
|---------------------------|-------|------------|
| Paul Bowerman, A.M.       | ..... | Languages  |
| Melvin D. Brockie, Ph.D.  | ..... | Economics  |
| Charles E. Bures, Ph.D.   | ..... | Philosophy |
| Paul C. Eaton, A.M.       | ..... | English    |
| Heinz Ellersiek, Ph.D.    | ..... | History    |
| Peter Fay, Ph.D.          | ..... | History    |
| Robert Huttonback, 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

|                       |       |           |
|-----------------------|-------|-----------|
| George Langdon, Ph.D. | ..... | History   |
| Howard Sherman, Ph.D. | ..... | Economics |
| David Smith, Ph.D.    | ..... | English   |
| Robert D. Wayne, M.A. | ..... | German    |

## LECTURERS

|                             |       |            |
|-----------------------------|-------|------------|
| Charles K. Ferguson, Ed.D.  | ..... | Psychology |
| Edward Hutchings, Jr., B.A. | ..... | Journalism |
| Alexander Kosloff, Ph.D.    | ..... | Russian    |
| Peter Miller, Ph.D.         | ..... | English    |
| Charles Newton, Ph.B.       | ..... | English    |
| Orpha Ochse, Ph.D.          | ..... | Music      |
| Lolita Sapriel, B.A.        | ..... | French     |
| Robert R. Wark, Ph.D.       | ..... | Art        |

\*On leave of absence, first term 1963-64

VISITING LECTURERS

|                         |                              |
|-------------------------|------------------------------|
| Victor D. DuBois, M.A.  | <i>International Affairs</i> |
| Louis Dupree, Ph.D.     | <i>International Affairs</i> |
| John Hanessian, Jr.     | <i>International Affairs</i> |
| Willard A. Hanna, Ph.D. | <i>International Affairs</i> |

INSTRUCTORS

|                     |                     |
|---------------------|---------------------|
| John Atkins, A.M.   | <i>Anthropology</i> |
| Herbert Booth, M.A. | <i>Speech</i>       |
| Byrd L. Jones, B.A. | <i>History</i>      |
| John Zeigel, M.A.   | <i>English</i>      |

RESEARCH ASSISTANT

|                   |                       |
|-------------------|-----------------------|
| Doris Logan, B.A. | <i>Public Affairs</i> |
|-------------------|-----------------------|

## DIVISION OF PHYSICS, MATHEMATICS AND ASTRONOMY

Carl D. Anderson, *Chairman*

## PROFESSORS EMERITI

|                                |                     |
|--------------------------------|---------------------|
| Jesse W. M. DuMond, Ph.D. .... | Physics             |
| Paul S. Epstein, Ph.D. ....    | Theoretical Physics |
| C. C. Lauritsen, 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 Boehm, Ph.D. ....                                      | Physics  |
| H. F. Bohnenblust, Ph.D. ....                                | Mathematics  |
| R. F. Christy, Ph.D. ....                                    | Theoretical Physics  |
| Eugene W. Cowan, Ph.D. ....                                  | Physics  |
| Leverett Davis, Jr., Ph.D. ....                              | Theoretical Physics  |
| Robert P. Dilworth, Ph.D. ....                               | Mathematics  |
| Olin J. Eggen, Ph.D. ....                                    | Astronomy  |
| A. Erdélyi, D.Sc. ....                                       | Mathematics  |
| Richard P. Feynman, Ph.D. ....                               | <i>Richard Chace Tolman Professor of Theoretical Physics</i> |
| William A. Fowler, Ph.D. ....                                | Physics  |
| Murray Gell-Mann, Ph.D. ....                                 | Theoretical Physics  |
| Roy W. Gould,* Ph.D. ....                                    | Electrical Engineering & Physics                             |
| Jesse L. Greenstein, Ph.D. ....                              | Astrophysics   |
| Marshall Hall, Jr., Ph.D. ....                               | Mathematics  |
| Robert B. King, Ph.D. ....                                   | Physics  |
| Thomas Lauritsen,* Ph.D. ....                                | Physics  |
| Robert B. Leighton, Ph.D. ....                               | Physics  |
| W. A. J. Luxemburg, Ph.D. ....                               | Mathematics  |
| Harden M. McConnell, Ph.D. ....                              | Chemistry & Physics  |
| Rudolf L. Mössbauer, Ph.D., Sc.D., Nobel Laureate .....      | Physics  |
| Guido Münch, Ph.D. ....                                      | Astronomy  |
| H. Victor Neher, Ph.D. ....                                  | Physics  |
| John R. Pellar, Ph.D. ....                                   | Physics  |
| William R. Smythe, Ph.D. ....                                | Physics  |
| 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. ....                                | Aeronautics & Mathematics                                    |
| Fritz Zwicky, Ph.D. ....                                     | Astrophysics   |

## VISITING PROFESSOR

|                           |         |
|---------------------------|---------|
| Hans A. Bethe, Ph.D. .... | Physics |
|---------------------------|---------|

## RESEARCH ASSOCIATES

|                                   |                 |
|-----------------------------------|-----------------|
| Gordon J. Stanley, Dipl.E.E. .... | Radio Astronomy |
| Olga T. Todd, Ph.D. ....          | Mathematics     |

## VISITING ASSOCIATES

|                               |           |
|-------------------------------|-----------|
| Richard G. Barnes, Ph.D. .... | Physics   |
| John Firor, Ph.D. ....        | Astronomy |

\*On leave of absence, 1963-64

|                             |                     |
|-----------------------------|---------------------|
| Fred Hoyle, M.A.            | Physics             |
| William J. Karzas, Ph.D.    | Physics             |
| William L. Kraushaar, Ph.D. | Physics             |
| Heinz-Otto Kreiss, Ph.D.    | Mathematics         |
| Stanley Mandelstam, Ph.D.   | Theoretical Physics |
| Cornell H. Mayer, M.S.      | Radio Astronomy     |
| Richard S. Varga, Ph.D.     | Mathematics         |
| Harold Zirin, Ph.D.         | Astronomy           |

## ASSOCIATE PROFESSORS

|                            |                     |
|----------------------------|---------------------|
| Richard A. Dean, Ph.D.     | Mathematics         |
| F. Brock Fuller, Ph. D.    | Mathematics         |
| Adriano M. Garsia, Ph.D.   | Mathematics         |
| Alexander Goetz, Ph.D.     | Physics             |
| Milton Lees, Ph.D.         | Mathematics         |
| Jon Mathews, Ph.D.         | Theoretical Physics |
| J. B. Oke, Ph.D.           | Astronomy           |
| Jerome Pine, Ph.D.         | Physics             |
| Maarten Schmidt, Ph.D.     | Astronomy           |
| Fredrik Zachariasen, Ph.D. | Theoretical Physics |

## SENIOR RESEARCH FELLOWS

|                                   |                 |
|-----------------------------------|-----------------|
| John N. Bahcall, Ph.D.            | Physics         |
| E. Margaret Burbidge, Ph.D.       | Physics         |
| Bille C. Carlson, Ph.D.           | Mathematics     |
| Calvin M. Class, Ph.D.            | Physics         |
| Ricardo Gomez,* Ph.D.             | Physics         |
| Icko Iben, Jr., Ph.D.             | Physics         |
| Hans G. E. Kобрак, Ph.D.          | Physics         |
| John Owen Maloy, Ph.D.            | Physics         |
| Thomas A. Matthews, Ph.D.         | Radio Astronomy |
| David Morris, Ph.D.               | Radio Astronomy |
| Joe H. Mullins, Ph.D.             | Physics         |
| Venkataraman Radhakrishnan, B.Sc. | Radio Astronomy |
| Richard L. Sears, Ph.D.           | Physics         |

## ASSISTANT PROFESSORS

|                                 |                     |
|---------------------------------|---------------------|
| Richard E. Block, Ph.D.         | Mathematics         |
| Peter L. Crawley, Ph.D.         | Mathematics         |
| Everett C. Dade, Ph.D.          | Mathematics         |
| Steven C. Frautschi, Ph.D.      | Theoretical Physics |
| Ralph W. Kavanagh, Ph.D.        | Physics             |
| Donald E. Knuth, Ph.D.          | Mathematics         |
| Gerry Neugebauer, Ph.D.         | Physics             |
| Foster Strong, M.S.             | Physics             |
| James D. van Putten, Jr., Ph.D. | Physics             |
| Rochus Vogt, Ph.D.              | Physics             |

## LECTURERS

|                            |         |
|----------------------------|---------|
| Frank B. Estabrook, Ph.D.  | Physics |
| Robert W. Hellwarth, Ph.D. | Physics |

## INSTRUCTOR

|                      |             |
|----------------------|-------------|
| John D. Dixon, Ph.D. | Mathematics |
|----------------------|-------------|

## RESEARCH FELLOWS

|                        |                     |
|------------------------|---------------------|
| Ernest Abers, Ph.D.    | Theoretical Physics |
| David K. Aitken, Ph.D. | Physics             |
| Peter Alexander, Ph.D. | Physics             |
| Tsuyoshi Ando, Ph.D.   | Mathematics         |

\*On leave of absence, first term 1963-64.

|                                       |                     |
|---------------------------------------|---------------------|
| Louis A. P. Balazs, Ph.D.             | Theoretical Physics |
| Barry C. Barish, Ph.D.                | Physics             |
| Arsene J. Boury, Ph.D.                | Physics             |
| Donald S. Burnett, Ph.D.              | Physics             |
| Georgeanne Caughlan, M.S.             | Physics             |
| George E. Collins, Ph.D.              | Mathematics         |
| Colin W. Cryer, Ph.D.                 | Mathematics         |
| Jorrit de Boer, Ph.D.                 | Physics             |
| Robert F. Deery, Ph.D.                | Physics             |
| Jörg Eichler, Ph.D.                   | Physics             |
| Thornton R. Fisher, Ph.D.             | Physics             |
| James D. Halpern, Ph.D.               | Mathematics         |
| Yasuo Hara, Ph.D.                     | Theoretical Physics |
| Clemens A. Heusch, Ph.D.              | Physics             |
| Egbert Kankeleit, Ph.D.               | Physics             |
| Alan T. Moffet, Ph.D.                 | Radio Astronomy     |
| Norton L. Moise, Ph.D.                | Physics             |
| Fernando B. Morinigo, Ph.D.           | Physics             |
| Yuval Ne'eman, Ph.D.                  | Theoretical Physics |
| Peter D. M. Parker, Ph.D.             | Physics             |
| Richard B. Read, Ph.D.                | Radio Astronomy     |
| Hans B. Ryde, Ph.D.                   | Physics             |
| Philip A. Seeger, Ph.D.               | Physics             |
| D. Gary Swanson, Ph.D.                | Physics             |
| Geoffrey D. Symons, Ph.D.             | Physics             |
| William G. Wagner, Ph.D. <sup>1</sup> | Theoretical Physics |
| Sven B. F. Wahlborn, Ph.D.            | Theoretical Physics |
| Hubert Winkler, Ph.D.                 | Physics             |
| John D. Wyndham, Ph.D.                | Radio Astronomy     |

## GRADUATE FELLOWS AND ASSISTANTS, 1962-63

|                               |                              |
|-------------------------------|------------------------------|
| Bruce J. Aborn, B.S.          | Arthur N. Chester, B.S.      |
| Eric G. Adelberger, B.S.      | Franklin F. K. Cheung, B.S.  |
| David G. Agresti, B.S.        | Barry G. Clark, B.S.         |
| Norman W. Albright, M.S.      | Milton J. Clauser, S.B.      |
| John P. Andelin, Jr., B.S.    | Edward T. Cline, B.S.        |
| Stephen A. Andrea, B.A.       | Carl R. Clinesmith, B.S.     |
| Claude Arpigny, Lic.Sci.      | Charles L. Cocke, Jr., B.A.  |
| Robert C. Ashenfelter, B.S.   | Donald G. Coyne, B.S.        |
| Andrew D. Bacher, A.B.        | Yvon Cusson, B.S.            |
| Luis Baez-Duarte, B.S.        | Roger F. Dashen, A.B.        |
| James M. Bardeen, A.B.        | Cary N. Davids, M.S.         |
| J. Frederick Bartlett, M.S.   | John W. Davies, B.A.         |
| Leonard D. Baumert, M.A.      | Anthony N. Derzko, B.Sc.     |
| Douglas S. Beder, B.Sc.       | Robert E. Diebold, M.S.      |
| Glenn LeRoy Berge, B.A.       | Theodore N. Divine, M.S.     |
| Thomas M. Bieniewski, M.S.    | Frank S. Dietrich III, B.A.  |
| Elliott D. Bloom, B.A.        | Richard Dolen, B.E.Ph.       |
| James L. Blue, A.B.           | John J. Domingo, B.S.        |
| Fred A. Blum, Jr., B.S.       | Stanley D. Ecklund, B.S.     |
| James D. Bowman, B.S.         | Joseph C. Fineman, B.S.      |
| Gerald L. Bradley, B.S.       | Thornton R. Fisher, B.A.     |
| Richard T. Brockmeier, M.S.   | Edward B. Fomalont, B.S.     |
| Lucian C. Carter III, B.S.    | Douglas G. Fong, A.B.        |
| John I. Castor, B.S.          | Lorraine L. Foster, B.A.     |
| Subhash Chandra, M.S.         | Gary S. Fraley, B.S.         |
| George F. Chapline, Jr., B.A. | Lyman J. Fretwell, Jr., B.S. |
| Philip J. Chase, B.A.         | Fergus J. Gaines, M.Sc.      |
| Ronald B. Chesler, A.B.       |                              |

<sup>1</sup>Richard Chace Tolman Research Fellow

Robert J. Gerbracht, B.A.  
David R. Goosman, B.A.  
Robert Gordon, A.B.  
Charles A. Greenhall, B.A.  
David H. Griffel, B.Sc.  
David E. Groce, B.S.  
Donald E. Groom, B.S.  
Melinda F. Groom, A.B.  
Fletcher I. Gross, B.S.  
James E. Gunn, B.A.  
Ralph S. Hager, B.S.  
William D. Harrison, B.Sc.  
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*Operated Jointly with the Carnegie Institution of Washington*  
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STAFF MEMBERS

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Arne A. Wyller, Ph.D.

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| Peter C. Conti, Ph.D.      | Henrietta H. Swope, A.M.  |
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| John E. Gaustad, Ph.D.     | John B. Whiteoak, Ph.D.   |
| Leonard V. Kuhi, Ph.D.     | Robert L. Wildey, Ph.D.   |

ENGINEERS

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| Bruce H. Rule, B.S. | Byron Hill, B.S. |
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Gilbert D. McCann, *Director*

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| Joel N. Franklin   | Robert L. Walker, <i>Chairman</i> |

STAFF MEMBERS

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| Joel N. Franklin, Ph.D.  | Kendrick Hebert, Head,<br>Programming Group            |
| Kenneth Lock, Ph.D.      | Charles Ray, Head,<br>Facilities and Engineering Group |
| Peter Lockemann, Ph.D.   |  |
| Gilbert D. McCann, Ph.D. |  |
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### INDUSTRIAL RELATIONS CENTER

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*Professor of Economics and Industrial Relations*

(Mrs.) Geraldine M. Beideman, M.A., *Associate Research Director,*

*Benefits and Insurance Research Section*

Robert N. Fick, M.S., *Assistant Director,*

*Management Development Section*

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Arthur H. Young, *Lecturer Emeritus on Industrial Relations*

### DEPARTMENT OF AIR SCIENCE (AFROTC))

#### PROFESSOR

Major Leo T. Woods, U.S.A.F., M.S.

#### ASSISTANT PROFESSORS

Major William R. Knight, U.S.A.F., M.S.

Captain Donald L. Stearns, U.S.A.F., M.S.

#### ASSISTANTS

T/Sgt. Richard E. Stafford, U.S.A.F.

T/Sgt. Wallace E. Lacher, U.S.A.F.

S/Sgt. Andrew F. Ventimiglia, U.S.A.F.

### DEPARTMENT OF PHYSICAL EDUCATION

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

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Keith H. Jensen, B.S.

James H. Nerrie, B.S.

Edward T. Preisler, B.A.

#### TRAINER

Paul G. Barthel, M.A.

#### ASSISTANTS

Lee A. Andrews, B.A.

Shelby C. Calhoun, B.A.

John Lamb

Walter Mack, M.A.

### ATHLETIC COUNCIL

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

## INSTITUTE LIBRARIES

Harald Ostvold, M.A., *Director*Evelyn Huston, M.A., *Associate Director*

## REPRESENTATIVES FOR THE DEPARTMENTAL LIBRARIES

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| Tom M. Apostol, Ph.D.      | Charles H. Papas, Ph.D.    |
| Arthur James Boucot, Ph.D. | Bruce H. Sage, Ph.D.       |
| Charles R. DePrima, Ph.D.  | William R. Samples, Ph.D.  |
| Armin J. Deutsch, Ph.D.    | Walter A. Schroeder, Ph.D. |
| David C. Elliott, Ph.D.    | Ernest E. Sechler, Ph.D.   |
| Robert D. Gray, B.S.       | Albert Tyler, Ph.D.        |
| Robert B. King, Ph.D.      | Fritz Zwicky, Ph.D.        |

## STUDENT HEALTH SERVICES

Richard F. Webb, M.D., *Director of Health Services*

|                                 |   |
|---------------------------------|---|
| R. Stewart Harrison, M.D. ....  | <i>Assistant Director and Consultant in Radiology</i> |
| Daniel C. Siegel, M.D. ....     | <i>Consulting Psychiatrist</i>                        |
| N. Y. Matossian, M.D. ....      | <i>Attending Physician</i>                            |
| Haskell J. Weinstein, M.D. .... | <i>Attending Physician</i>                            |
| Kenneth W. Eells, Ph.D. ....    | <i>Institute Psychologist</i>                         |
| Alice A. Shea, R.N. ....        | <i>Nursing Director</i>                               |

The Faculty Committee on Student Health acts in an advisory capacity to the Director of Health Services on all matters of policy pertaining to the Health Program and administers the Emergency Health Fund.

## STUDENT MUSICAL ACTIVITIES

|                        |                                      |
|------------------------|--------------------------------------|
| John C. Deichman ..... | <i>Director of Student Band</i>      |
| Olaf Frodsham .....    | <i>Director of Student Glee Club</i> |

## FACULTY

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A.B., Cornell College (Iowa), 1922; A.M., University of Wisconsin, 1924; Ph.D., 1926. California Institute, 1946-. (106 Throop) 415 South Hill Avenue.

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Daniel Kwoh-i Ai, Ph.D., *Research Fellow in Engineering*

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## 40 Officers and Faculty

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### Tom M. Apostol, Ph.D., Professor of Mathematics

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B.S., Chiao-Tung University, China, 1949; Ph.D., University of California (Los Angeles), 1955. California Institute, 1955-57; 1958-. (252 Crelin) 3300 Las Lunas Street.

**Theodore Yao-Tsu Wu, Ph.D., Professor of Applied Mechanics**

B.S., Chiao-Tung University, 1946; M.S., Iowa State University, 1948; Ph.D., California Institute, 1952. Research Fellow, 1952-55; Assistant Professor, 1955-57; Associate Professor, 1957-61; Professor, 1961-. (315 Thomas) 3300 Las Lunas Street.

**Oliver Reynolds Wulf, Ph.D., Research Associate in Physical Chemistry**

B.S., Worcester Polytechnic Institute, 1920; M.S., American University, 1922; Ph.D., California Institute, 1926. California Institute, 1945-. (56 Crelin) 557 Berkeley Avenue, San Marino.

**Arne A. Wyller, Ph.D., Senior Research Fellow in Astronomy**

Ph.D., Harvard University, 1955; University of Oslo, 1961. Research Associate, Institute of Theoretical Astrophysics, Blindern, Norway. California Institute, 1963-64.

**John Derek Wyndham, Ph.D., Research Fellow in Radio Astronomy**

B.S., University of Cambridge, 1959; Ph.D., 1963. California Institute, 1963-64. (103 Robinson) 441 South Catalina Avenue, Apt. 5.

**Don M. Yost, Ph.D., Professor of Inorganic Chemistry**

B.S., University of California, 1923; Ph.D., California Institute, 1926. Instructor, California Institute, 1927-29; Assistant Professor, 1929-35; Associate Professor, 1935-41; Professor, 1941-. (107 Gates) 1025 San Pasqual Street.

**Arthur Howland Young, Lecturer in Industrial Relations, Emeritus**

California Institute, 1939-52. 3 Rosemary Lane, Santa Barbara.

**Fredrik Zachariasen, Ph.D., Associate Professor of Theoretical Physics**

B.S., University of Chicago, 1951; Ph.D., California Institute, 1956. Assistant Professor, 1960-62; Associate Professor, 1962-. (160 Sloan) 399 Cherry Drive.

**Adam Richard Zak, Ph.D., Research Fellow in Aeronautics**

B.E., Auckland University, New Zealand, 1956; M.S., Purdue University, 1959; Ph.D., 1961. California Institute, 1961-. (217 Firestone) 3829 East Mountain View.

**Robert Eugene Zartman, Ph.D., Research Fellow in Geology**

B.S., Pennsylvania State University, 1957; M.S., California Institute, 1959; Ph.D., 1963. Research Fellow, 1962-63.

**Laszlo Zechmeister, Dr.Ing., Professor of Organic Chemistry, Emeritus**

Diploma of Chemist, Eidgenossische Technische Hochschule, Zurich, Switzerland, 1911; Dr.Ing., 1913; Professor, California Institute, 1940-59; Professor Emeritus, 1959-. (254 Crellin) 1122 Constance Street.

**John Stoufer Zeigel, \*\* M.A., Instructor in English**

B.A., Pomona College, 1956; M.A., Claremont, 1959. California Institute, 1962-. (307 Dabney) 346 Pleasant Street.

**E-An Zen, Ph.D., Visiting Associate Professor of Geology**

B.A., Cornell University, 1951; A.M., Harvard University, 1952; Ph.D., 1955. Geologist, U.S. Geological Survey, 1959-. California Institute, 1963.

**Alfred Mayland Ziegler, Ph.D., Research Fellow in Paleontology**

B.S., Bates College, 1959; Ph.D., Oxford University, 1963. California Institute, 1963-64.

**Harold Zirin, Ph.D., Visiting Associate in Astronomy**

A.B., Harvard College, 1950; A.M., Harvard University, 1951; Ph.D., 1953. Member, Senior Research Staff, High Altitude Observatory, Boulder, Colorado, 1955-; Professor Adjoint, University of Colorado, 1960-. California Institute, 1963.

**Emile Zuckerkandl, Ph.D., Research Fellow in Chemistry**

M.S., University of Illinois, 1948; Ph.D., Sorbonne, 1959. Staff Member, National Center for Scientific Research, Montpellier, France, 1949-. California Institute, 1959-63.

**Edward Edom Zukoski, Ph.D., Associate Professor of Jet Propulsion**

B.S., Harvard College, 1950; M.S., California Institute, 1951; Ph.D., 1954. Research Engineer, Jet Propulsion Laboratory, 1950-57; Lecturer, California Institute, 1956-57; Assistant Professor, 1957-60; Associate Professor, 1960-. (202 Karman) 2386 Las Lunas Street.

**Fritz Zwicky, Ph.D., Professor of Astrophysics; Staff Member, Mount Wilson and Palomar Observatories**

B.S., Federal Institute of Technology, Zurich, Switzerland, 1920; Ph.D., 1922. Research Fellow International Education Board, California Institute, 1925-27; Assistant Professor of Theoretical Physics, 1927-29; Associate Professor, 1929-41; Professor of Astrophysics, 1941-. (201 Robinson) 2065 Oakdale Street.

## CALIFORNIA INSTITUTE OF TECHNOLOGY

## GRADUATE FELLOWS, SCHOLARS AND ASSISTANTS, 1962-63

Mahoud Khairy Abd-el-Gawad, *Smith-Mundt Fellow, Mechanical Engineering*  
 B.Sc. (Hons), Alexandria University (Egypt), 1960

Bruce Jerome Aborn, *Graduate Teaching Assistant, Institute Scholar, Mathematics*  
 B.S., Ohio State University, 1961; M.A., Middlebury College, 1961

Ahmad Khalil Abu-Shumays, *Graduate Research Assistant, Institute Scholar, Aeronautics*  
 B.S., California Institute, 1962

Kenneth Hoyt Adams, *Gillette-Paper Mate Fellow, Materials Science*  
 B.S., California Institute, 1959; M.S., 1960

Eric George Adelberger, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*  
 B.S., California Institute, 1960

David George Agresti, *Graduate Research Assistant, Institute Scholar, Physics*  
 B.S., Ohio State University, 1959; M.S., California Institute, 1962

Harlow Garth Ahlstrom, *Institute Scholar, Aeronautics*  
 B.S., University of Washington, 1959; M.S., 1959

Nazeer Ahmed, *Graduate Research Assistant, Institute Scholar, Aeronautics*  
 B.E., University of Mysore (India), 1961; M.S., California Institute, 1962

Ezekiel Olabisi Akinrimisi, *U.S. Public Health Service Trainee, Biology*  
 B.Sc., Michigan State University, 1960

Irwin Emanuel Alber, *Daniel and Florence Guggenheim Fellow, Mechanical Engineering*  
 B.S., University of California (Los Angeles), 1962

Norman Webster Albright, *Institute Scholar, Physics*  
 B.S., California Institute, 1956; M.S., 1962

Shelton Setzer Alexander, *Institute Scholar, Geophysics*  
 B.S., University of North Carolina, 1956; M.S., California Institute, 1959

Eudoxia Aliferis, *Phi Kappa Phi Fellow, Institute Scholar, Biology*  
 B.S., University of Massachusetts, 1962

Hector Alvarez-Pavez, *Anaconda Fellow, Geology*  
 Ing.Civ., University of Chile, 1958

John Philip Andelin, Jr., *Graduate Research Assistant, Institute Scholar, Physics*  
 B.S., California Institute, 1955; M.S., Stanford University, 1956

Harvie Andre, *Special Funds Grantee, Institute Scholar, Chemical Engineering*  
 B.Sc., University of Alberta, 1962

Stephen A. Andrea, *National Defense Education Act Fellow, Mathematics*  
 B.A., Oberlin College, 1960

Charles Bruce Archambeau, *Mobil Oil Company Fellow, Institute Scholar, Geology*  
 B.S., University of Minnesota, 1955; M.S., 1959

Robert James Arenz, (S.J.), *Institute Scholar, Aeronautics*  
 B.S., Oregon State College, 1945; M.S., Lic. in Phil., St. Louis University, 1957

George S. Argyropoulos, *Graduate Teaching Assistant, Institute Scholar, Mechanical Engineering*  
 Dipl. in M. and E.E., National Technical University of Athens, 1960; M.S., California Institute, 1961

John Theodore Armstrong, *Graduate Teaching Assistant, Dobbins Scholar, Mechanical Engineering*  
 B.S., California Institute, 1962

John Henry Arndt, Jr., *Graduate Teaching Assistant, Dobbins Scholar, Chemical Engineering*  
 B.S., California Institute, 1962

James Louis Aronson, *Graduate Teaching Assistant, Institute Scholar, Geology*  
B.A., Rice University, 1959; M.S., California Institute, 1961

Claude Arpigny, *Belgian-American Foundation Fellow, NATO Fellow, Institute Scholar, Astronomy*  
Lic. Sci., University of Liège, 1958

Robert Carl Ashenfelter, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., Harvey Mudd College, 1961

John Fredrich Asmus, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.S., California Institute, 1958; M.S., 1959

Percy Max Augustus, *U.S. Public Health Service Trainee, Civil Engineering*  
B.S.C.E., University of Kentucky, 1962

Boris Auksmann, *Stewart-Warner Corporation Fellow, Strolee of California Fellow, Mechanical Engineering*  
B.A.Sc., University of British Columbia, 1955; M.S. California Institute, 1958; M.E., 1959

Andrew Dow Bacher, *National Science Foundation Fellow, Physics*  
B.A., Harvard College, 1960

Luis Baez-Duarte, *University of Venezuela Fellowship, Mathematics*  
B.S., California Institute, 1959

Donald Baganoff, *Graduate Teaching Assistant, Graduate Research Assistant, Institute Scholar, Aeronautics*  
B.S., Purdue University, 1957; M.S., Washington University, 1960

Peter Baine, *Graduate Teaching Assistant, Clinedinst Scholar, Chemistry*  
G.R.I.C., Royal Technical College (Salford, England), 1961

Philip Oren Banks, *Graduate Teaching Assistant, Institute Scholar, Geochemistry*  
S.B., Massachusetts Institute of Technology, 1958

James Maxwell Bardeen, *Graduate Teaching Assistant, Institute Scholar, Physics*  
A.B., Harvard College, 1960

John Roger Baker, *NATO Fellow, Institute Scholar, Chemical Engineering*  
B.Sc. (Hons), College of Science and Technology (England), 1961; M.Sc., 1962

Dennis Barrett, *Institute Scholar, Biochemistry*  
A.B., University of Pennsylvania, 1957

J. Frederick Bartlett, *Graduate Research Assistant, E. N. Brown Scholar, Astronomy*  
B.S., Yale University, 1958; M.S., California Institute, 1961

Richard George Batt, *Graduate Teaching Assistant, E. N. Brown Scholar, Aeronautics*  
B.S.E., Princeton University, 1955; M.S., California Institute, 1958

Leonard Daniel Baumert, *Institute Scholar, Mathematics*  
B.A., University of California (Los Angeles), 1952; M.A., 1959

Douglas Stanley Beder, *Rand Fellow, Physics*  
B.Sc., McGill University, 1961

Wayne Metcalf Beebe, *Graduate Research Assistant, Institute Scholar, Aeronautics*  
B.S., California Institute, 1951; M.S., 1952

George Wood Beeler, Jr., *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.S.E., Princeton University, 1960; M.S., California Institute, 1961

Wilhelm Behrens, *NATO Fellow, Institute Scholar, Aeronautics*  
Dipl.Ing., Technical University (Munich), 1960

Thomas Andrew Beineke, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Chemistry*  
B.S., Ohio University, 1961

John Edward Beitzel, *National Science Foundation Fellow, Geology*  
B.S., Michigan College of Mining and Technology, 1961

James Melvin Bell, *National Science Foundation Faculty Fellow, Civil Engineering*  
B.S., Colorado State College of Agriculture and Mechanic Arts, 1954; M.S., California Institute, 1955

## 72 Graduate Appointments

Lon Edward Bell, *Graduate Teaching Assistant, Drake Scholar, Mechanical Engineering*  
B.S., California Institute, 1962

Thomas Livingston Benjamin, *U.S. Public Health Service Trainee, Graduate Teaching Assistant, Institute Scholar, Biology*  
B.A., Amherst College, 1959

David Bernard Benson, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.S., California Institute, 1962

Glenn LeRoy Berge, *National Science Foundation Fellow, Astronomy*  
B.A., Luther College, 1960; M.S., California Institute, 1962

Shawn Biehler, *Graduate Research Assistant, Institute Scholar, Geophysics*  
B.S.E., Princeton University, 1958; M.S.E., 1959; M.S., California Institute, 1961

Thomas Mark Bieniewski, *Institute Scholar, Physics*  
B.S., University of Detroit, 1958; M.S., California Institute, 1960

Charles Edgar Billings, *U.S. Public Health Service Air Pollution Fellow, Civil Engineering*  
B.S., Northeastern University, 1950; S.M., Harvard University, 1953

Harry Spencer Blackiston, Jr., *Lockheed Leadership Fellow, Aeronautics*  
B.S., Purdue University, 1957; M.S., 1959

Charles Melvin Blair, *Leeds and Northrup Foundation Fellow, Graduate Teaching Assistant, Chemistry*  
B.A., Rice University, 1961

David Jordan Blakemore, *Graduate Teaching Assistant, Institute Scholar, Electrical Engineering*  
B.S., California Institute, 1960; M.S., 1961

Robert Roy Blandford, *National Science Foundation Fellow, Geology*  
B.S., California Institute, 1959

Elliott Daniel Bloom, *Graduate Research Assistant, Institute Scholar, Physics*  
B.A., Pomona College, 1962

James Lawrence Blue, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*  
A.B., Occidental College, 1961

Fred Andrew Blum, Jr., *National Science Foundation Fellow, Physics*  
B.S., University of Texas, 1962

Ronald David Boettcher, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.S., California Institute, 1962; B.A., Occidental College, 1962

Richard Jay Laurent Bondar, *Graduate Teaching Assistant, Institute Scholar, Biology*  
B.Sc. (Hons), McGill University, 1962

Robert William Bower, *Howard Hughes Fellow, Electrical Engineering*  
A.B. (Hons), University of California, 1962

James David Bowman, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1961

James Brown Boyd, *U.S. Public Health Service Trainee, Graduate Teaching Assistant, Institute Scholar, Biochemistry*  
B.A., Cornell University, 1959

William Charles Boyle, *U.S. Public Health Service Trainee, Civil Engineering*  
C.E., University of Cincinnati, 1959; M.S., 1960

Gerald Lee Bradley, *National Science Foundation Fellow, Graduate Teaching Assistant, Mathematics*  
B.S., Harvey Mudd College, 1962

Arthur Gerald Brady, *Graduate Teaching Assistant, Institute Scholar, Civil Engineering*  
B.E., University of Auckland, 1959; M.E., 1960; B.Sc., 1961

Ralph Eric Bredehorst, *U.S. Public Health Service Fellow, Civil Engineering*  
B.S., California Institute, 1961

Richard Taber Brockmeier, *Danforth Foundation Fellow, Physics*  
B.A., Hope College, 1959; M.S., California Institute, 1961

David Armstrong Brueckner, *U.S. Public Health Service Fellow, Chemistry*  
B.S., Ohio University, 1960

Carl James Buczek, *International Business Machines Fellow, Electrical Engineering*  
B.E.E., Rensselaer Polytechnic Institute, 1956; M.S., California Institute, 1959

Thomas Edmund Burke, *Graduate Teaching Assistant, Murray Scholar, Chemistry*  
B.A., University of Minnesota, 1962

Klaus Victor Bury, *Graduate Research Assistant, Murray Scholar, Applied Mechanics*  
B.A.Sc., University of Toronto, 1959; B.A., Sir George Williams University (Montreal), 1962

William Berrian Bush, *Graduate Teaching Assistant, Institute Scholar, Aeronautics*  
B.S., Princeton University, 1955

Roger William Caputi, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
B.S., California Institute, 1957

Lucian Carlton Carter III, *National Science Foundation Fellow, Physics*  
B.A., University of Texas, 1960; B.S. (Chem), 1960; B.S. (Physics), 1961

David Chapman Cartwright, *Tozer Foundation Fellow, Graduate Teaching Assistant,  
Institute Scholar, Mechanical Engineering*  
B.S., Hamline University, 1962

John Irvin Castor, *National Science Foundation Fellow, Astronomy*  
B.S., Fresno State College, 1961

Tsui Chiu Chan, *Tektronix Foundation Fellow, Electrical Engineering*  
B.E., McGill University, 1961; M.S., California Institute, 1962

Subhash Chandra, *Graduate Research Assistant, Institute Scholar, Astronomy*  
B.S., University of Lucknow, 1954; M.S., 1958; M.S., California Institute, 1961

Chang-chih Chao, *Graduate Research Assistant, Institute Scholar, Engineering Science*  
B.S., National Taiwan University, 1956; M.S., Virginia Polytechnic Institute, 1960

George Frederick Chapline, Jr., *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.A., University of California (Los Angeles), 1961

William Massee Chapple, *Standard Oil Company of California Fellow, Geology*  
B.S., California Institute, 1956; M.S., 1957

Phillip John Chase, *Graduate Teaching Assistant, Earle C. Anthony Scholar,  
Mathematics*  
B.A., The College of Wooster, 1961

Shiou-Shan Chen, *Graduate Teaching Assistant, Institute Scholar, Chemical Engineering*  
B.S., Taiwan Provincial Taipei Institute of Technology, 1958; M.S., California Institute, 1962

Ronald Benjamin Chesler, *Graduate Teaching Assistant, Earle C. Anthony Scholar,  
Physics*  
A.B., University of Pennsylvania, 1961

Arthur Noble Chester, *National Science Foundation Fellow, Physics*  
B.S., The University of Texas, 1961

Franklin Fan-Keung Cheung, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.S., Yale University, 1962

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

Billie Mae Chu, *Institute Scholar, Aeronautics*  
B.A., Agnes Scott College (Georgia), 1948; M.A., Emory University, 1949

Armando Cisternas S., *Graduate Research Assistant, Institute Scholar, Geology*  
Min.Eng., University of Chile, 1957; M.S., California Institute, 1960

Vicente Armando Cittarella, *Graduate Teaching Assistant, Earle C. Anthony Scholar,  
Mechanical Engineering*  
B.S., Stevens Institute of Technology, 1962

Barry Gillespie Clark, *Van Maanen Fellow, Graduate Research Assistant, Astronomy*  
B.S., California Institute, 1959

Peter Osgoode Clark, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.E.Ph., McGill University, 1960; M.S., California Institute, 1961

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

Don Paul Clauzing, *Pacific Scientific Company Fellow, Materials Science*  
B.S., Iowa State University, 1952; M.S., California Institute, 1962

Edward Thomas Cline, Jr., *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Mathematics*  
B.S., California Institute, 1962

Carl Rudolph Clinesmith, *Robert A. Millikan Fellow, Physics*  
B.S., University of Washington, 1959

Donald Henry Close, *Howard Hughes Fellow, Graduate Teaching Assistant, Electrical Engineering*  
B.S., University of Kansas, 1960; M.S., California Institute, 1962

Charles Lewis Cocke, *National Science Foundation Fellow, Physics*  
B.A., Haverford College, 1962

René Clément Collette, *Graduate Research Assistant, General Precision Scholar, Electrical Engineering*  
Ing.Civil A.I.M., University of Liège, 1958; M.S., California Institute, 1960

Bruce Leroy Conroy, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
S.B., Massachusetts Institute of Technology, 1962

John Thomas Cookson, Jr., *U.S. Public Health Service Trainee, Civil Engineering*  
B.S., Washington University, 1961; M.S., 1962

Terrill Alan Cool, *National Science Foundation Cooperative Fellow, Mechanical Engineering*  
B.S., University of California (Los Angeles), 1961; M.S., California Institute, 1962

James Edward Cordes, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.S., California Institute, 1962; B.A., Occidental College, 1962

Harold Thompson Couch, *Peter E. Fluor Memorial Fellow, Chemical Engineering*  
B.S.E., Princeton University, 1958; M.S., University of Southern California, 1961

Donald Gerald Coyne, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., University of Kansas, 1958

Lelia M. Coyne, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.S., University of California (Los Angeles), 1961

Richard Clark Crewdson, *Atomic Energy Commission Fellow, Engineering Science*  
B.S., Lafayette College, 1961

Donald Leslie Cronin, *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
B.S., Rutgers University, 1957; M.S., California Institute, 1961

Steven Collins Crow, *National Science Foundation Cooperative Fellow, Aeronautics*  
B.S., California Institute, 1962

Robert Fredrick Cuffel, *Union Carbide Corporation Fellow, Chemical Engineering*  
B.S., Iowa State College, 1959; M.S., California Institute, 1960

Iain George Currie, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Applied Mechanics*  
Associate, Royal College of Science and Technology (Glasgow), 1960; M.A.Sc., University of British Columbia, 1962

Joseph Renald Yvon Cusson, *Graduate Research Assistant, Institute Scholar, Physics*  
B.Sc., University of Montreal, 1960

Joseph Jay Dannenberg, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*  
A.B., Columbia College, 1962

Roger Fred Dashen, *National Science Foundation Cooperative Fellow, Physics*  
A.B., Harvard College, 1960

Ted Herbert Davey, *Graduate Teaching Assistant, Dobbins Scholar, Electrical Engineering*  
B.S., California Institute, 1962

Cary Nathan Davids, *Imperial Oil Fellow, Murray Scholar, Physics*  
B.Sc. (Hons), University of Alberta, 1961; M.Sc., 1962

John Warren Davies, *Graduate Research Assistant, Institute Scholar, Physics*  
B.A., State University of Iowa, 1961

Lee Walker Davison, *Graduate Research Assistant, Institute Scholar, Applied Mechanics*  
B.S., University of Idaho, 1959; M.S., New York University, 1961

Jacques de Barbeyrac Saint-Maurice, *Graduate Teaching Assistant, Graduate Research Assistant, Institute Scholar*  
Dipl.C.A.E., Ecole Nationale Supérieure de l'Aéronautique (Paris), 1959; M.S., California Institute, 1960

Charles David DeBoer, *National Science Foundation Fellow, Chemistry*  
B.S., Iowa State University, 1962

Everett Leon DeLano, Jr., *North American Aviation Full Studies Science Fellow, Aeronautics*  
B.S., Northrop Institute of Technology, 1959

David Tilton Denhardt, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Biology*  
B.A., Swarthmore College, 1960

Paul Claire Denny, *U.S. Public Health Service Fellow, Biology*  
B.A., Westmont College (Santa Barbara), 1960

Robert Dewey de Pencier, *Graduate Teaching Assistant, Institute Scholar, Mechanical Engineering*  
B.Sc., Queen's University (Ontario), 1959; M.S., California Institute, 1960

Nicholas Anthony Derzko, *Graduate Teaching Assistant, Murray Scholar, Mathematics*  
B.Sc., University of Toronto, 1962

Alan Jerome DeVilbiss, *Graduate Teaching Assistant, Institute Scholar, Electrical Engineering*  
B.S., Louisiana Polytechnic Institute, 1960; M.S., California Institute, 1961

C. Forbes Dewey, Jr., *National Science Foundation Fellow, Graduate Teaching Assistant, Aeronautics*  
B.E., Yale University, 1956; M.S., Stanford University, 1957

Robert Ernest Diebold, *Institute Scholar, Physics*  
B.S., University of New Mexico, 1958; M.S., California Institute, 1960

Andrew Dienes, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.Eng., McGill University, 1962

Frank Sigel Dietrich III, *National Science Foundation Fellow, Physics*  
B.A., Haverford College, 1959

Theodore Neil Divine, *National Science Foundation Cooperative Fellow, Astronomy*  
S.B., Massachusetts Institute of Technology, 1959; M.S., University of Michigan, 1960

Richard Dolen, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.E.Ph., Cornell University, 1957

John Jacob Domingo, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1955

## 76 Graduate Appointments

James Albert Doutt, *Graduate Research Assistant, Institute Scholar, Geology*  
B.S., Pennsylvania State University, 1962

Alan Sander Dubin, *Graduate Teaching Assistant, Ryerson Scholar, Chemistry*  
C.E., University of Cincinnati, 1960

David James Duchamp, *National Science Foundation Fellow, Chemistry*  
B.S., University of Southwestern Louisiana, 1961

Michael B. Duke, *Graduate Teaching Assistant, Institute Scholar, Geochemistry*  
B.S., California Institute, 1957; M.S., Pennsylvania State University, 1958; M.S., California  
Institute, 1961

David Ray Dyroff, *National Science Foundation Fellow, Chemistry*  
B.S., University of Illinois, 1962

Stanley Duane Ecklund, *National Science Foundation Fellow, Graduate Teaching  
Assistant, Physics*  
B.S., University of Minnesota, 1961

Larre Nyman Egbert, *U.S. Public Health Service Trainee, Graduate Teaching Assistant,  
Biology*  
B.S. (Hons), Utah State University, 1959; M.S., 1963

Robert Charles Erdmann, *Atomic Energy Commission Fellow, Mechanical Engineering*  
B.S.M.E., Newark College of Engineering, 1960; M.S., University of California (Los Angeles),  
1962

William Winston Evans, *Graduate Teaching Assistant, Earle C. Anthony Scholar,  
Mechanical Engineering*  
B.Sc., University of Alberta, 1962

David Arthur Evensen, *Space Technology Laboratories Fellow, Aeronautics*  
B.S., Worcester Polytechnic Institute, 1959; M.S., California Institute, 1960

Pierre Facon, *National Aeronautics and Space Administration International University  
Fellow, COPERS Scholar, Mechanical Engineering*  
Ing., Ecole Nationale Supérieure d'Electricité et de Mécanique (Nancy), 1962

William Thomas Fehlberg, *Atomic Energy Commission Fellow, Graduate Teaching  
Assistant, Engineering Science*  
B.S.E., University of Michigan, 1960

Michael John Ferguson, *Graduate Teaching Assistant, Earle C. Anthony Scholar,  
Electrical Engineering*  
B.A.Sc., University of Toronto, 1962

Michael Timberlake Field, *Institute Scholar, Geology*  
S.B., Massachusetts Institute of Technology, 1961

Philip Filner, *U.S. Public Health Service Trainee, Graduate Teaching Assistant,  
Institute Scholar, Biology*  
B.A., Johns Hopkins University, 1960

Joseph Clinton Fineman, *Graduate Teaching Assistant, ARCS Scholar, Physics*  
B.S., California Institute, 1958

Michael Hamilton Fisch, *National Science Foundation Fellow, Chemistry*  
A.B., Columbia College, 1960

Hugo Breed Fischer, *National Defense Education Act Fellow, Civil Engineering*  
B.S., California Institute, 1958

Thornton Roberts Fisher, *Graduate Research Assistant, Institute Scholar, Physics*  
B.A., Wesleyan University, 1958

Jeffrey Edward Flatgaard, *U.S. Public Health Service Trainee, Graduate Teaching  
Assistant, Institute Scholar, Biology*  
A.B., Johns Hopkins University, 1962

Efthymios Stefanos Folias, *U.S. Aeronautical Research Laboratories Fellow,  
Aeronautics*  
B.S., University of New Hampshire, 1959; M.S., 1960

Edward Berel Fomalont, *Graduate Research Assistant, Clinedinst Scholar, Astronomy*  
B.S., University of Pennsylvania, 1961

Douglas Gun Fong, *Graduate Teaching Assistant, Institute Scholar, Physics*  
 A.B., Princeton University, 1961

James Norman Foster, *Graduate Teaching Assistant, Dobbins Scholar, Chemistry*  
 B.A., Occidental College, 1959

Lorraine Lois Foster, *National Science Foundation Cooperative Fellow, Graduate Research Assistant, Mathematics*  
 B.A., Occidental College, 1960

Michael Eugene Fourney, *Institute Scholar, Aeronautics*  
 B.S.A.E., West Virginia University, 1958; M.S., California Institute, 1959

Gary Scott Fraley, *Graduate Teaching Assistant, Laws Scholar, Physics*  
 B.S., California Institute, 1962

Lyman Jefferson Fretwell, Jr., *Graduate Research Assistant, Institute Scholar, Physics*  
 B.S., California Institute, 1956

Michael Fried, *Nutrition Foundation Fellow, Graduate Teaching Assistant, Institute Scholar, Biology*  
 B.A., Hunter College, 1959

Robert Peter Frosch, *National Science Foundation Cooperative Fellow, Chemistry*  
 B.S., Union College, 1959

Fergus John Gaines, *Graduate Teaching Assistant, Laws Scholar, Mathematics*  
 B.Sc., University College (Dublin), 1960; M.Sc., 1961

William Claude Galley, *Graduate Teaching Assistant, Laws Scholar, Chemistry*  
 B.Sc., McGill University, 1962

Terry Randolph Galloway, *Richfield Oil Corporation Fellow, Graduate Research Assistant, Chemical Engineering*  
 B.S., University of California, 1962

John Kelsey Gardner, *Graduate Research Assistant, Institute Scholar, Geophysics*  
 B.S., University of Arizona, 1953; M.S., 1958

George Donald Garlick, *Kennecott Copper Corporation Fellow, Geochemistry*  
 B.Sc., University of Witwatersrand, 1956; M.S., California Institute, 1961

Michael Saunders Gazzaniga, *U.S. Public Health Service Fellow, Biology*  
 A.B., Dartmouth College, 1961

Robert Joseph Gerbracht, *National Science Foundation Fellow, Physics*  
 B.A., Reed College, 1960

Edward George Gibson, *R. C. Baker Foundation Fellow, Mechanical Engineering*  
 B.S., University of Rochester, 1959; M.S., California Institute, 1960

Lavelle Roger Gibson, *Graduate Teaching Assistant, Institute Scholar, Electrical Engineering*  
 B.S., University of Oklahoma, 1962

Philip Mwangi Githinji, *Institute Scholar, Mechanical Engineering*  
 B.S.M.E., Purdue University, 1960; M.S., California Institute, 1961

Edward Stanley Glazer, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
 A.B. (Hons), University of Pennsylvania, 1961

Ellen Rose Glowacki, *Graduate Teaching Assistant, Institute Scholar, Biology*  
 B.A., Swarthmore College, 1960

William Andrew Goddard III, *National Science Foundation Fellow, Engineering Science*  
 B.S., University of California (Los Angeles), 1960

Jacques Godin, *University of Montreal Fellow, Mechanical Engineering*  
 B.App.Sc., University of Montreal, 1954

Alexander Franklin Hermann Goetz, *Institute Scholar, Geology*  
 B.S., California Institute, 1961; M.S., 1962

Harris Gold, *Rand Fellow, Aeronautics*  
 B.M.E., Polytechnic Institute of Brooklyn, 1958; M.S.M.E., Columbia University, 1959

Robert Goldstein, *Graduate Research Assistant, Institute Scholar, Engineering Science*  
B.S., Columbia University, 1959; M.S., California Institute, 1960

Stuart Frederick Goldstein, *Graduate Teaching Assistant, Institute Scholar, Biology*  
B.A., University of Minnesota, 1962

David Reeves Goosman, *National Science Foundation Fellow, Physics*  
B.A., Reed College, 1962

Robert Gordon, *National Defense Education Act Fellow, Mathematics*  
A.B., University of California (Los Angeles), 1962

Lester Sylvon Gorelic, *Graduate Teaching Assistant, Rutherford Scholar, Chemistry*  
B.S., Illinois Institute of Technology, 1962

Muvaffak Ilhan Gozaydin, *Turkish Government Fellow, Mechanical Engineering*  
M.S., Technical University of Istanbul, 1958

James Alexander Grant, *Graduate Teaching Assistant, Institute Scholar, Geology*  
B.Sc. (Hons), Aberdeen University, 1957; M.A., Queen's University (Ontario), 1959

Dennis Jerome Graue, *National Science Foundation Fellow, Chemical Engineering*  
B.S., University of Colorado, 1961; M.S., California Institute, 1962

Augustine Heard Gray, Jr., *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Engineering Science*  
S.B., Massachusetts Institute of Technology, 1959; S.M., 1959

Louise Dillon Gray, *Institute Scholar, Engineering Science*  
B.S., University of California (Los Angeles), 1957; M.S., 1959

Charles August Greenhall, *National Science Foundation Fellow, Applied Mathematics*  
B.A., Pomona College, 1961

William Franklin Greenman, *Graduate Teaching Assistant, Rutherford Scholar, Graduate Research Assistant, Materials Science*  
B.S., California Institute, 1960; M.S., 1962

David Henry Griffel, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Physics*  
B.Sc. (Hons), Birmingham University (England), 1961

Hayes Osbie Griffith, *National Science Foundation Fellow, Chemistry*  
A.B., University of California (Riverside), 1960

David Eiben Groce, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1958

John James Grocki, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Chemistry*  
B.S., Worcester Polytechnic Institute, 1962

Donald Eugene Groom, *Graduate Research Assistant, Institute Scholar, Physics*  
A.B., Princeton University, 1956

Melinda Ann Groom, *Francis J. Cole Fellow, Physics*  
A.B., Bryn Mawr College, 1961

Fletcher Ivan Gross, *National Science Foundation Cooperative Fellow, Mathematics*  
B.S., California Institute, 1960

William Paul Gruber, *Alfred P. Sloan Foundation Fellow, Mechanical Engineering*  
B.S., University of Washington, 1962

James Edward Gunn, *National Science Foundation Fellow, Astronomy*  
B.A., Rice University, 1961

Ralph Stuart Hager, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.S., University of Minnesota, 1961

Lawrence William Hallanger, *Graduate Teaching Assistant, Institute Scholar, Mechanical Engineering*  
B.S., Harvey Mudd College, 1961; M.S., California Institute, 1962

Charles Robert Hamilton, *Graduate Teaching Assistant, Institute Scholar, Psychobiology*  
B.S., University of the South, 1957

Anthony Michael John Hannon, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Civil Engineering*  
B.E., University College (Cork), 1960

Robert Duane Hanson, *Graduate Research Assistant, Institute Scholar, Civil Engineering*  
B.S., University of Minnesota, 1957; M.S.C.E., 1958

William Morgan Hardham, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
B.S., The Pennsylvania State University, 1961

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

David Garrison Harkrider, *Graduate Research Assistant, Institute Scholar, Geophysics*  
B.S., Rice University, 1953; M.A., 1957

Charles Woods Harper, Jr., *Graduate Teaching Assistant, Institute Scholar, Geology*  
S.B., Massachusetts Institute of Technology, 1959; S.M., 1961

William Douglas Harrison, *Graduate Research Assistant, Institute Scholar, Physics*  
B.Sc., Mount Allison University (New Brunswick), 1958; B.Sc. (Spec.), Imperial College of Science and Technology (University of London), 1960

Kenneth Gunder Harstad, *National Science Foundation Fellow, Aeronautics*  
B.S.M.E., University of North Dakota, 1961; S.M., Massachusetts Institute of Technology, 1962

Donald LeRoy Hartill, *National Science Foundation Fellow, Physics*  
S.B., Massachusetts Institute of Technology, 1961

James Burkett Hartle, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Physics*  
A.B., Princeton University, 1960

Kenneth Edwin Harwell, *Graduate Teaching Assistant, Institute Scholar, Aeronautics*  
B.S., University of Alabama, 1958; M.S., California Institute, 1960

G. Laurie Hatch, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., Tufts University, 1959

Loren Endicott Hatlen, *U.S. Public Health Service Trainee, Graduate Teaching Assistant, Institute Scholar, Biology*  
B.A., University of California (Santa Barbara), 1962

Edward Hauptmann, *Graduate Teaching Assistant, Institute Scholar, Mechanical Engineering*  
B.Sc., University of Alberta, 1960; M.S., California Institute, 1961

Michael George Hauser, *National Science Foundation Fellow, Physics*  
B.E.Ph., Cornell University, 1962

Robert Lambdin Heath, *U.S. Public Health Service Trainee, Institute Scholar, Biochemistry*  
S.B., Massachusetts Institute of Technology, 1956; S.M., 1958

Mathilde Jeannette Hebb, *National Science Foundation Fellow, Physics*  
A.B., Bryn Mawr College, 1961

Gilbert Arthur Hegemier, *Graduate Teaching Assistant, T. S. Brown Scholar, Aeronautics*  
B.E.S., Brigham Young University, 1959; M.S., California Institute, 1960

Malcolm Lee Heimer, *Charles Le Geyt Fortescue Fellow, Howard Hughes Scholar, Electrical Engineering*  
B.S.E.E., Bucknell University, 1962

Thomas McCalfree Helliwell, *Institute Scholar, Physics*  
B.A., Pomona College, 1958

William Lynderman Hendry, *Howard Hughes Fellow, Mechanical Engineering*  
B.S., University of California (Los Angeles), 1962

David Cecil Hensley, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.S., University of Arizona, 1960

Thomas Louis Henyey, *Sinclair Fellow, Graduate Research Assistant, Geology*  
A.B., University of California, 1962

William George Herkstroeter, *National Science Foundation Fellow, Chemistry*  
B.A., Wesleyan University, 1960

Robert Henry Hertel, *Graduate Teaching Assistant, Institute Scholar, Electrical Engineering*  
S.B., Massachusetts Institute of Technology, 1958; M.S., California Institute, 1959

Robert Hickling, *Graduate Teaching Assistant, Engineering Science*  
M.A., University of St. Andrews, 1954

Henry Hunter Hill, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.A., Rice University, 1960

Jack Hubert Hill, *Douglas Aircraft Company Fellow, Aeronautics*  
B.S., University of Oklahoma, 1952; M.S. (Ae.), 1954; M.S. (Inst. Eng.), 1954

Brian Mark Hoffman, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*  
B.S., University of Chicago, 1962

John Arthur Holbrook, *General Electric Foundation Fellow, Mathematics*  
B.S., Queen's University (Ontario), 1961; M.A., 1962

Lincoln Steffens Hollister, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Geology*  
B.A., Harvard College, 1961

Walter Richard Holmquist, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Chemistry*  
B.S., Washington and Lee University, 1957; B.S., California Institute, 1961

Wallace Irving Honeywell, *Graduate Teaching Assistant, Institute Scholar, Chemical Engineering*  
B.S., Stanford University, 1959; M.S., 1960

John Leonard Honsaker, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1955

Roger LeBaron Hooke, *National Science Foundation Fellow, Graduate Teaching Assistant, Geology*  
B.A., Harvard College, 1961

Leo Horowitz, *Graduate Teaching Assistant, Hughes Scholar, Applied Mechanics*  
B.S., Drexel Institute of Technology, 1962

John Raymond Hribar, *Graduate Teaching Assistant, Institute Scholar, Materials Science*  
B.S., California Institute, 1961; M.S., 1962

Paul Yu-fei Hu, *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
B.S., University of Maryland, 1961; M.S., California Institute, 1962

Evan Eugene Hughes, Jr., *National Science Foundation Fellow, Physics*  
B.S., California Institute, 1962

Gordon Frierson Hughes, *Corning Glass Works Foundation Fellow, Electrical Engineering*  
B.S., California Institute, 1959; M.S., 1960

Johannes Huisman, *Standard Oil Company of California Fellow, Chemical Engineering*  
Dipl., Dordrecht Technical College (The Netherlands), 1956; Dipl., Royal Melbourne Technical College, 1959; M.S., California Institute, 1962

Glen Owen Hultgren, *Institute Scholar, Chemistry*  
B.S., University of California, 1958

Richard O'Neil Hundley, *Institute Scholar, Physics*  
B.S., California Institute, 1957; M.S., 1959

Thomas Kintzing Hunt, *Graduate Research Assistant, Institute Scholar, Physics*  
B.A., Pomona College, 1959; M.S., California Institute, 1961

Robert John Huskey, *Graduate Teaching Assistant, Institute Scholar, Biology*  
 B.S., University of Oklahoma, 1960; M.S., 1962

Clyde Allen Hutchison III, *U.S. Public Health Service Trainee, Graduate Teaching Assistant, Institute Scholar, Biology*  
 B.S., Yale University, 1960

Kwang-chou Hwang, *Graduate Teaching Assistant, Institute Scholar, Chemical Engineering*  
 B.S., Taiwan University, 1956; M.S., California Institute, 1961

Li-San Hwang, *Graduate Research Assistant, Institute Scholar, Civil Engineering*  
 B.S., National Taiwan University, 1958; M.S., Michigan State University, 1962

Edmond Remy Iagolnitzer, *NATO Fellow, Mechanical Engineering*  
 Dipl.Ing., Ecole des Mines (Nancy), 1962

Abou-Bakr Khalil Ibrahim, *United Arab Republic Fellow, Geology*  
 B.S., A'in Shams University (Cairo), 1958; M.S., New Mexico Institute of Mining and Technology, 1962

Martin Henry Israel, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Physics*  
 S.B., The University of Chicago, 1962

Martin Stanley Itzkowitz, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*  
 A.B., Columbia University, 1962

Alexander Donald Jacobson, *Howard Hughes Fellow, Electrical Engineering*  
 B.S., University of California (Los Angeles), 1955; M.S., 1958

Marlyn Tony Jakub, *Atomic Energy Commission Fellow, Mechanical Engineering*  
 B.S., Carnegie Institute of Technology, 1958; M.S., California Institute, 1962

David Fielding James, *Graduate Teaching Assistant, Dobbins Scholar, Mechanical Engineering*  
 B.Sc., Queen's University (Ontario), 1962

Paul Christian Jennings, *General Electric Foundation Fellow, Civil Engineering*  
 B.S., Colorado State University, 1959; M.S., California Institute, 1960

Donald Frederick Jensen, *National Science Foundation Fellow, Applied Mechanics*  
 B.S., Virginia Polytechnic Institute, 1962

Ronald Harry Jensen, *U.S. Public Health Service Fellow, Graduate Teaching Assistant, Chemistry*  
 B.S., Lawrence College, 1960

John Meurig John, *Thomas and Elizabeth Williams Fellow, Mathematics*  
 B.Sc., University College of Swansea (Wales), 1961; M.Sc., 1962

Lane Richard Johnson, *Graduate Research Assistant, Murray Scholar, Geology*  
 B.S., University of Minnesota, 1960; M.S., 1962

Jack Randolph Jokipii, *National Science Foundation Fellow, Physics*  
 B.S., University of Michigan, 1961

Arnold Richard Jones, *Consolidated Electrodynamics Fellow, Electrical Engineering*  
 B.S. (Chem), California Institute, 1961; B.S. (Elect. Eng.), 1962

Barbara Ann Jones, *Hixon Fund Fellow, Graduate Teaching Assistant, Institute Scholar, Biology*  
 B.S., University of Illinois, 1962

Janet Gretchen Jones, *National Science Foundation Fellow, Chemistry*  
 B.A., Swarthmore College, 1961

Noel Duane Jones, *U.S. Public Health Service Fellow, Chemistry*  
 B.S., Rensselaer Polytechnic Institute, 1959

Lisle Thomas Jory, *Harvey Mudd Fellow, Institute Scholar, Geology*  
 B.A.Sc., University of British Columbia, 1950

Nora Sigrum Josephson, *National Science Foundation Fellow, Physics*  
 B.A., University of California (Riverside), 1962

Howard Arthur Kabakow, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Physics*  
B.S., California Institute, 1962

David Kabat, *National Science Foundation Fellow, Graduate Teaching Assistant, Biology*  
Sc.B., Brown University, 1962

Keishi Kawamo, *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
B.E., Waseda University (Tokyo), 1959

Boris Jules Kayser, *National Science Foundation Fellow, Physics*  
A.B., Princeton University, 1960

Susan Elizabeth Kayser, *Institute Scholar, Astronomy*  
A.B., Radcliffe College, 1960

Robert Kenneth Keenan, *Howard Hughes Fellow, Electrical Engineering*  
B.Sc., University of California (Los Angeles), 1962

Gordon Ernest Keller, *National Defense Education Act Fellow, Mathematics*  
B.A., Houghton College, 1960; M.A., University of Buffalo, 1962

Kenneth Irwin Kellermann, *Graduate Research Assistant, Institute Scholar, Physics*  
S.B., Massachusetts Institute of Technology, 1959

Regis Baker Kelly, *Graduate Teaching Assistant, Institute Scholar, Biology*  
B.Sc. (Hons), Edinburgh University, 1961; Dipl. Bioph., 1961

Vassilios Kerdemelidis, *Boeing Fellow, Electrical Engineering*  
B.E., National School of Engineering, University of New Zealand, 1957; M.S., California Institute, 1961

James W. Kessel, *U.S. Public Health Service Fellow, Chemistry*  
B.S., University of Michigan, 1958

Leon Frank Keyser, *Graduate Teaching Assistant, Roeser Scholar, Chemistry*  
B.S., University of Notre Dame, 1959

Joseph R. Kilner, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., Case Institute of Technology, 1957

Jonathan Alan King, *Woodrow Wilson Foundation Fellow, Graduate Teaching Assistant, Biology*  
B.S., Yale University, 1962

Ronald Allan Kleban, *Graduate Teaching Assistant, Institute Scholar, Electrical Engineering*  
B.S., California Institute, 1961; M.S., 1962

John Michael Klineberg, *Graduate Research Assistant, Aeronautics*  
B.S.E., Princeton University, 1960; M.S., California Institute, 1962

Gerhard Joachim Klose, *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
B.S., California Institute, 1959; M.S., 1960

Charles Robert Klotz, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Mechanical Engineering*  
B.S., Fenn College, 1962

Karl Kent Knapp, *Atomic Energy Commission Fellow, Mechanical Engineering*  
B.S., California Institute, 1959; M.S., 1960

Wolfgang Gustav Knauss, *National Aeronautics and Space Administration Fellow, Institute Scholar, Aeronautics*  
B.S., California Institute, 1958; M.S., 1959

Donald Ervin Knuth, *Graduate Teaching Assistant, Institute Scholar, Mathematics*  
B.S., Case Institute of Technology, 1960

Hon-Yim Ko, *Graduate Teaching Assistant, Drake Scholar, Civil Engineering*  
B.Sc., University of Hong Kong, 1962

William L. Ko, *National Aeronautics and Space Administration Fellow, Aeronautics*  
B.S., National Taiwan University, 1950; M.S., California Institute, 1959

Robert Ching-Yee Koh, *Graduate Research Assistant, Institute Scholar, Applied Mechanics*  
B.S., California Institute, 1960; M.S., 1961

William Patrick Kolodny, *Graduate Teaching Assistant, Institute Scholar, Mathematics*  
B.S., North Carolina State College, 1961

Warner Bruce Kover, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Chemistry*  
B.S., Yale University, 1959

Stanley Garson Krane, *Graduate Teaching Assistant, Institute Scholar, Biochemistry*  
B.S., City College of New York, 1957; M.S., Michigan State University, 1958

Daniel Julius Krause, *Shell Companies Foundation Fellow, Materials Science*  
B.Met.E., Ohio State University, 1958; M.S., California Institute, 1959

Joel Ivan Krugler, *U.S. Steel Foundation Fellow, Physics*  
B.E.E., The Cooper Union, 1959

Robert Leroy Kruse, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Mathematics*  
B.A., Pomona College, 1960; M.S., California Institute, 1962

Logan Keith Kuiper, *Graduate Teaching Assistant, ARCS Scholar, Applied Mechanics*  
B.A., State University of Iowa, 1962

Joel Kwok, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.S., University of California, 1959

John Ling-Yee Lam, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.A., Rice University, 1962

Joseph Buckley Lambert, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*  
B.S., Yale University, 1962

William Edgar Lambert III, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Chemistry*  
B.S., Wesleyan University, 1962

Angelo Anthony Lamola, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*  
S.B., Massachusetts Institute of Technology, 1961

James Edward Lancaster, *Institute Scholar, Engineering Science*  
B.S., Seattle Pacific College, 1961

James Daniel Larson, *Graduate Research Assistant, Institute Scholar, Physics*  
S.B., Massachusetts Institute of Technology, 1957; M.S., California Institute, 1959

Raymond Walter Latham, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.Eng., McGill University, 1958; M.S., California Institute, 1959

Jark Chong Lau, *Institute Scholar, Aeronautics*  
Dipl., Royal Melbourne Technical College, 1957

Joseph Po-keung Lau, *Graduate Research Assistant, Institute Scholar, Engineering Science*  
B.Sc., Purdue University, 1962

George Melvin Lawrence, *Electro-Optical Systems Fellow, Graduate Research Assistant, Institute Scholar, Physics*  
B.S., University of Utah, 1959

Andrew Scott Lebor, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., University of Cincinnati, 1956

Jen-shih Lee, *Institute Scholar, Aeronautics*  
B.S., National Taiwan University, 1961

## 84 Graduate Appointments

Kelvin Shun Hung Lee, *Radio Corporation of America Fellow, Electrical Engineering*  
B.S., California Institute, 1960; M.S., 1961

Richard Michael Leichus, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Electrical Engineering*  
B.S., Stevens Institute of Technology, 1962

Robert Cary Leif, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.S., University of Chicago, 1959

Vladimir Ivanovich Lendyel, *Interuniversity Committee on Travel Grants Fellow, Institute Scholar, Physics*  
Dipl., State University of Uzhgorod, 1955

Arnold Vincent Lesikar, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.A., Rice University, 1958

Michael Jerry Levine, *Institute Scholar, Physics*  
B.S., University of Illinois, 1958

Paul Hersh Levine, *Institute Scholar, Physics*  
S.B., Massachusetts Institute of Technology, 1956; M.S., California Institute, 1957

Richard Joseph Levine, *Nutrition Foundation Fellow, Graduate Teaching Assistant, Institute Scholar, Biology*  
A.B., Princeton University, 1960

Mark Levinson, *Graduate Research Assistant, Drake Scholar, Engineering Science*  
B.A.E., Polytechnic Institute of Brooklyn, 1951; M.S., 1960

Miguel Enrique Levy, *Graduate Research Assistant, Institute Scholar, Materials Science*  
B.S., California Institute, 1962

Milton Levy, *Graduate Teaching Assistant, Institute Scholar, Mathematics*  
B.A., Cornell University, 1956; M.S., New Mexico State University, 1960

George Waldimir Lewicki, *Howard Hughes Fellow, Electrical Engineering*  
S.B., Massachusetts Institute of Technology, 1960; M.S., California Institute, 1961

John Eldon Lewis, *Graduate Teaching Assistant, Bennett Scholar, Aeronautics*  
B.S., University of California, 1962

Alfred George Lieberman, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.S., Polytechnic Institute of Brooklyn, 1958; M.S., California Institute, 1959

Gerald Richard Liebling, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.S., Polytechnic Institute of Brooklyn, 1959

Amable Liñan-Martinez, *National Aeronautics and Space Administration International University Fellow, Aeronautics*  
Ae.E., University of Madrid, 1962

Ronald Keith Linde, *Graduate Research Assistant, Drake Scholar, Materials Science*  
B.S., University of California, 1961; M.S., California Institute, 1962

Gerald Herbert Lindsey, *Graduate Teaching Assistant, Institute Scholar, Aeronautics*  
B.E.S., Brigham Young University, 1960; M.S., 1961

Peter James Lingane, *U.S. Public Health Service Fellow, Graduate Teaching Assistant, Chemistry*  
A.B., Harvard College, 1962

John Kailin Link, *Robert A. Millikan Fellow, Graduate Teaching Assistant, Institute Scholar, Physics*  
B.S., Antioch College, 1959

Alan Lippert, *Alfred P. Sloan Foundation Fellow, Mechanical Engineering*  
B.M.E., Cornell University, 1961; M.S., 1962

Ericson John List, *Graduate Teaching Assistant, Institute Scholar, Civil Engineering*  
B.E. (Hons), University of Auckland, 1961; B.Sc., 1962; M.E., 1962

Chung-Chiun Liu, *Graduate Teaching Assistant, Institute Scholar, Chemical Engineering*  
B.Sc., Cheng Kung University (Taiwan), 1959; M.S., California Institute, 1962

Joseph Tsu Chieh Liu, *Graduate Teaching Assistant, Institute Scholar, Aeronautics*  
B.S., University of Michigan, 1957; M.S., 1958

Robert Shing-Hei Liu, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
B.S., Howard Payne College, 1961

Anastasios Gerasimos Livitsanos, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.E., Stevens Institute of Technology, 1962

J. Barrie Logan, *National Science Foundation Fellow, Graduate Teaching Assistant, Biology*  
B.S., University of Texas, 1962

Helmut Karl Valentin Lotsch, *NATO Fellow, Electrical Engineering*  
Dipl.Ing., Karlsruhe Institute of Technology, 1958; M.S., California Institute, 1962

Chien-Shih Lu, *Graduate Research Assistant, Murray Scholar, Chemical Engineering*  
B.S., National Taiwan University, 1956; M.S., University of Houston, 1962

Hans Ludewig, *Institute Scholar, Mechanical Engineering*  
B.Sc., (cum laude), University of Natal, 1959; M.Sc., 1961; M.S., California Institute, 1962

Waldemar T. Lungerhausen, Jr., *National Science Foundation Cooperative Fellow, Astronomy*  
B.S., California Institute, 1962

Huey-Lin Luo, *Graduate Research Assistant, Institute Scholar, Materials Science*  
B.S., National Taiwan University, 1956; M.S., Iowa State College, 1959

Loren Daniel Lutes, *Barry Wright Corporation Fellow, Applied Mechanics*  
B.Sc., University of Nebraska, 1960; M.Sc., 1961

Ben Edward Lynch, *Graduate Research Assistant, Institute Scholar, Physics*  
B.E.Ph., Cornell University, 1960

Alexander Newell Lyon, *Graduate Teaching Assistant, Institute Scholar, Biology*  
B.S., California Institute, 1962

Robert James Macek, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., South Dakota State College, 1958

Gordon Frank MacGinitie, *Francis J. Cole Fellow, Electrical Engineering*  
B.S., Stanford University, 1957; M.S., 1959

Jack William Macki, *National Science Foundation Fellow, Mathematics*  
B.S., University of Idaho, 1960

Robert Alister MacLeod, *Graduate Teaching Assistant, Institute Scholar, Mathematics*  
B.Sc., University of Alberta, 1961

Rajeshwar Kumar Malhotra, *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
I.Sc., Ewing Christian College (Allahabad, India), 1956; B.S., Oregon State College, 1959; M.S., Cornell University, 1961

Peter John Mantle, *Graduate Teaching Assistant, Institute Scholar, Aeronautics*  
D.C.Ae., The College of Aeronautics (Cranfield, England), 1958

Franklin Lester Marshall, *Graduate Teaching Assistant, Garrett Corporation Scholar, Mechanical Engineering*  
B.S., California Institute, 1962

J. Howard Marshall III, *Institute Scholar, Physics*  
B.S., California Institute, 1957

Egon Marx-Oberländer, *Graduate Research Assistant, Institute Scholar, Physics*  
E.E., University of Chile, 1959

Sami Faiz Masri, *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
B.S., University of Texas, 1960; M.S., 1961; California Institute, 1962

John Wallace Matthews, *National Science Foundation Cooperative Fellow, Electrical Engineering*  
B.S., University of California (Los Angeles), 1962

## 86 Graduate Appointments

David James McCloskey, *National Science Foundation Fellow, Engineering Science*  
B.S., Stanford University, 1958; M.S., 1959

Malcolm McColl, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.S., Wayne State University, 1957; M.S., California Institute, 1958

Edward Rae Held McDowell, *National Science Foundation Fellow, Chemical Engineering*  
B.Chem.E., Cornell University, 1955; M.S., California Institute, 1960

Stewart Douglas McDowell, *Graduate Teaching Assistant, Institute Scholar, Geology*  
B.S., Pennsylvania State University, 1960; M.S., California Institute, 1962

Arthur Francis McGarr, *Graduate Teaching Assistant, Institute Scholar, Geology*  
B.S., California Institute, 1962

Thomas Richard McGetchin, *Graduate Teaching Assistant, Institute Scholar, Geology*  
A.B., Occidental College, 1959; Sc.M., Brown University, 1961

Patrick Anthony McGovern, *General Electric International Fellow, Electrical Engineering*  
B.E. (Hons), University of Queensland, 1961; B.Sc., 1962

Francis Clay McMichael, *Institute Scholar, Civil Engineering*  
B.S., Lehigh University, 1958; M.S., California Institute, 1959

James Henry McNally, *Graduate Research Assistant, Institute Scholar, Physics*  
B.Eng.Phys., Cornell University, 1959

Chiang Chung Mei, *Graduate Teaching Assistant, Engineering Science*  
B.S.C.E., National Taiwan University, 1955; M.S., Stanford University, 1958

Osório Chagas Meirelles, *Pan American Union Fellow, Graduate Teaching Assistant, Electrical Engineering*  
B.Sc., University of Brazil, 1960; M.S., California Institute, 1962

Laurent Justin Meister, *French Ministry of Foreign Affairs Fellow, Geology*  
Geoph.Eng., University of Strasbourg, 1958; Dipl.Ing., Ecole Nationale Supérieure du Pétrole et des Moteurs (Paris), 1960

Stanley Brun Mellsen, *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
B.Sc., University of Alberta, 1961; M.S., California Institute, 1962

Joseph Carby Mendez, *Graduate Teaching Assistant (Mathematics), Clinedinst Scholar, Aeronautics*  
B.A.E., Georgia Institute of Technology, 1961; M.S., 1962; M.S., California Institute, 1962

Manuel E. Mendez, *Observatorio Astronomico Nacional (Mexico) Fellow, Astronomy*  
Ch.E., University of Mexico, 1959; M.S., California Institute, 1962

Arthur William Merkl, *Institute Scholar, Chemistry*  
B.S., University of Cincinnati, 1958

Lauren Vail Merritt, *Graduate Teaching Assistant, Dobbins Scholar, Electrical Engineering*  
B.S., California Institute, 1962

Robert Melville Metzger, *Woodrow Wilson Fellow, Chemistry*  
B.S., University of California (Los Angeles), 1962

Fernando Mexia-Algar, *Smith-Mundt Fellow, Elias Ahuja Fellow, Electrical Engineering*  
Ae.E., Aeronautical Engineering Technical University (Madrid), 1955

Heinz Dieter Middendorf, *Institute Scholar, Engineering Science*  
Dipl.Ph., Technische Hochschule Darmstadt, 1959; M.S., Purdue University, 1961

James Eardley Midgley, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S.E., University of Michigan, 1956

Dimitri Manuel Mihalas, *Van Maanen Fellow, Graduate Teaching Assistant, Institute Scholar, Astronomy*  
A.B., University of California (Los Angeles), 1959; M.S., California Institute, 1960

Paul George Mikolaj, *National Science Foundation Cooperative Fellow, Chemical Engineering*  
 B.Ch.E., Fenn College, 1958; M.S., University of Rochester, 1960

Ralph Fraley Miles, Jr., *Graduate Research Assistant, Institute Scholar, Physics*  
 B.S., California Institute, 1955; M.S., 1960

Richard Graham Miller, *Graduate Research Assistant, Institute Scholar, Physics*  
 B.Sc., University of Alberta, 1960; M.Sc., 1961

Robert Loomis Millette, *Nutrition Foundation Fellow, U.S. Public Health Service Fellow, Graduate Teaching Assistant, Institute Scholar, Biology*  
 B.S., Oregon State College, 1954; M.S., 1959

Catalin Dan Mitescu, *General Atomic Fellow, Physics*  
 B.Eng., McGill University, 1958

Kenneth Martin Mitzner, *Howard Hughes Fellow, Electrical Engineering*  
 S.B., Massachusetts Institute of Technology, 1958; M.S., California Institute, 1959

Norton Leonard Moise, *Graduate Research Assistant, Institute Scholar, Physics*  
 B.S., University of Illinois, 1948; M.A., University of California (Los Angeles), 1954; M.S., California Institute, 1959

Donald Joseph Mokski, *Atomic Energy Commission Fellow, Applied Mechanics*  
 B.S., University of Buffalo, 1954

Charles Gray Montgomery, *Graduate Research Assistant, Institute Scholar, Physics*  
 B.A., Yale University, 1959; M.S., California Institute, 1961

Donald Wayne Moon, *Graduate Research Assistant, Institute Scholar, Materials Science*  
 B.S., University of Illinois, 1956; M.S., 1957

Lawrence Carlton Moore, Jr., *Graduate Teaching Assistant, Laws Scholar, Mathematics*  
 B.S., North Carolina State College, 1961

Thomas Gerald Moore, *Graduate Research Assistant, Institute Scholar, Physics*  
 B.A., Occidental College, 1962

Otto Moosburner, *U.S. Public Health Service Fellow, Civil Engineering*  
 B.C.E., Manhattan College, 1962

Darwin Pete Moradiellos, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
 B.S., University of Florida, 1959

Fernando B. Morinigo, *Graduate Research Assistant, Institute Scholar, Physics*  
 B.S., University of Southern California, 1957

Milton Edward Morrison, *Graduate Teaching Assistant, Rutherford Scholar, Chemical Engineering*  
 B.S., Iowa State University, 1961; M.S., California Institute, 1962

Robert George Mortimer, *Institute Scholar, Chemistry*  
 B.S., Utah State University, 1958; M.S., 1959

Francis Guy Moses, *Graduate Research Assistant, Institute Scholar, Chemistry*  
 B.A., University of Delaware, 1958

Calvin Elroy Moss, *National Science Foundation Fellow, Physics*  
 B.S., University of Virginia, 1961

Werner Alfred Mukatis, *Du Pont Postgraduate Teaching Fellow, Graduate Teaching Assistant, Chemistry*  
 B.S., Northwestern University, 1960

John Brian Murphy, *Graduate Teaching Assistant, Drake Scholar, Electrical Engineering*  
 B.S.E.E., Bradley University, 1961

John Fletcher Murphy, *Graduate Teaching Assistant, Blacker Scholar, Aeronautics*  
 B.S., University of Notre Dame, 1957; M.S., California Institute, 1962

James Charles Murray, *Smith-Mundt Fellow, Engineering Science*  
 B.Sc. (Hons), University College (Dublin), 1960; M.Sc. (Hons), 1961

Elliott Robert Nagelberg, *Howard Hughes Fellow, Electrical Engineering*  
 B.E.E., The City College of New York, 1959; M.E.E., New York University, 1961

Paul Joel Nahin, *Graduate Teaching Assistant, Institute Scholar, Electrical Engineering*  
B.S., Stanford University, 1962

Robert Ronald Natale, *Schlumberger Foundation Fellow, Electrical Engineering*  
B.E.S., Johns Hopkins University, 1962

Richard Stevens Naylor, *National Science Foundation Fellow, Geology*  
S.B., Massachusetts Institute of Technology, 1961

Eugene Byrd Nebeker, *Graduate Teaching Assistant, Institute Scholar, Chemical Engineering*  
B.S., Stanford University, 1959; M.S., California Institute, 1960

Gary Lawrence Neil, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
B.Sc. (Hons), Queen's University (Ontario), 1962

Michael Harvey Nesson, *U.S. Public Health Service Trainee, Graduate Teaching Assistant, Institute Scholar, Biology*  
S.B., Massachusetts Institute of Technology, 1960

John Carl Nickel, *Electro-Optical Systems Fellow, Graduate Research Assistant, Institute Scholar, Physics*  
B.A., University of California (Riverside), 1958; M.S., California Institute, 1960

Niels Norby Nielsen, *Graduate Teaching Assistant, Institute Scholar, Civil Engineering*  
C.E., Technical University (Copenhagen), 1954

George Carroll Nieman, *National Science Foundation Fellow, Chemistry*  
B.S., California Institute, 1961

Helga Ninnemann, *Institute Scholar, Biology*  
M.S., University of Frankfurt, 1957-62

Frederick Reyes Norwood, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Applied Mechanics*  
B.S., University of California (Los Angeles), 1962

Harris Anthony Notarys, *Graduate Research Assistant, Institute Scholar, Physics*  
S.B., Massachusetts Institute of Technology, 1954

Maurice Joseph Nugent, Jr., *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
B.A., University of Colorado, 1961

Heiko Herbert Ohlenbusch, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.S., Columbia University, 1959

Takako Maeda Ohtomo, *University of Hawaii East-West Center Scholar, Biology*  
B.S., Tohoku University, 1959; M.S., 1961

Michael Edmond James O'Kelly, *Francis J. Cole Fellow, Applied Mechanics*  
B.E., National University of Ireland (Cork), 1958; M.S., California Institute, 1960; M.E., 1961;  
M.S., Columbia University, 1962

Baldomero M. Olivera, Jr., *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.S., (*summa cum laude*), University of the Philippines, 1960; B.S.Chem., 1961

Edwin Soland Olson, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
B.A., St. Olaf College, 1959

Mervyn Daniel Olson, *Johnson's Wax Fund Fellow, Graduate Research Assistant, Aeronautics*  
B.A., Sc., University of British Columbia, 1962

Patrick Gerard O'Regan, *Graduate Teaching Assistant, Institute Scholar, Electrical Engineering*  
B.E., University College (Cork), 1957; M.S., California Institute, 1959

Howard Oringer, *Graduate Teaching Assistant, Electrical Engineering*  
B.E., Stevens Institute of Technology, 1962

Martin Lawrence Pall, *Nutrition Foundation Fellow, Graduate Teaching Assistant, Institute Scholar, Biology*  
B.A., Johns Hopkins University, 1962

Jerald Vawer Parker, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Physics*  
B.S., California Institute, 1960

Peter Donald MacDougall Parker, *Graduate Research Assistant, Institute Scholar, Physics*  
B.A., Amherst College, 1958

Robert Reid Parmerter, *Graduate Research Assistant, Dobbins Scholar, Aeronautics*  
B.S., California Institute, 1958; M.S., 1959

Richard Walker Patch, *National Science Foundation Fellow, Engineering Science*  
B.S., Purdue University, 1953; M.S., California Institute, 1958

Dinshaw Jehangir Patel, *Institute Scholar, Chemistry*  
B.Sc., Jai Hind College (Bombay), 1961

Robert Francis Pawula, *Howard Hughes Fellow, Electrical Engineering*  
B.S., Illinois Institute of Technology, 1960; M.S., Massachusetts Institute of Technology, 1961

John Davie Pearson, *Graduate Research Assistant, Institute Scholar, Physics*  
B.Sc., Brown University, 1956

Charles William Peck, *Robert A. Millikan Fellow, Graduate Research Assistant, Physics*  
B.S., New Mexico College of Agricultural and Mechanical Arts, 1956

Jerry Clifford Peck, *Institute Scholar, Aeronautics*  
B.S., California Institute, 1957; M.S., 1958; Ae.E., 1959

Philip Carl Peters, *National Science Foundation Fellow, Physics*  
B.S., Purdue University, 1960

Roger Lee Peterson, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.S., Northwestern University, 1960

James Sibley Petty, *Graduate Research Assistant, Institute Scholar, Aeronautics*  
B.S., California Institute, 1959; M.S., 1960

Demetrius Philippou, *Graduate Teaching Assistant, Institute Scholar, Aeronautics*  
D.L.C. (Hons), Loughborough College (England), 1954; M.S., California Institute, 1961

Joram Paul Piatigorsky, *Graduate Teaching Assistant, Institute Scholar, Biology*  
A.B. (*cum laude*), Harvard College, 1962

Alfred Cyril Pinchak, *Garrett Corporation Fellow, Graduate Teaching Assistant, Mechanical Engineering*  
B.S.E.E., Case Institute of Technology, 1957; M.S.E., Purdue University, 1959

Leonard William Piszkiewicz, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
B.S., Loyola University (Chicago), 1962

Robert Franklin Poe, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1961; A.B., University of California, 1962

Robert Leslie Poeschel, *Howard Hughes Fellow, Electrical Engineering*  
B.S., University of Illinois, 1960; M.S., 1960

Raymond Felix Poggi, *French Ministry of Foreign Affairs Fellow, Electrical Engineering*  
Ing., Ecole Polytechnique (Paris), 1960

David Peter Pope, *Graduate Teaching Assistant, Graduate Research Assistant, Institute Scholar, Materials Science*  
B.S., University of Wisconsin, 1961; M.S., California Institute, 1962

John William Porter, Jr., *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
B.A., Rice University, 1959; M.S., California Institute, 1960

Charles Young Prescott, *National Science Foundation Fellow, Physics*  
B.A., Rice University, 1961

Paul Walton Purdom, Jr., *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1961; M.S., 1962

Om Parkash Puri, *International Cooperation Administration Fellow, Materials Science*  
B.Sc. (Hons), Panjab University, 1950; M.Sc. (Hons), 1951; M.S., California Institute, 1962

Jay C. Pyle, *Graduate Teaching Assistant, Institute Scholar, Civil Engineering*  
B.S., Agricultural and Mechanical College of Texas, 1962

Roger James Radloff, *Graduate Teaching Assistant, Institute Scholar, Biology*  
B.S., Iowa State University, 1962

James Ray Rapp, *Graduate Teaching Assistant, Bennett Scholar, Chemistry*  
A.B., Harvard College, 1960

Bernard Charles Reardon, *Graduate Teaching Assistant, Institute Scholar, Electrical Engineering*  
B.E., University College (Cork), 1957; M.S., California Institute, 1959

John Douglas Reichert, *National Science Foundation Fellow, Physics*  
B.A., University of Texas, 1961; B.S., 1961

Norman Molesworth Rice, *Woodrow Wilson Fellow, Graduate Teaching Assistant, Mathematics*  
B.Sc. (Hons), Queen's University (Ontario), 1962

Ira Richer, *National Science Foundation Fellow, Electrical Engineering*  
B.E.E., Rensselaer Polytechnic Institute, 1959; M.S., California Institute, 1960

Frank Ridolphi, *Atomic Energy Commission Fellow, Mechanical Engineering*  
B.S., California Institute, 1962

Arthur Dale Riggs, *Arthur McCallum Fellow, Graduate Teaching Assistant, Biology*  
A.B., University of California (Riverside), 1960

Thomas Charles Rindfleisch, *National Science Foundation Fellow, Physics*  
B.S., Purdue University, 1962

Peter Paul Augustine Rispin, *Graduate Teaching Assistant, Drake Scholar, Mechanical Engineering*  
B.Sc., University College (Cork), 1959; M.Sc., 1961

Harvey Lee Roberson, *Rutherford Scholar, Applied Mechanics*  
B.S., California Institute, 1948; M.S., 1949

Alan Proctor Roberts, *Institute Scholar, Immunology*  
B.A., University of New Hampshire, 1958

Harriett Anne Robillard, *Graduate Teaching Assistant, Institute Scholar, Biology*  
B.S., Jacksonville State College, 1962

Leon S. Rochester, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Physics*  
A.B., University of Chicago, 1962

Richard Dale Rocke, *Howard Hughes Fellow, Applied Mechanics*  
B.S.M.E., Bradley University, 1960; M.S., University of Southern California, 1962

David John Roddy, *Graduate Research Assistant, Institute Scholar, Geology*  
A.B., Miami University, 1955; M.S., 1957

Sergio Enrique Rodriguez, *National Science Foundation Cooperative Fellow, Chemical Engineering*  
B.S., California Institute, 1951; M.S., 1952

David Herbert Rogstad, *Graduate Teaching Assistant, Laws Scholar, Physics*  
B.S., California Institute, 1962

George Robert Root, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Electrical Engineering*  
B.S., California Institute, 1962

Allan Joseph Rosen, *National Science Foundation Fellow, Chemistry*  
A.B., Harvard College, 1959

Dana Lincoln Roth, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Chemistry*  
B.S., University of California (Los Angeles), 1962

Charles Joseph Ruger, *Graduate Teaching Assistant, Murray Scholar, Aeronautics*  
B.Ae., Polytechnic Institute of Brooklyn, 1962

Viviane Claude Rupert, *Graduate Teaching Assistant, Rutherford Scholar, Aeronautics*  
Ing.d'Aéronautique, Ecole Nationale Supérieure de l'Aéronautique (Paris), 1961; M.S., California  
Institute, 1962

John Christian Russ, *Alfred P. Sloan Foundation Fellow, Materials Science*  
B.S., California Institute, 1962

Richard Lawson Russell, *U.S. Public Health Service Trainee, Arthur McCallum Fellow,*  
*Graduate Teaching Assistant, Biology*  
A.B. (*cum laude*), Harvard College, 1962

Anil Sadgopal, *Arthur McCallum Fellow, Graduate Teaching Assistant, Institute*  
*Scholar, Biology*  
B.Sc. (Hons), University of Delhi, 1960; M.Sc., Indian Agricultural Research Institute, 1962

Jack Saltiel, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.A., Rice University, 1960

Samuel Marvin Savin, *National Science Foundation Fellow, Graduate Teaching*  
*Assistant, Geology*  
B.A., Colgate University, 1961

Stanley Arthur Sawyer, *National Defense Education Act Fellow, Graduate Teaching*  
*Assistant, Mathematics*  
B.S., California Institute, 1960

Joseph Emil Scheibe, Jr., *U.S. Public Health Service Trainee, Arthur McCallum Fellow,*  
*Graduate Teaching Assistant, Biology*  
A.B., University of California, 1960

Louis Vincent Schmidt, *Institute Scholar, Aeronautics*  
B.S., California Institute, 1946; M.S., 1948; Ae.E., 1950

Robert James Schneider, *Graduate Teaching Assistant, Royal W. Sorensen Scholar,*  
*Electrical Engineering*  
B.S., Washington University, 1961

Dwight Clare Schroeder, *U.S. Public Health Service Trainee, Civil Engineering*  
B.S., California Institute, 1950

Fred Albert Schwab, *Society of Exploration Geophysicists Fellow, Graduate Research*  
*Assistant, Geology*  
B.A. (Hons), University of California (Los Angeles), 1960

Henry Gerard Schwartz, Jr., *U.S. Public Health Service Trainee, Civil Engineering*  
B.S.C.E., Washington University, 1961; M.S., 1962

Steven Emanuel Schwarz, *Howard Hughes Fellow, Electrical Engineering*  
B.S., California Institute, 1959; A.M., Harvard College, 1960; M.S., California Institute, 1961

Richard Anthony Scott, *Graduate Teaching Assistant, Institute Scholar, Engineering*  
*Science*  
B.Sc., University College (Cork), 1957; M.Sc., 1960

William Addison Scott, *U.S. Public Health Service Trainee, Arthur McCallum Fellow,*  
*Graduate Teaching Assistant, Biology*  
B.S., University of Illinois, Biology

Philip Anthony Seeger, *Graduate Research Assistant, Institute Scholar, Physics*  
B.A., Rice University, 1958

George Andrew Seielstad, *Graduate Research Assistant, Institute Scholar, Physics*  
A.B., Dartmouth College, 1959

George August Sellers, *Graduate Teaching Assistant, Earle C. Anthony Scholar,*  
*Geology*  
B.S., The Pennsylvania State University, 1959; M.S., California Institute, 1961

Edwin Charles Seltzer, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1959

L. S. Senhouse, Jr., *Howard Hughes Fellow, Physics*  
B.M.E., College of the City of New York, 1955; M.S., University of California (Los Angeles),  
1957

**Kenneth Lee Servis**, *Graduate Teaching Assistant, Dobbins Scholar, Chemistry*  
B.S., Purdue University, 1961

**William Lewis Shackleford**, *National Science Foundation Cooperative Fellow, Engineering Science*  
B.E., Yale University, 1959; M.S., California Institute, 1960

**Usha Balvantrai Shah**, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.S., Khalsa College (Bombay), 1961

**Lawrence Fred Shampine**, *National Science Foundation Cooperative Fellow, Graduate Research Assistant, Mathematics*  
B.S., California Institute, 1961

**Wesley Loren Shanks**, *Robert A. Millikan Fellow, Graduate Research Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1960

**David H. Sharp**, *National Science Foundation Fellow, Physics*  
A.B., Princeton University, 1960

**Robert Victor Sharp**, *Graduate Teaching Assistant, Institute Scholar, Geology*  
B.S., California Institute, 1956; M.S., 1961

**Neil Rolfsen Sheeley, Jr.**, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1960

**Harvey Kenneth Shepard**, *National Science Foundation Fellow, Physics*  
B.S., University of Illinois, 1960; M.S., California Institute, 1962

**Sang Chul Shim**, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
B.S., Seoul National University, 1962

**Jon Hardy Shirley**, *Graduate Research Assistant, Institute Scholar, Physics*  
A.B., Middlebury College, 1957

**Alex Shumka**, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.A.Sc., University of Toronto, 1957; M.S., California Institute, 1958

**Harris Julian Silverstone**, *National Science Foundation Fellow, Chemistry*  
A.B., Harvard College, 1960

**George Warren Simon**, *Space Technology Laboratories Fellow, Graduate Research Assistant, Physics*  
A.B., Grinnell College, 1955; M.S., California Institute, 1961

**Boris Simpser-Dubovoy**, *Smith-Mundt Fellow, Civil Engineering*  
C.E., University of Mexico, 1961

**Robert Edmund Singleton**, *Graduate Research Assistant, R. C. Baker Foundation Scholar, Engineering Science*  
B.S., North Carolina State College, 1960; M.S., California Institute, 1962

**William Alex Sinoff**, *Graduate Research Assistant, Institute Scholar, Mathematics*  
B.S., California Institute, 1960

**Ralph Vencil Skarda, Jr.**, *Graduate Teaching Assistant, Institute Scholar, Mathematics*  
B.A., Pomona College, 1961

**Lionel Joseph Skidmore**, *Space Technology Laboratories Fellow, Electrical Engineering*  
B.S., Tulane University, 1957; M.S., 1959

**Erik Jaak Hendrik Slachmuylers**, *NATO Fellow, Aeronautics*  
B.W.E.ir,Rijksuniversiteit-Gent, 1958; Electromech.Eng., 1960; M.S., California Institute, 1961

**Michael Elmer Slater**, *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
B.S., University of California (Los Angeles), 1958; M.S., California Institute, 1961

**Morton Bruce Slater**, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Mathematics*  
B.S., The City College of New York, 1962

**Richard Kanne Sloan**, *Institute Scholar, Physics*  
B.S., The Pennsylvania State University, 1954; M.S., California Institute, 1956

Richard Franklin Smisek, *Murray Scholar, Mechanical Engineering*  
B.S., California Institute, 1957; M.S., 1958

Jay Smith III, *Garrett Corporation Scholar, Graduate Research Assistant, Applied Mechanics*  
B.S., Virginia Polytechnic Institute, 1962

Jerome Allan Smith, *National Science Foundation Fellow, Aeronautics*  
B.S.E., University of Michigan, 1962

Lewis Lofsky Smith, *Graduate Teaching Assistant, Institute Scholar, Astronomy*  
B.A., University of California, 1960; M.S., California Institute, 1961

Frank Thomas Snively, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., Antioch College, 1959; M.S., California Institute, 1961

Zoltán Géza Soos, *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*  
B.A., Harvard College, 1962

Furman Yates Sorrell, Jr., *Graduate Research Assistant, Institute Scholar, Aeronautics*  
B.S., North Carolina State College, 1960; M.S., California Institute, 1961

Edmund Eugene Spaeth, *Stauffer Chemical Company Fellow, Applied Mechanics*  
B.S., Stanford University, 1962

Frank William Spaid, *National Science Foundation Cooperative Fellow, Mechanical Engineering*  
B.S., Oregon State College, 1959; M.S., California Institute, 1961

Walter Albert Specht, Jr., *Howard Hughes Fellow, Electrical Engineering*  
B.S., California Institute, 1957

Robert John Spiger, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.S., University of Washington, 1962

Robert Edward Spitzer, *Graduate Research Assistant, Institute Scholar, Aeronautics*  
B.S., University of Illinois, 1961; M.S., 1962

William Dean Squire, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.S., California Institute, 1950; M.S., 1960

Gaetan Joseph St-Cyr, *Howard Hughes Fellow, Electrical Engineering*  
B.S., California Institute, 1962

James Henry Strauss, Jr., *U.S. Public Health Service Trainee, Arthur McCallum Fellow, Graduate Teaching Assistant, Biology*  
B.S., Saint Mary's University, 1960

Frederick William Studier, *Arthur McCallum Fellow, Biophysics*  
B.S., Yale University, 1958

Peter Rick Sumner, *National Science Foundation Fellow, Chemistry*  
B.S., Antioch College, 1961

Alexander James Sutherland, *New Zealand Universities Travelling Scholar, Graduate Research Assistant, Institute Scholar, Civil Engineering*  
B.E. (Hons), University of Auckland, 1961; M.E., 1962

Donald Gary Swanson, *Electro-Optical Systems Fellow, Graduate Research Assistant, Institute Scholar, Physics*  
B.S., University of Oregon, 1958; M.S., California Institute, 1961

Jerold Lindsay Swedlow, *Aeronautical Research Laboratories Fellow, Aeronautics*  
B.S., California Institute, 1957; M.S., Stanford University, 1960

Christopher Kwong Wah Tam, *Graduate Teaching Assistant, Earle C. Anthony Scholar, Applied Mechanics*  
B.Eng., McGill University, 1962

Ivo Tammaru, *National Science Foundation Cooperative Fellow, Graduate Teaching Assistant, Physics*  
B.S., California Institute, 1959

## 94 Graduate Appointments

Ta-liang Teng, *Graduate Research Assistant, Institute Scholar, Geology*  
B.S., National Taiwan University, 1959

Henry Archer Thiessen, *National Science Foundation Fellow, Physics*  
B.S., California Institute, 1961; M.S., 1962

Donal Diepen Thomas, *National Science Foundation Fellow, Chemistry*  
B.S., University of California, 1960

Mitchell Thomas, Jr., *Graduate Research Assistant, Institute Scholar, Engineering Science*  
B.A., Harvard College, 1958; M.S., University of Illinois, 1959

Dino Sabatino Tinti, *Graduate Teaching Assistant, Institute Scholar, Chemistry*  
B.A., University of California (Riverside), 1962

Alan Morton Title, *Graduate Teaching Assistant, Institute Scholar, Physics*  
A.B. (Hons), University of California (Los Angeles), 1959; M.S., Columbia University, 1960

M. Nafi Toksöz, *Turkish Mineral Research and Development Institute Fellow, Graduate Research Assistant, Institute Scholar, Geophysics*  
Geoph.Eng., Colorado School of Mines, 1958; M.S., California Institute, 1960

Pin Tong, *Institute Scholar, Aeronautics*  
B.S., National Taiwan University, 1960

Harry Warren Townes, *National Science Foundation Cooperative Fellow, Mechanical Engineering*  
B.S., Brown University, 1959; M.S., California Institute, 1960

Richard Ripley Tracy, *Graduate Research Assistant, Institute Scholar, Aeronautics*  
B.S., California Institute, 1952; M.S., 1957

Laurence Munro Trafton, *Graduate Teaching Assistant, Dobbins Scholar, Astronomy*  
B.S., California Institute, 1960; M.S., 1961

John Burgess Trenholme, *Graduate Research Assistant, Institute Scholar, Materials Science*  
B.S., California Institute, 1961; M.S., 1962

John Michael Trischuk, *Graduate Research Assistant, Institute Scholar, Physics*  
B.E., McGill University, 1961

Wai Keung Tso, *United States Steel Foundation Fellow, Civil Engineering*  
B.Sc. (Eng.), University of London, 1959; M.S., California Institute, 1960

Chang-chyi Tsuei, *Graduate Research Assistant, Institute Scholar, Materials Science*  
B.S., National Taiwan University, 1960

Dorothy Yung Hsun Tuan, *Arthur McCallum Fellow, Graduate Teaching Assistant, Biology*  
S.B., National Taiwan University, 1962

Eliot Francis Tucker, *U.S. Public Health Service Trainee, Civil Engineering*  
B.S., Northeastern University, 1962

Gary B. Turner, *Graduate Research Assistant, Institute Scholar, Electrical Engineering*  
B.S., California Institute, 1962

Nicholas John Turro, Jr., *National Science Foundation Fellow, Graduate Teaching Assistant, Chemistry*  
B.A., Wesleyan University, 1960

Thomas Janney Tyson, *Graduate Teaching Assistant, Dobbins Scholar, Aeronautics*  
B.S., California Institute, 1954; M.S., University of California, 1958

Harris Ellsworth Ulery, *U.S. Rubber Fellow, Chemistry*  
B.A., Grinnell College, 1959

John Clayton Urey, *U.S. Public Health Service Trainee, Arthur McCallum Fellow, Graduate Teaching Assistant, Biology*  
B.A., Swarthmore College, 1960

Donald Herman Valentine, *Graduate Teaching Assistant, Drake Scholar, Chemistry*  
B.A., Wesleyan University, 1962

Ernesto Vallerani, *Graduate Teaching Assistant, Aeronautics*  
Ing., Politecnico (Milan), 1961

Charles William Van Atta, *Institute Scholar, Aeronautics*  
B.S.E., University of Michigan, 1957; M.S.E., 1958

Dwayne Robert VanBesien, *Graduate Teaching Assistant, Blacker Scholar, Electrical Engineering*  
B.S.E.E., Bradley University, 1962

Lorin Lee Vant-Hull, *Robert A. Millikan Fellow, Graduate Research Assistant, Institute Scholar, Physics*  
B.S., University of Minnesota, 1954; M.S., University of California (Los Angeles), 1956

Larry Shelton Varnell, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., University of the South, 1961

Giulio Vitalie Samuele Venezian, *International Nickel Company Fellow, Graduate Teaching Assistant, Engineering Science*  
B.Eng.Phys., McGill University, 1960

Joseph L. Vogl, *Graduate Research Assistant, Institute Scholar, Physics*  
A.B., Columbia College, 1957; M.S., California Institute, 1959

Richard Bernard Wade, *Graduate Research Assistant, Institute Scholar, Mechanical Engineering*  
B.Sc.Eng., University of Natal, 1958; M.Sc.Eng., 1960

David John Wahl, *Institute Scholar, Electrical Engineering*  
B.S. (Hons), Washington State University, 1962

Harold Paul Waits, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.S., University of Illinois, 1959

Charles Chang-Ping Wang, *Institute Scholar, Aeronautics*  
B.S., National Taiwan University, 1959; National Tsing Hua University, 1961

Yui-Loong Wang, *Graduate Research Assistant, Chemical Engineering*  
B.S., Taiwan College of Engineering, 1956; M.S., California Institute, 1958

John Watson, *Graduate Teaching Assistant, Institute Scholar, Geology*  
B.S., University of Oklahoma, 1954; M.S., 1959; M.S., California Institute, 1961

Kenneth Watson, *Graduate Research Assistant, Institute Scholar, Geology*  
B.A., University of Toronto, 1957; M.S., California Institute, 1959

Ronald Watson, *Institute Scholar, Mechanical Engineering*  
B.S. (M.E.), Illinois Institute of Technology, 1952; M.S., California Institute, 1953

Donald Harris Webb, *Graduate Research Assistant, Institute Scholar, Physics*  
B.S., Michigan State College, 1953; M.S., University of California (Los Angeles), 1955

Nea Conder Webb, *Graduate Research Assistant, Institute Scholar, Chemistry*  
B.A., Vanderbilt University, 1959

Robert William Weinman, *National Science Foundation Fellow, Physics*  
B.E.Ph., Cornell University, 1960

Robert Avrum Weisberg, *Arthur McCallum Fellow, Institute Scholar, Virology*  
A.B., Harvard College, 1958

George McClelland Whitesides, *National Science Foundation Fellow, Chemistry*  
A.B., Harvard College, 1960

Donald Martin Wiberg, *Graduate Teaching Assistant, Institute Scholar, Mechanical Engineering*  
B.S., California Institute, 1959; M.S., 1960

Jack Milton Widholm, *U.S. Public Health Service Trainee, Arthur McCallum Fellow, Graduate Teaching Assistant, Biology*  
B.S., University of Illinois, 1961

John Fergus Wilkinson, *National Defense Education Act Fellow, Graduate Teaching Assistant, Mathematics*  
B.S., California Institute, 1961

## 96 Graduate Appointments

Richard R. Williams, *National Science Foundation Fellow, Aeronautics*  
B.S., Purdue University, 1961; M.S., California Institute, 1962

Clarence George Winterheimer, *Alfred P. Sloan Foundation Fellow, Electrical Engineering*  
B.A. (*cum laude*), Evansville College, 1957; B.S. (*magna cum laude*), 1958

Thomas Henry Wirth, *Graduate Research Assistant, Institute Scholar, Chemistry*  
A.B., Cornell University, 1959

Richard Alan Wolf, *National Science Foundation Fellow, Physics*  
B.E.Ph., Cornell University, 1962

Franklin Bruce Wolverton, *National Science Foundation Fellow, Graduate Teaching Assistant, Physics*  
B.S., University of Michigan, 1961

James Sui-Wing Wong, *Graduate Teaching Assistant, Institute Scholar, Mathematics*  
B.S., Baylor University, 1960

Po Kee Wong, *Graduate Teaching Assistant, Institute Scholar, Mechanical Engineering*  
B.Sc., Taiwan Provincial Cheng Kung University, 1956; M.Sc., University of Utah, 1961

David Eldon Wood, *National Science Foundation Fellow, Chemistry*  
B.S., Oklahoma State University, 1960; M.S., California Institute, 1961

Joe William Woodward, *National Science Foundation Cooperative Fellow, Chemical Engineering*  
B.S., Texas Agricultural and Mechanical College, 1960; M.S., California Institute, 1961

David Clark Wooten, *Alfred P. Sloan Foundation Fellow, Applied Mechanics*  
B.A., Rice University, 1960; M.S., 1962

Francis Taming Wu, *Graduate Research Assistant, Institute Scholar, Geology*  
B.S., National Taiwan University, 1959

Jain-Ming Wu, *Institute Scholar, Aeronautics*  
B.S., National Taiwan University, 1955; M.S., California Institute, 1959

Ying-Chu Lin Wu, *Amelia Earhart Fellow, Institute Scholar, Aeronautics*  
B.E., National Taiwan University, 1955; M.S., Ohio State University, 1959

James Yoh, *Graduate Teaching Assistant, Institute Scholar, Electrical Engineering*  
B.S., California Institute, 1962

Gerold Yonas, *Daniel and Florence Guggenheim Foundation Fellow, Engineering Science*  
B.E.Ph., Cornell University, 1962

Elton Theodore Young, II, *National Science Foundation Fellow, Graduate Teaching Assistant, Biology*  
B.A., University of Colorado, 1962

Clyde Stewart Zaidins, *Graduate Teaching Assistant, Institute Scholar, Physics*  
B.S., California Institute, 1961

Jonas Stasys Zmuidzinas, *Institute Scholar, Physics*  
B.S., Indiana Technical College, 1958; M.S., California Institute, 1959

Laurence Bei-yu Zung, *Graduate Research Assistant, Institute Scholar, Engineering Science*  
B.Sc., Purdue University, 1962

George Zweig, *International Business Machines Fellow, Physics*  
B.S., University of Michigan, 1959

Michael Jeffrey Yarus, *National Science Foundation Cooperative Fellow, Biology*  
B.A., Johns Hopkins University, 1960

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Mrs. James R. Page  
Mrs. I. Graham Pattinson  
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Arthur N. Prater  
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Mrs. Charles H. Prisk  
Mrs. W. F. Prisk  
William F. H. Purcell  
Simon Ramo  
Richard S. Rheem  
Will Richeson, Jr.  
Bernard J. Ridder  
Mrs. Alden G. Roach  
Harold Roach  
Mrs. Harry W. Robinson  
Albert B. Ruddock  
Mrs. Albert B. Ruddock  
Billings K. Ruddock  
Merritt K. Ruddock  
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Mrs. Howard J. Schoder  
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Mrs. W. L. Valentine  
William W. Valentine  
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Howard G. Vesper  
Harry J. Volk  
Richard R. Von Hagen  
Mrs. Gurdon W. Wattles  
Robert Welles  
Roy E. Wendahl  
J. Robert White  
R. J. Wig  
James W. Wilkie  
Leighton A. Wilkie  
Robert J. Wilkie  
Lawrence A. Williams  
P. G. Winnett  
Adrian G. Wood  
Mrs. Adrian G. Wood  
Dean E. Wooldridge  
Mrs. Archibald B. Young  
William E. Zisch

## INDUSTRIAL ASSOCIATES

The Industrial Associates was established in 1949 to provide a practical channel for communications and intellectual interchange between the scientists and engineers of industry and the faculty of the Institute. Companies with a strong research interest have been attracted by this plan. Features of the program are early distribution of research reports, special conferences, and an exchange of visits by faculty and company scientists. The membership fees make up a significant part of the unrestricted income available for the support of faculty salaries and research.

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

The membership as of September 1, 1963, was as follows:

Aerojet-General Corporation  
Aerospace Corporation  
Beckman Instruments, Inc.  
Bell & Howell Research Center  
Bell Telephone Laboratories, Inc.  
The Boeing Company  
California Research Corporation  
Campbell Soup Company  
Carnation Company  
Continental Oil Company  
Douglas Aircraft Company, Inc.  
Eastman Kodak Company  
E. I. du Pont de Nemours and Company, Inc.  
Ford Motor Company  
The Garrett Corporation  
General Dynamics Corporation  
General Electric Company  
General Motors Corporation  
Giannini Controls Corporation  
Gulf Research and Development Company  
Hercules Powder Company  
Hughes Aircraft Company  
International Business Machines Corporation

Litton Industries, Inc.  
Lockheed Aircraft Corporation  
Marathon Oil Company  
North American Aviation, Inc.  
Northrop Corporation  
Pan American Petroleum Corporation  
Phelps Dodge Corporation  
The Procter & Gamble Company  
Richfield Oil Corporation  
Shell Oil Company  
Socony Mobil Oil Company, Inc.  
Space Technology Laboratories, Inc.  
Standard Oil Company of California  
The Superior Oil Company  
Texaco Inc.  
Thompson Ramo Wooldridge Inc.  
Union Carbide Corporation  
Union Oil Company of California  
United States Steel Corporation (Columbia-Geneva Steel Division and  
Consolidated Western Steel Division)  
Westinghouse Electric Corporation

# 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 two four-year undergraduate courses, one in Engineering and the other in Science, both leading to the degree of Bachelor of Science and both planned so that interchange between them is not unduly difficult. For the first year, the work of all undergraduates is identical. Differentiation between these two courses begins with the second year. The Engineering course is of a general fundamental character, with a minimum of specialization in the separate branches of engineering. It includes an unusually thorough training in the basic sciences of physics, chemistry, and mathematics, as well as the professional subjects common to all branches of engineering. With minor exceptions, the student does not concentrate in his chosen field until the fourth year. The Engineering course also includes a large proportion of cultural studies, time for which is secured by eliminating the more narrowly particularized subjects. Such a curriculum, it is hoped, will provide a combination of the fundamental scientific training with a broad human outlook. This is, in fact, the type of collegiate education endorsed by leading engineers—a training which avoids technical narrowness on the one hand and broad superficiality on the other.

The course in Science affords, even more fully, an intensive training in physics, chemistry, and mathematics. In the third and fourth years optional studies are included which permit some measure of specialization in a chosen field of science. Instruction is also provided in French, German and Russian, with the object of giving the student a sufficient reading knowledge to follow the scientific and technical literature in those languages. The Science course includes the same proportion of cultural studies as the Engineering course, and for the same reason—to enlarge the student's mental horizon beyond the limits of his immediate professional interest and thus better qualify him to realize his opportunities and fulfill his responsibilities as a citizen and a member of his community.

The inclusion in the curriculum of a large proportion of non-scientific and

non-technical subjects is one of the fundamental elements in the Institute's educational policy. The purpose which these studies is meant to achieve has already been indicated. Under the general designation of the Humanities, they include literature and composition, history and government, economics, philosophy, and psychology. To them the student devotes about one-fourth of his time during his undergraduate years (and, if he proceeds for the degree of Master of Science he continues with elective subjects in the Humanities throughout his fifth year). Formal instruction in the Humanities is supplemented by lectures by, and opportunities for contact with, distinguished scholars who are attracted to Pasadena by the opportunities for research at the Huntington Library and Art Gallery. In addition to these academic and semi-academic pursuits, the Institute encourages a reasonable participation in student activities of a social, literary, or artistic nature, such as student publications, debating, dramatics, and music; and all undergraduates are required to take regular exercise, preferably in the form of intercollegiate or intramural sports. In short, every effort is made in the undergraduate section of the Institute to carry on a well-rounded, well-integrated program which will not only give the student sound training in his professional field but 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 any of the 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 (nearly 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 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.

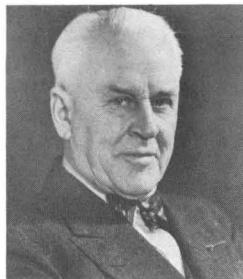
The great period of the Institute's life began, then, under the guidance of three men of vision—Hale, Noyes, and Millikan. They were distinguished research scientists, and they soon attracted graduate students. In 1920 the enrollment was 9 graduate students and 359 undergraduates under a faculty of 60; a decade later there were 138 graduate students, 510 undergraduates, and a faculty of 180. At the present time there are about 700 undergraduates, 600 graduate students, and a faculty of about 450.



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, southern Californians, who could now feel pride in the Institute as well as hope. 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.

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



CALTECH'S NOBEL LAUREATES

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

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 the laboratory finished in 1929, but courses in theoretical aerodynamics had been given at the Institute for many years by Professors Harry Bateman and P. S. Epstein. As early as 1917 Throop Institute had had a wind tunnel in which, the catalog proudly boasted, constant velocities of 4 to 40 miles an hour could be maintained, "the controls being very sensitive." The new program, under the leadership of Theodore von Kármán, included graduate study and research at the level of the other scientific work at the Institute, and GALCIT (Guggenheim Aeronautical Laboratory at 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 1942, 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 240, 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 4000 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.

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.

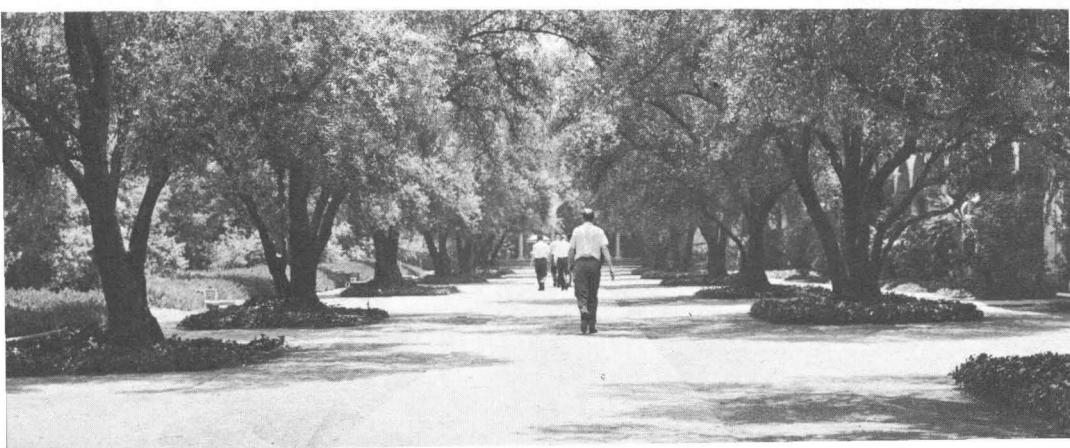
Today the Institute has 8746 alumni scattered all over the world, many eminent in their fields of engineering and science. Five of them have received Nobel prizes: Carl D. Anderson (B.S. '27, Ph.D. '30), Edwin M. McMillan (B.S. '27, M.S. '29), Linus Pauling (Ph.D. '25), William Shockley (B.S. '32) and Donald A. Glaser (Ph.D. '50).

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 over \$41,000,00 and those invested in endowment over \$54,000,000.

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 and in 1950 a new engineering building. In 1951 a cosmic ray laboratory was built and in 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. 1957 saw the completion of the Eudora Hull Spalding Laboratory of Engineering, an important addition to the facilities available for instruction and research in chemical and electrical engineering, and a new student health center, the gift of Mrs. Archibald Young in memory of her husband who was long an Institute Associate. A new radio astronomy observatory—one of the finest in the world—was completed in the Owens Valley in 1959.

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.

*Olive Walk, which bisects the campus*



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 Arnold O. Beckman Auditorium and the Willis Booth Computing Center are scheduled for completion in late 1963. Construction will begin soon on the Robert A. Millikan Memorial Library (gift of Dr. Seeley G. Mudd).

### 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 Center concentrates on research and teaching in the field of employer-employee relationships; it is guided in this program 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 economic, psychological, social, 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. The Management Development Section arranges many types of meetings for this purpose.

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. In its work the Center adheres to its basic policy of not duplicating unnecessarily the work of other schools and organizations.

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 engineering and science students of the California Institute of Technology, emphasizing the fundamentals of supervision and working with people.

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



*Throop Hall*



*Gordon A. Alles Laboratory  
for Molecular Biology*

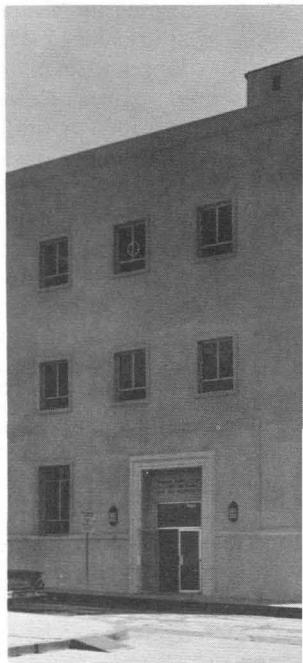


*Winnett Student Center*



*W. M. Keck  
Engineering  
Laboratories*

*Athenaeum*



*Karman Laboratory  
of Fluid Mechanics  
and Jet Propulsion*

The Center is located on the campus at 383 South Hill Avenue, but its mailing address is simply California Institute of Technology, Pasadena.

#### THE BENEFITS AND INSURANCE RESEARCH SECTION

In recognition of the growing importance of employee benefit and insurance programs in industrial relations, the Benefits and Insurance Research Section was established in 1955 as a part of the Industrial Relations Center. The Section is financed through special gifts from a large number of companies interested in supporting a program of objective research and instruction in this field. In its special area the work of the Section parallels closely the program of activities and services developed by the Industrial Relations Center.

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

#### THE MANAGEMENT DEVELOPMENT SECTION

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 expanding demand for training in the knowledge and skills required for supervision caused the establishment of the Management Development Section in 1957 as a part of the Industrial Relations Center.

This Section 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 campus or off campus, full-time or part-time, for representatives of a variety of companies or specially designed for the management of a specific company. The courses do not carry academic credit.

Detailed information about the courses, conferences, and other services available through this Section can be secured from the Management Development Section, 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, 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 interconnected 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 7090, an IBM 7040 and a Burroughs 220. The IBM 7040 functions primarily as the communication control computer and sets up problems for the IBM 7090 on a large high speed disc memory. A core memory programmed interplexor (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.

#### 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 of the Institute, 1896-1917.

HIGH VOLTAGE RESEARCH LABORATORY, 1923. Erected with funds provided by the Southern California Edison Company. Retired 1959 with basic research completed, and rebuilt in 1960 as 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, 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 of the Institute, 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. Formerly 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. Erected with funds provided by the International Education Board and the General Education Board. Following completion of the 200-inch Hale Telescope, this 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 to 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 SHOP, 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, Chairman of the Board of Trustees 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 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 Holmby Hills.

*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 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**, 1963. 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 a member 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 bookstacks throughout the libraries are open to all readers. The collections constitute strictly a working library, including subscriptions to more than 3000 periodicals.

#### OFF-CAMPUS FACILITIES

**KRESGE SEISMOLOGICAL LABORATORY**, 1928, and **DONNELLEY SEISMOLOGICAL LABORATORY**, 1957 (of the Division of the Geological Sciences), North San Rafael Avenue, Pasadena.

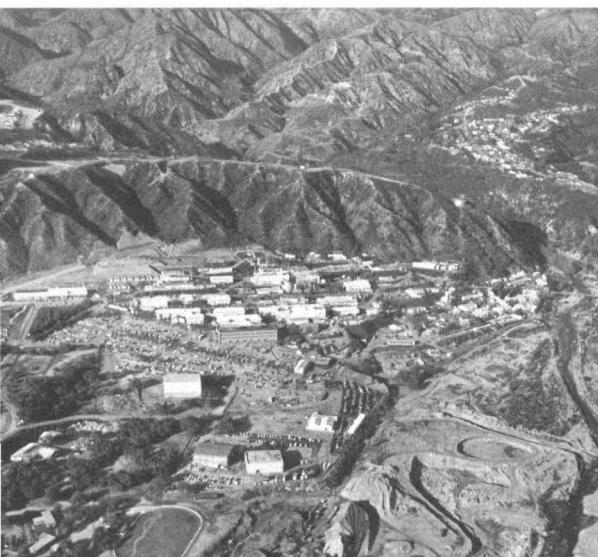
The second laboratory was the gift of Mr. and Mrs. C. Pardee Erdman of Santa Barbara, The Kresge Foundation of Detroit, Michigan, and the James Irvine Foundation of San Francisco; and named in honor of Mrs. Erdman's father, Mr. Reuben H. Donnelley.

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

JET PROPULSION LABORATORY, 4800 Oak Grove Drive, Pasadena, 1944. Owned and sponsored by the National Aeronautics and Space Administration and operated by the Institute.

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.

RADIO ASTRONOMY OBSERVATORY, near Bishop, 1958.



*The Jet Propulsion Laboratory,  
operated by Caltech for  
the National Aeronautics and  
Space Administration*



*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 or other of the two divisions according to background and interests. A special committee coordinates the program and provides overall 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 267); 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.

Details of the scholastic requirements for the Ph.D. degree in Applied Mathematics are given under Section IV, (page 222).

### ASTRONOMY

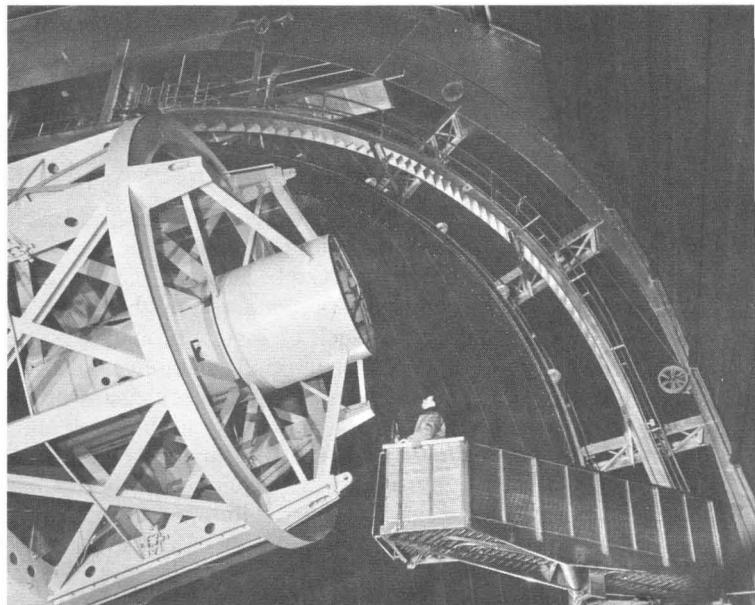
The Rockefeller Boards provided in 1928 for the construction by the Institute of an astronomical observatory on Palomar Mountain, equipped with a

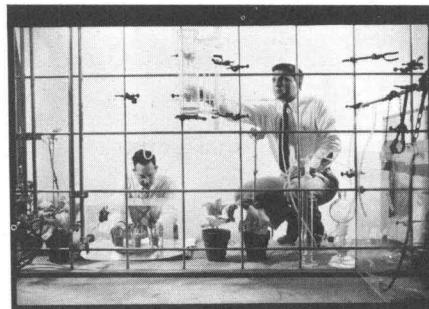
200-inch reflecting telescope, 48-inch and 18-inch Schmidt wide-angle telescopes and other auxiliary instruments, together with an astrophysical laboratory on the Institute campus. The purpose of this observatory is to supplement, not to duplicate, the facilities of the Mount Wilson Observatory of the Carnegie Institution of Washington, which, while not a part of the California Institute, is located even closer to Pasadena than is Palomar Mountain. 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 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 that 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, in which they function as a single scientific organization under the direction of Dr. I. S. Bowen, 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 in which members of the Staff of Mount Wilson Observatory join with the Institute Faculty.

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. 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, unusual 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, and astrophysics.





*Biologists produce synthetic climatic conditions for studies of greenhouse plants*

## 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 botany, zoology, microbiology and so on. 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 adviser 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, psychobiology, and virology. 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.

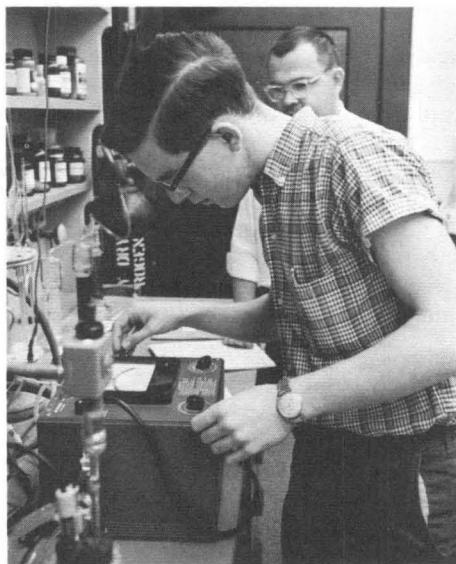
#### PHYSICAL FACILITIES

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 of 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 sea-water 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 (p. 136).



*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.

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, and the structure of liquids.

#### 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 organic compounds and a laboratory course in which fundamental manipulative techniques are acquired through the preparation of important types of pure organic compounds by useful general reactions. 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 238, whereas the Chemical Engineering Option requires professional courses which include chemical engineering thermodynamics, engineering mathematics, and introductory electronics.

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, applied mechanics, chemical engineering 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 transport*

## GRADUATE WORK

The degree of Master of Science is offered in both Chemistry and Chemical Engineering. All masters' programs at the Institute require at least 27 units of Humanities courses. In chemistry at least 40 units of research and an acceptable thesis are required; graduate courses in the student's field of interest complete the requirements. In chemical engineering there are advanced professional courses and an intensive laboratory course in engineering measurements and research methods; the remaining time is available for elective studies in either science or engineering.

Programs for study and research leading to the degree of Doctor of Philosophy are offered in the various fields of chemistry and chemical engineering and also in fields related to other scientific areas such as chemical biology, geochemistry, and chemical physics. Some of the fields of research in which members of the Divisional staff and their students are engaged are listed on pages 281 and 287-288.

## GEOLOGY

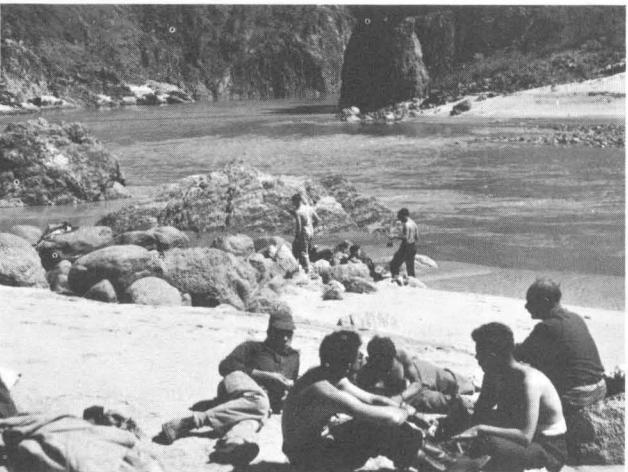
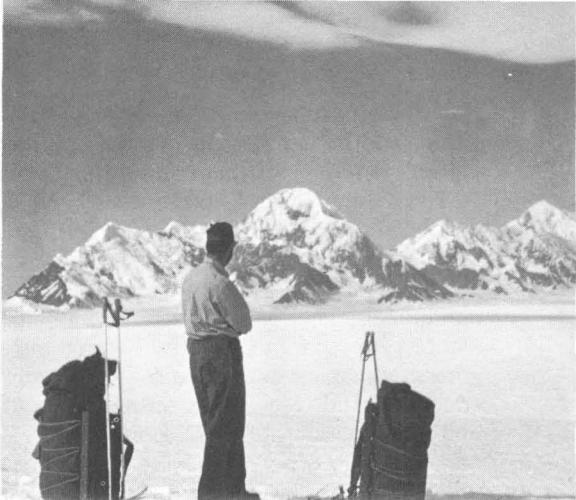
The Division of Geological Sciences is closely allied with the other active and creative fields of science and engineering at Caltech. Accordingly, a favorable intellectual atmosphere exists for education and research in geology, geobiology, geochemistry, geophysics and aspects of planetary science. 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; 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.

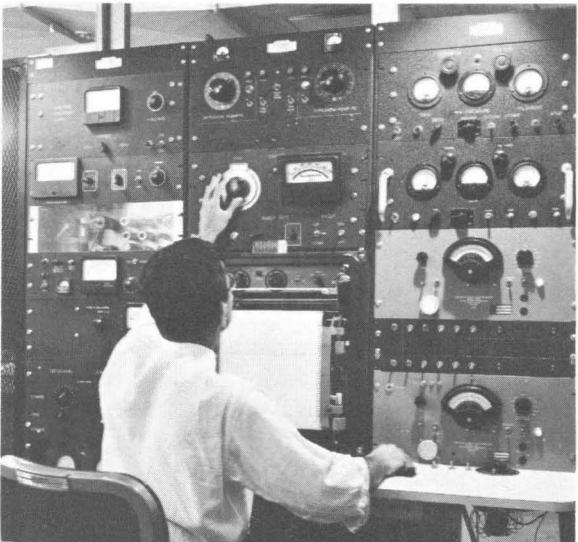
Favorable opportunity for study of dynamic aspects of paleontology and evolution as revealed by morphology, ecology, and biogeochemistry is provided by the combination of personnel, reference collections, and modern geochemical tools and techniques available here. Biologic principles and

*Field work on an Alaskan Glacier*



*Field class at the bottom of the Grand Canyon*

*Instrument panel for a mass spectrometer*



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 Mountain 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-around 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, 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

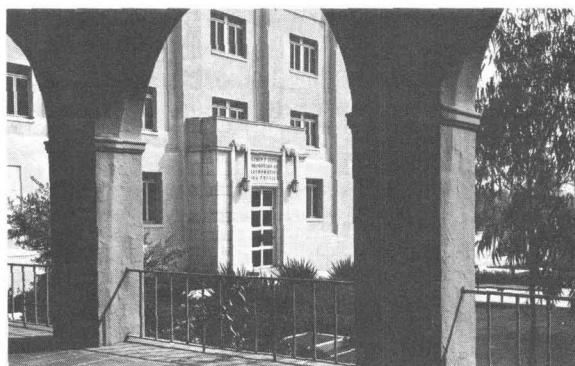
The four-year undergraduate program in mathematics leads to the degree of Bachelor of Science. The purpose of the undergraduate option is to give the student an understanding of the broad outlines of modern mathematics, to stimulate his interest in research, and to prepare him for later work, either 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 for Mathematics and Physics. Books, 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 as yet taken this course will take it as their selected course in mathematics during their junior year concurrently with

Ma 108, and will 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 in Section VI of this catalog. The courses Ma 102, 103, 104, 105, 109, 112, 116 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.

Entering graduate students are normally admitted directly to the Ph.D. program. A master's degree is awarded in exceptional cases. General requirements are listed under A and B of Section IV. The program of study for a master's degree must include 27 or more units of graduate humanities electives, at least 135 units of graduate course work in mathematics, and the submission of a thesis. The thesis requirement may be waived at the discretion of the department.

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 221-222; they give information on placement examinations, admission to candidacy and final examinations.

*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.

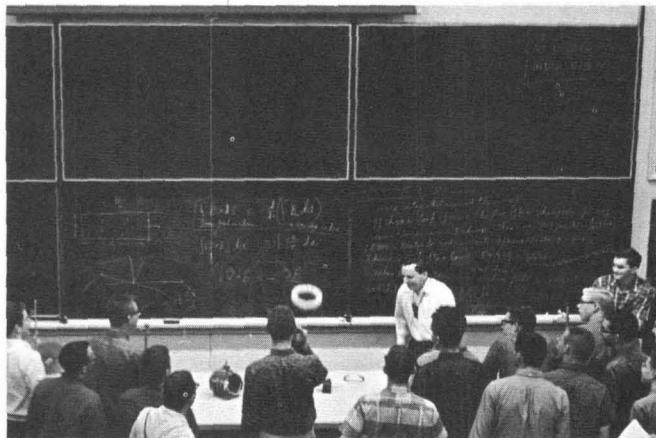
The program of a first year graduate program, in addition to the elementary seminar Ma 190, will consist as a rule of two or three 100-series courses. The student is reminded of the language requirements and of the requirements for a subject minor or a distributed minor. It is advisable for a student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

Beginning at the latest with the second year the student will be expected to begin his independent research work and 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 about any field in pure or applied mathematics and is not restricted to the immediate interests of the staff in mathematics. These include: group theory, matrix theory, lattice theory, algebraic geometry; algebraic and analytic theory of numbers; topology; and in analysis: differential equations, asymptotic expansions, special functions, theory of integration, functional analysis, mathematical problems of classical mathematical physics and applied mathematics, numerical analysis; combinatorial analysis.

A program in Applied Mathematics has been organized as a joint program of the Divisions of Mathematics, Physics, and Astronomy and the Division of Engineering and Applied Science. The course of study will lead to the Ph.D. degree and is expected to require 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 desire to major in physics take during their junior and senior years intensive courses 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 given also an opportunity to participate in some of the thirty to sixty research projects which are always under way and the graduate seminars 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 221). 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 research projects in physics. Students so employed are also expected to register for 15 or more units of research.

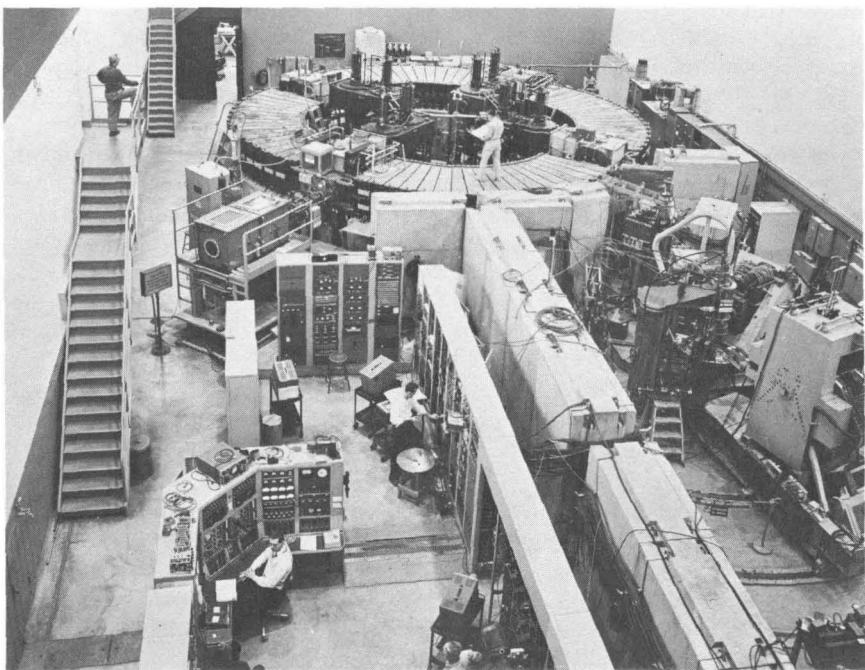
The Norman Bridge Laboratory of Physics is equipped to carry on research in most of the principal fields of physics. An addition to this laboratory has been especially constructed for the work in cosmic rays and the study of elementary particles. Special facilities for research in nuclear physics are 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 either may select his own problem in consultation with the department or may work into some 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. There is at present a continuing demand for physicists in the National Defense activities of the government, and many graduates are engaged in such work.

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 post-doctoral 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.

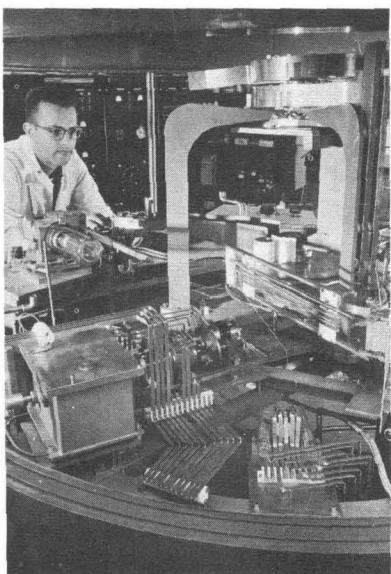
The engineering curriculum is thus extremely flexible and a student will be advised to seek breadth as well as reasonable concentration in a technical area. No one rigidly prescribed curriculum can serve the needs of all students. Nor do the traditional curricula of the specialized branches of engineering 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 in engineering exist in aeronautics, applied mechanics, chemical, civil, electrical, mechanical engineering, and materials science, with courses broadly outlined, leading to advanced degrees. An inter-divisional program in Applied Mathematics is offered as explained on page 131. 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 more specialized and advanced nature. A sixth year 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 includes those curricula and facilities which are a part of the options of Civil, Electrical, 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 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, and environmental health.



*A graduate student in mechanical engineering uses a high temperature spectrometer to study the X-ray diffraction patterns of metals*

## 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 pages 146-147). 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 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; magneto-hydrodynamics 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.
- 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 pp. 146-147 for details).

In all four of the above areas primary emphasis is placed on the underlying mathematics, physics, and chemistry and to 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.m., 10-foot diameter wind tunnel which has been in continuous service for over 30 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, 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. 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, and stress propagation. The laboratory facilities for jet propulsion and hydrodynamics are described in the sections on the Jet Propulsion Center and on Hydrodynamics starting on page 146. 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 4,000 persons, of which some 1,350 are professional engineers or scientists. The Laboratory is owned and supported by the 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," which 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.

The facilities of the Institute are available to students working towards advanced degrees, and to qualified workers who wish to carry out researches in the fields outlined above. In some cases the off-campus facilities can also be made for such purposes. A few fellowships can be granted to selected students.

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 fifth-year course. The sixth-year work, however, may be taken only by students who have completed the fifth-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 page 131)*

#### APPLIED MECHANICS

Advanced instruction and research leading to the degrees of Master of Science and Doctor of Philosophy in Applied Mechanics is offered in such subjects as Mechanical Vibrations, Structural Dynamics, Earthquake and Blast Effects on Structures, Wave Propagation in Solids, Shell Theory, Theoretical and Experimental Analysis of Stress and Strain in Real and Ideal Solids, Dynamic Instrumentation, and certain subjects in the fields of Hydrodynamics, Propulsion, Heat Transfer, and Nuclear Energy applications. In addition, certain areas of Applied Mechanics are strongly emphasized by the Graduate School of Aeronautics as described in the separate section of Aeronautics.

Research studies in these areas which will illustrate current interests include: non-linear vibrations, randomly excited mechanical systems, response of multi-degree-of-freedom systems to shock and vibration, energy dissipation in structures, dynamic structural analysis and design for earthquake and blast loads, effects of local geology and soil conditions on strong earthquake ground motion, vibrations and buckling of shells, wave propagation in bars and plates, fracture mechanics in metals and polymers, heat transfer to fluids near the critical point, hydrodynamic interactions of submicroscopic particles, and non-Newtonian behavior of dilute solutions of macromolecules. For related research activities in the areas of Aeronautics, Hydrodynamics and Jet Propulsion see the separate sections so designated.

The work for the degree of Master of Science in Applied Mechanics 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 Mathe-

matics and Physics as well as courses in other options of the Division of Engineering. Students who have completed four-year B.S. programs in undergraduate options such as Applied Mechanics, Engineering Science, Applied Physics, 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 sixth year of specialized 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, 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 well equipped with a good selection of 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 special purpose electric analog computers of both the direct and the electronic differential analyzer type are available in these laboratories. Other specialized laboratories which might be mentioned 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 of streaming birefringence.

#### CHEMICAL ENGINEERING (See pages 124-126)

#### CIVIL ENGINEERING

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

The fifth year of study at the Institute is organized to be a logical continuation of the first four years of study. The emphasis during the first four years at 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 fifth year of study involves more specialized engineering subjects but the student is not encouraged to overspecialize in one particular field of civil engineering.

Greater specialization is provided by the 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 studies, and is encouraged to elect related course work of advanced nature in the basic sciences. The engineer's 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. Research leading to a thesis is required for the engineer's degree and for the doctor's degree.

In some instances a student who has not specialized in civil engineering as an undergraduate will be admitted for graduate study in that field if he intends to pursue a program of study leading toward the Civil Engineer or Ph.D. degree. As preparation for advanced study and research, a good four-year undergraduate program in mathematics and the sciences may be substituted for a four-year undergraduate engineering course with the approval of the faculty. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his program in consultation with a member of the faculty. In some cases, the student may be required to make up deficiencies in undergraduate work. However, in every case the student will be urged to take some courses which will broaden his understanding of the overall field of civil engineering, as well as courses in his specialty. Most graduate students are also required to take further work in applied mathematics.

The general areas of civil engineering in which advanced work is offered are (1) structural engineering and applied mechanics, (2) soil mechanics and foundation engineering, (3) hydraulics: hydrodynamics, hydraulic engineering and hydrology, and (4) environmental health engineering. 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.

Excellent research facilities are available to qualified graduate students in all the fields above. 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 below. The Laboratory for Environmental Health Engineering is also located in the W. M. Keck Engineering Laboratories, and some of this work is closely integrated with the research work in hydraulics and water resources.

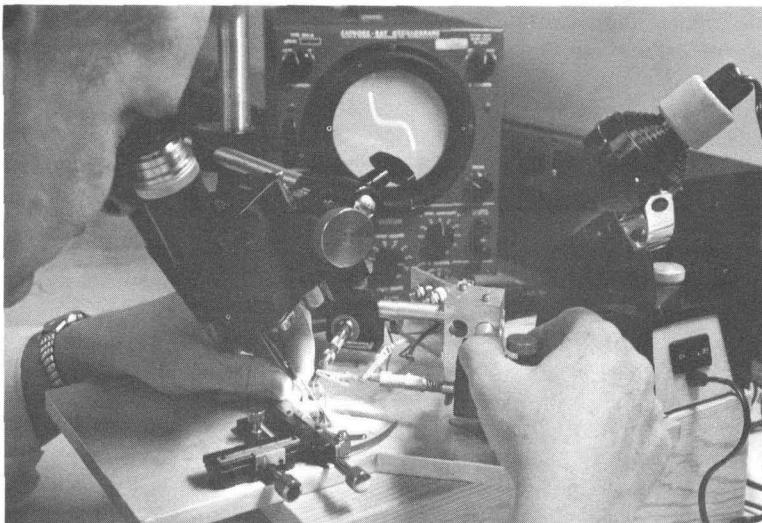
In recent years, graduate students and members of the staff have pursued a variety of research programs such as analysis of structures subjected to dynamic loadings (such as earthquakes); compaction of soil by vibration; design criteria for various hydraulic structures; investigation of laws of sediment transportation by streams and settling in sedimentation tanks; water quality criteria; and sterilization of sewage.

#### ELECTRICAL ENGINEERING

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

Electrical engineering affords opportunity for many choices of life work relating to research, design, production, operation, and management. Some phases of these activities and the commercial semi-technical phases of the electrical industry require only the preparation of the four-year course, but the better, or more normal, preparation for an electrical engineering career

requires the completion of the five-year course leading to the degree of Master of Science.



*Electrical engineer  
investigating the solid state  
physics of thin films*

Other fields of endeavor call for a knowledge of mathematics, physics and electrical engineering in excess of that obtainable in the five-year curricula. To meet this need the Institute has provided courses of graduate study and research in electrical engineering leading to the degrees of Electrical Engineer and Doctor of Philosophy. These courses provide for advanced work in the application of mathematical analysis and physical laws to mechanical and electrical problems and may be taken by a limited number of exceptional students who have completed the five-year electrical engineering course at the Institute or by students from other colleges who have substantially the same preparation.

The distinctive features of undergraduate work and graduate work in electrical engineering at the California Institute of Technology are the creative atmosphere in which the student finds himself and the large amount of physics and mathematics courses included in the engineering curricula. The graduate work in electrical engineering in particular brings graduate students into close touch with research men and current problems.

Of the several electrical engineering laboratories at the California Institute, the Computing Center, the Solid State Physics Laboratories, and the Electromagnetic Radiation Laboratory are outstanding:

The *Computing Center* (see page 113) provides comprehensive facilities for research and instruction in the development of computer systems and their

application to the solution of complex mathematical problems in engineering and science. Engineering research in this area ranges over switching theory, switching circuit instrumentation, engineering analysis and advanced programming.

The *Electromagnetic Radiation Laboratories* are devoted to theoretical and experimental studies of electromagnetic radiation phenomena. They provide 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, fundamental laser research, artificial dielectrics, and surface wave antennas. Experimental work in progress includes the generation, propagation and detection of coherent optical radiations, the study of magnetohydrodynamics, and microwave interactions with plasmas.

The *Solid State Physics Laboratories* are involved principally, but not exclusively in the understanding of thin films. Facilities are available for the making of thin films by vacuum evaporation and electrodeposition. Research now in progress concerns tunneling phenomena in thin dielectric layers and transmission characteristics of superconducting thin films. The nature of flux reversal and anisotropy in thin magnetic films is being investigated as well as the interaction between magnetic materials and microwaves. Other investigations are involved with semiconductor devices and their applications to modern electronic circuits.

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 251. The fields of study may include such topics as fluid mechanics, rheology of biological fluids, reactor physics, plasma physics, combustion and other application 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

Study for the degree of Master of Science in Materials Science ordinarily will consist of three terms of course work totaling at least 140 units. The student is allowed considerable freedom in choosing his courses. However, he should consult with one or more of the members of the Faculty Advisory Committee to ensure that he selects a sequence of courses suitable to his background and plans for future work. 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 doctorate 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.

Ample facilities are available for education and research in materials science. 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.

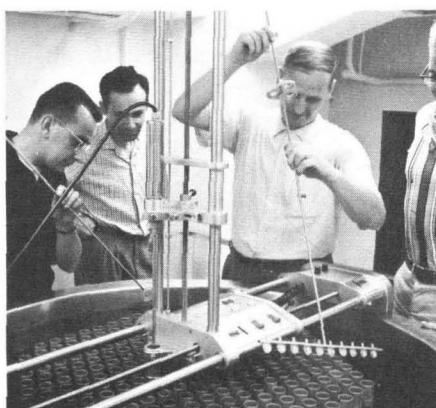
## MECHANICAL ENGINEERING

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

The general program of instruction in mechanical engineering is organized on a five-year basis in which the fifth-year schedule 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 fifth year, therefore, is somewhat more specialized, with options in general mechanical engineering, jet propulsion, physical metallurgy, or nuclear engineering. A schedule of subjects is specified for each of these fifth-year options which may be modified by petition to 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 five general areas: (1) hydrodynamics, (2) design, mechanics, and dynamics, (3) physical metallurgy and mechanics of materials, (4) thermodynamics and heat power, and (5) nuclear energy. Extensive facilities are available in hydrodynamics as described on page 139. 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. Instruction and research in materials science including physical metallurgy is carried on in the Laboratory of Engineering Materials occupying two floors of the W. M. Keck Engineering Laboratories. Extensive laboratory facilities have been developed for the study of mechanics of materials, particularly under conditions of dynamic loading,



*Determination of neutron flux distribution in a sub-critical nuclear reactor*

which are located in a special laboratory. 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.

#### JET PROPULSION

During 1948 at the California Institute of Technology, a Jet Propulsion Center was established 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 peace-time 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 peace-time 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 include 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. Particle flows in rocket nozzles, heat transfer to the electrodes of plasma accelerators, emissivities of gases at very high temperature, and unsteady flame theory represent a few of the topics that are currently under investigation.

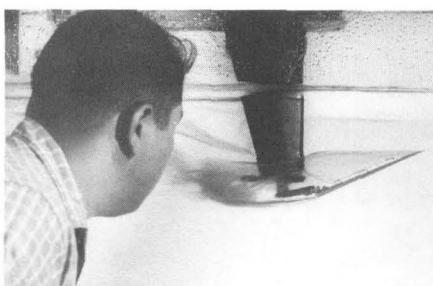
### HYDRODYNAMICS

Instruction and research in hydrodynamics and hydraulic engineering are concerned with various subjects which complement other Institute work in fluid mechanics. Current interest 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.

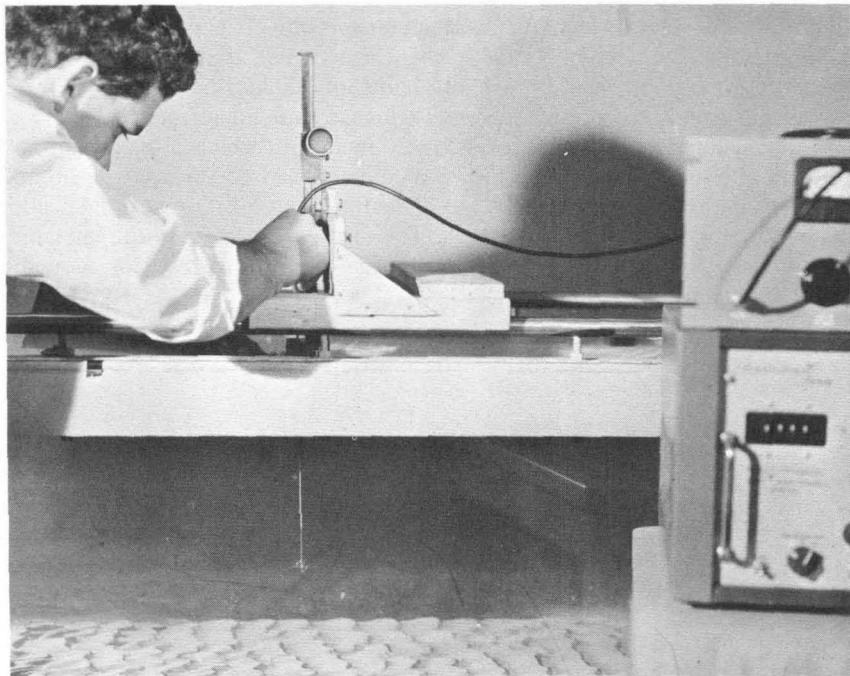
*Hydrodynamics Laboratory.* This laboratory is located in the von Karman Laboratory of Fluid Mechanics and Jet Propulsion. It contains three major experimental facilities—the high speed water tunnel, the free surface water tunnel and the controlled atmosphere launching tank. The high-speed water tunnel 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 100 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 building provides space for an expanded basic research pro-

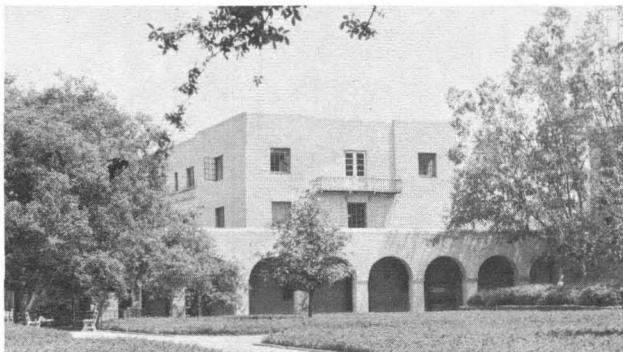


*In the Hydrodynamics Laboratory, an investigator works on a fundamental flow problem in fluid mechanics*

gram in various phases of fluid mechanics and hydraulic engineering related to development and control of water resources. The facilities include three recirculating tilting flumes for research in open channel flow and sediment transport (one is 130 feet long with cross section 43 inches wide by 24 inches deep; another is 60 feet long, and the third is 40 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; special tanks and circulation systems needed in research; and miscellaneous equipment for a variety of student laboratory experiments. Research projects are an integral part of the academic program and are carried out by the faculty, and by graduate students as thesis projects.



*Flume experiment on sediment entrainment in a growing boundary layer*



*Dabney Hall of the Humanities*

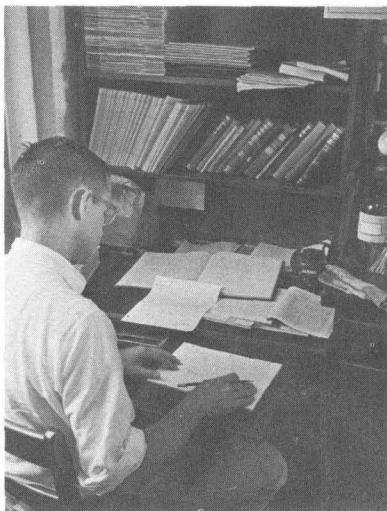
## The Humanities

One of the distinctive features of the California Institute is its emphasis upon the humanistic side of the curriculum. The faculty is in thorough sympathy with this aim and gives full support to it. Every student is required to take in each of his four undergraduate years one or more humanistic courses. These courses in the Division of the Humanities include the subjects English and foreign literatures, European and American history, philosophy and social ethics, economics (including industrial relations), and government. All of them are so planned and articulated that the student obtains a solid ground and not merely the superficial acquaintance which is too often the outcome of a free elective system. The standards of intellectual performance in these studies are maintained on the same plane as in the professional subjects.

Ample quarters for the work in humanities are provided in Dabney Hall, which was given to the Institute in 1928 by Mr. and Mrs. Joseph B. Dabney of Los Angeles as an evidence of their interest in the humanities program of the Institute and their desire to support it. Besides the usual class and lecture rooms, Dabney Hall of the Humanities contains a divisional library and reading room, offices for members of the humanities faculty, a public affairs room, and a student lounge which opens upon a walled garden of olive trees.

In connection with the acceptance of the gift of Dabney Hall, a special fund of \$400,000 for the support of instruction in the humanistic fields was subscribed by several friends of the Institute. In 1937 Mr. Edward S. Harkness gave the Institute an additional endowment fund of \$750,000 for the same purpose.

In addition to the regular staff of the Institute, scholars from other institutions give instruction or lectures in the Division of the Humanities. The proximity of the Huntington Library, with its unique opportunities for research in literature, history and economics, is assurance that the instruction given at the Institute in these fields will continue in the future, as in the past, to be strengthened by the association of visiting scholars.



## 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.

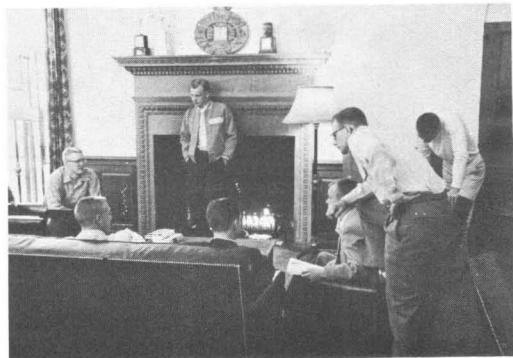
All seven Houses have their own elective officers and are given wide powers in the matter of arranging their own social events, preserving their own traditions, and in promoting the general welfare. The immediate supervision of the activities of each House is the responsibility of the House Resident 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 the 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.



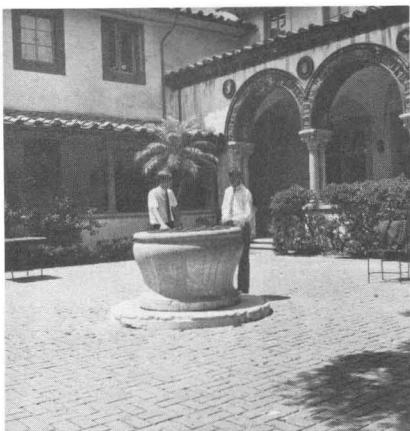
*Blacker*



*Dabney*



*Fleming*



*Ricketts*



*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 the Student Houses and commemorates his interest and effort 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 extra-curricular 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 extra-curricular 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



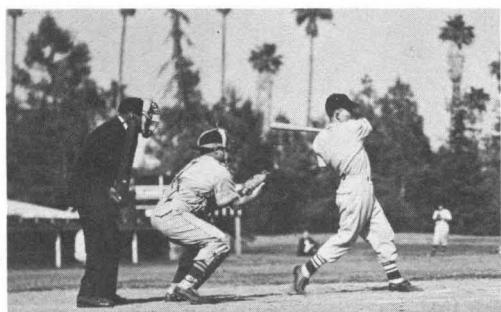
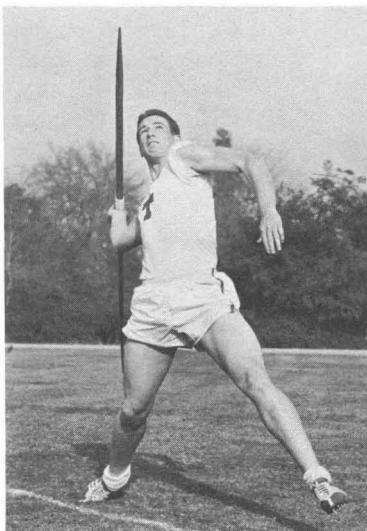
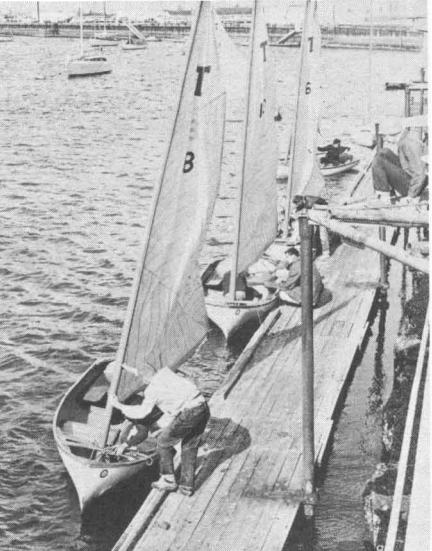
*An informal discussion  
with a distinguished visitor to the campus*

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 as to policy organization, etc., 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 with 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 twenty-three acres, includes football field, standard track, 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 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 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 was 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 inter-collegiate 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 tournament, and the annual Caltech invitational debate tournament held at the Institute. Bi-annually the Institute is represented at the National Pi Kappa Delta Speech tournament. Local activities include the annual Conger Peace Prize oration contest, and the interhouse speech contest for the Lincoln trophy. Student toastmasters' clubs, panels, and students competing for public speaking prizes of the national engineering societies are given guidance.

*Y.M.C.A.* The California Institute Y.M.C.A. 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. Friends of the Institute "Y" have provided a residence near the campus for the executive secretary, especially built to accommodate informal meetings of discussion groups.

*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, many reference books and many extra-curricular items—athletic supplies, stationery, fountain pens, etc. There is, on open shelves, an extensive collection of paper-backs and other books of general interest.

## DEPARTMENT OF AIR SCIENCE

THE Air Force Reserve Officer Training Corps (AFROTC) program at the California Institute of Technology consists of a four year integrated education and training curriculum in military Air Science, which permits the undergraduate to acquire the professional qualities and military education necessary to perform the functions of an Air Force Officer. Aerospace courses and military leadership training are conducted concurrently and compatibly with the student's normal undergraduate work. Successful completion of this curriculum results in commissioning as a Second Lieutenant in the United States Air Force upon graduation. The Institute's Department of Air Science, staffed by career Air Force officers and noncommissioned officers representing Headquarters AFROTC and Air University, is responsible for the ROTC program. This Air Force Detachment, which occupies campus facilities, is the only branch of the Armed Forces sponsored by the California Institute.

The AFROTC specialized program is divided into two major parts. The first two years of academic effort constitute a *Basic Course* (AS 1 and AS 2) designed to introduce the cadet to concepts of aerospace power, various aspects of offensive and defensive weapon systems both in atmospheric and space environments, as well as the advanced contemporary role and posture of the United States Air Force within the national defense framework. The last two years of achievement comprise an *Advanced Course* (AS 3 and AS 4), during which each junior and senior cadet, who meets specified mental, physical, and moral standards, receives tailored training with respect to the leadership and command disciplines essential to becoming an Air Force Officer. Upon entry into the final two year Advanced Course, the cadet must agree to faithfully pursue the Institute's established course of study leading to a degree, accept an Air Force Commission if tendered, and serve an active duty tour.

In addition to the academic work detailed in Section VI of this bulletin, a weekly (one hour) training period is devoted to a Leadership Laboratory which is, in effect, a proving ground for the training and evaluation of individual leadership and command attitudes and abilities. The Cadet Corps, commanded by advanced cadets and monitored by Air Force officers, forms the basis of the Leadership Laboratory. Moreover, many Corps sponsored voluntary activities augment the Leadership Laboratory. Among these are the functions of an honorary military society, rifle and drill team participation, formal dinners and military balls, as well as other Air Force ceremonies. The Department of Air Science conducts a planned program of Air Force Installation and aerospace industry visitations, orientation flying, sponsors topical lecturers, and arranges many other events which supplement and reinforce the AFROTC curriculum.

Between the junior and senior years, each cadet will attend an Air Force ROTC Summer Training Unit for a four week period. Here activities center around comprehensive junior officer training and active participation in Air Force life, work, and experiences.

For interested cadets who are qualified, an established Flight Instruction Program provides 35 hours of ground school, and 36½ hours of actual flight training to determine the student's adaptability for further pilot training. Flight instruction is conducted at a nearby Federal Aviation Authority approved civilian contract flying school at no monetary expense to the cadet.

Graduates of the Institute's AFROTC program are normally assigned to scientific, engineering, and technological positions within the Air Force structure. As a major portion of its primary mission, the USAF manages and operates a series of the world's most advanced, constantly expanding research, 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 superior in every respect, providing an extremely favorable opportunity for creative accomplishment. Physically qualified cadets have the option to apply for a program of pilot or navigator flight training. Air Force Distinguished Graduates may acquire advanced degrees as an initial military assignment with full tuition and other expenses paid by the Air Force, and receive the full pay and allowances of an officer during this graduate study period. Up to one-third of the graduating class may be designated as distinguished. 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 further graduate work on a personal basis.

The Air Force furnishes books and uniforms throughout the entire four years. Advanced cadets also receive a subsistence allowance each month during the entire calendar year. While at a Summer Training Unit the advanced cadet will receive full pay for the four weeks of duty. 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 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 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

Two applications are needed. One, for admission, is made on a form furnished by the California Institute on request, and is returned directly to the Institute together with an application fee of \$10. The other, to take examinations, may be secured by writing to the College Entrance Examination Board either in Los Angeles or Princeton (see below).

Completed admission application blanks and the \$10 application fee must reach the Admissions Office not later than February 15, 1964. (Application to take entrance examinations must be made directly to the College Board at an earlier date, for which see page 160.)

Applicants living outside of the United States must submit their credentials by November 1, 1963.

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, 1964. 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.

Arrangements to take the tests must be made by writing to the College Entrance Examination Board in advance of the closing dates and according to the instructions listed below.

#### 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 cover the principal topics of first-year algebra, intermediate algebra, trigonometry, and plane geometry, preferably including the basic notions of solid geometry. An introduction to elementary analytic geometry and the calculus is desirable but not necessary.

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, basic elementary shop work, 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 achievement tests in advanced mathematics and any two of the following: physics, chemistry, English. Note that the Scholastic Aptitude and the Advanced 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.

For admission in September, 1964 the Scholastic Aptitude Test and achievement tests must be taken no later than the January 12 College Board Test date. *It is important to note that no applicant can be considered in 1964 who has not taken the required tests by January 11, but tests taken on any prior date are acceptable.* No exception can be made to the rule that all applicants

must take these tests and no substitution of other tests for those listed above can be permitted.

Full information regarding the examinations of the College Entrance Examination Board is contained in the *Bulletin of Information* which may be obtained without charge 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 27896, Los Angeles 27, California:

|            |                     |                              |
|------------|---------------------|------------------------------|
| 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.

Each examination application submitted for registration must be accompanied by the examination fee of \$5 for the Scholastic Aptitude Test and \$7.50 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*

|                         |   |  |
|-------------------------|---|--|
| <i>To take tests on</i> | <i>In the United States,<br/>Canada, the Canal Zone,<br/>Mexico, or the West<br/>Indies, applications must<br/>be received by</i> | <i>In Europe, Asia, Africa,<br/>Central and South Ameri-<br/>ca, and Australia, applica-<br/>tions must be received by</i> |
| December 7, 1963        | November 9  | October 19   |
| January 11, 1964        | December 14   | November 23  |

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 February 15, provide further important data. Since, however, there are many more applicants to the California Institute than our facilities can accommodate, as much information as possible is desired on each candidate for admission. Wherever preliminary information shows that an applicant has a chance of gaining admission, 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 1, which is the date before which 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. 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 1, 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 August 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 Decem-

ber 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 in the schools. 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 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.* No advanced placement or credit will be given in English because the freshman course at the Institute (En 1 abc) is an advanced course of a level formerly (before 1959-60) given in the junior year.

*History.* An entering freshman may be excused from freshman history (H 1 abc: History of European Civilization) on the basis of a one-year college-level course, completed with a high mark, and a high score in the College Advanced Placement examination in that subject; units must be made up by Advanced Placement in any of the Senior Humanities Electives. He may be excused from sophomore history and government (H 2 abc: History and Government of the United States) on the same basis; units must be made up by Advanced Placement in any of the Senior Humanities Electives. (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 in addition the material of the first two terms of the sophomore year (Mathematics 2 ab). He will then take the third term sophomore work (Mathematics 2 c) in either the first or third terms of the sophomore year. In exceptional cases an entering freshman may be placed immediately in the sophomore course (Mathematics 2 abc). The special mathematics course in the freshman year is taken in place of the regular freshman Mathematics 1 abc and upon successful completion of this special course full credit is given for Mathematics 2 ab. Those who are permitted to enter immediately the sophomore Mathematics 2 abc will receive full credit for Mathematics 1 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 177.)

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 184-191. Note that there is a distinction between Honors

at Entrance and scholarship grants and that the latter are awarded on the basis of financial need as well as high standing on the entrance examinations. No one can be considered for a scholarship grant who has not sent in a scholarship form according to the instructions on page 184. In computing need the California Institute uses the figure of \$2900 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 \$400 for one academic year. The figure of \$2150 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 payment plan see pages 180-183.

#### 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 of each year. 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 Officer 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. Foreign students who will subsequently qualify for U.S. citizenship may be permitted to pursue the AFROTC program predicated upon approval by the Professor of Air Science. Entering students should indicate AFROTC on their initial pre-registration schedule card and notify the Registrar's Office of their intent.

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

The Institute admits to its upper classes (i.e., sophomore year and beyond) a limited number of able men who have made satisfactory records at other institutions of collegiate rank. 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, 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 159-162 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 159-162. 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, 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 161) to send the scores to the Institute. If the SAT has not been taken previously, it must be taken by the March 7 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 231-245) 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 page 166.

The Institute is presently making a radical revision of its basic two-year course in physics which is required of all students. The new course will be a course in Classical and Modern Physics in which the emphasis will be on modern ideas and applications, to be introduced to the student as early as possible. The revised first-year course was given for the first time in 1961-62 and 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 of 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, except that 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 24, 1964, is as follows:

|             |           |            |             |
|-------------|-----------|------------|-------------|
| Chemistry   | (3 hours) | 1:00 P.M.  | May 8, 1964 |
| English     | (1 hour ) | 9:00 A.M.  | May 9, 1964 |
| Mathematics | (2 hours) | 10:30 A.M. | May 9, 1964 |
| Physics     | (3 hours) | 2:00 P.M.  | May 9, 1964 |

No other examinations for admission to upper classes will be given in 1964.

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 172-176). In addition, they should note that to be permitted to register for any science or engineering options during their junior and senior years they must meet the scholastic requirements of the divisions concerned (see page 174).

Physical examinations, vaccination, etc. are required as in the case of students entering the freshman class (see page 164). 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 for information on which see page 165.

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

|  | <i>Registration<br/>Dates</i> | <i>Payable<br/>Fees</i> | <i>Instruction<br/>Begins</i> |
|--|-------------------------------|-------------------------|-------------------------------|
| Freshmen and Transfer Students . . . . . | Sept. 26, 1963                | Sept. 26, 1963          | Oct. 1, 1963                  |
| Upperclassmen and Graduate Students      | Sept. 30, 1963                | Sept. 30, 1963          | Oct. 1, 1963                  |

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 58 including 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 176). 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.

#### 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 be 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.

## SCHOLASTIC GRADING AND REQUIREMENTS

## SCHOLASTIC GRADING

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 173), 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.

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 class-

\*Except that C - is considered poor.

work, 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.

*Ineligibility for registration.* Any undergraduate student or Master's candidate 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

\*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.

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 175.)

(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 is ineligible to register for any term if he fails during the preceding term to remove a deficiency in physical education from an earlier term.

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 or at the Dean's discretion refer special cases 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 and may at the discretion of the Dean be required to appear. A second reinstatement will be granted only under very exceptional conditions.

*Deficiency.* Any freshman whose grade-point average during a term falls between 1.4 and 1.9 must obtain the approval of the Dean of Freshmen before registering. 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. 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 (credits divided by units) 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 schedules of undergraduate courses, for special departmental applica-

\*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.

tions 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 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 each of three classes remaining 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 1962-63 appears on page 349.

*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 199. 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 196 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 re-kindle, 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 recorded 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 achieved a grade-point average of 3.0 for all his courses in the freshman year and an average grade of 3.3 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 course and option.* Students who wish to enter one of the options in science must select their options and notify the Registrar's Office thereof shortly before the close of the freshman year. Students who wish to enter the engineering course must also notify the Registrar's Office thereof shortly before the close of the freshman year and should select some specialty in engineering.

*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.

## 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 inter-collegiate and intramural athletics, or by regular attendance at physical education classes. Men 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, (2) when they become 24 years of age, or (3) 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.

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

## STUDENT HEALTH

## 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 155. Required are smallpox vaccination, tetanus immunization and tuberculosis testing, all within six months of matriculation.

## THE DISPENSARY AND INFIRMARY

The Archibald Young Health Center is located on Arden Road, 50 feet south of California Boulevard. The services offered by the dispensary are available to graduate and undergraduate students; and faculty for emergency care and inoculations. The service offered to employees is for on-the-job injuries and inoculations. Only graduate and undergraduate students (and male employees for emergencies) are admitted to the infirmary. Ten beds are maintained and six emergency beds are available in the infirmary.

The staff consists of attending physicians, retained consultants, and nurses. A medical consultant in radiological safety is on the consulting staff. Diagnostic psychiatric and psychologic service is provided with limited treatment opportunity. Long term or cases requiring sanitarium care are referred to private outside physicians.

The infirmary is operated twenty-four hours a day, seven days a week during the academic year except during holidays (Thanksgiving, Christmas and spring recesses). The dispensary is open during the academic year from 9 a.m. to 5 p.m. Monday through Friday, and 9 a.m. to noon on Saturday. During the vacation periods, a somewhat restricted dispensary service is offered.

General office medical care is provided, minor emergency surgery is performed, and complete laboratory facilities are available at the dispensary through the Pasadena Clinical Laboratory. Close cooperation is maintained with leading specialists in all fields within Pasadena. The services of these

doctors are used freely in maintaining high standards of modern medical care. The medical services do not include optometric or dental care.

#### EMERGENCY HEALTH SERVICES

Over and above the routine medical services available to students at the Health Center, the Institute maintains and supervises a fund to assist both undergraduate and graduate students in meeting the costs of emergency medical, surgical, and hospitalization services in case of an accident or illness. The funds that allow the Institute to support this phase of its health program are derived from the Emergency Health Fund to which the following regulations appertain:

1. The sum of ten dollars of the student's tuition is annually credited to a special account. The Institute, as the custodian, invests these funds and credits the Emergency Health Fund with the income earned. The Fund will not be used for any other purpose than for the payment of the student's medical, surgical, and hospital expenses, including infirmary charges. Whether a case is one within the scope of the Fund will be decided by the Medical Director in consultation with the Health Committee.

Whenever the expenses for emergency care in any one fiscal year are less than the total deposited in the account for that year, the balance remaining shall be kept in the Fund, and shall remain invested. A balance kept over from one year will be used to render emergency medical and surgical aid to students in later years. The Fund is now stabilized at near \$20,000.

2. The Fund is not, in general, applicable to accidents, as distinguished from other emergency medical conditions, which occur away from the grounds of the Institute, unless these occur during authorized activities of the Institute.

3. Each student is insured up to \$500 in case of an accident suffered while on Institute property or while engaged in a recognized Institute activity. This coverage is provided by a policy contracted by the Institute and financed by the Emergency Health Fund.

4. The Fund does not cover conditions requiring treatment which arise during the vacation period.

5. The Fund does not cover conditions which existed at the time of admission to the Institute; nor does it cover chronic disease conditions which may develop while the student is at the Institute.

6. The Fund does not cover injuries incurred in connection with authorized intercollegiate athletics. However, the Department of Physical Education maintains two insurance plans, one for lesser and one for major expense, both for intercollegiate athletic participants.

7. The Fund does not provide for the families of graduate or undergraduate students.

8. The amount that has been allowed from the Fund for any one illness or injury is on a sliding scale up to \$325.00 maximum, but the Fund is not obli-

gated to pay this maximum, nor is there any obligation to pay for such expenses beyond the available balance of the Fund. The Health Committee reviews each case with the Medical Director and determines the amount of assistance to be granted from the Fund.

#### **ELIGIBLE EXPENSES**

1. The cost of a student's stay in the infirmary is charged to the Emergency Health Fund.
2. The costs of all medical and surgical services and hospitalization which need to be secured outside of the infirmary and dispensary are the responsibility of the student, although the Fund may help defray these costs.
3. Accidents occurring off the campus and out of the jurisdiction of the Institute (e.g., non-authorized athletics or automobile accidents) may be cared for in the infirmary but the charges will be borne by the student.
4. Medical services not falling within the purview of the Institute's health program may be obtained by students on a non-profit basis at the infirmary. A schedule of charges for cost of medicines, injections, and laboratory work is posted in the dispensary.

#### **SUMMER HEALTH COVERAGE**

All students, undergraduate and graduate, registered for summer work for academic credit are charged a health fee of \$7.50 per student. The fee makes the student eligible for (1) the benefits of the Emergency Health Fund on the same basis as during the regular academic year (Fall Registration to Spring Commencement), and (2) the extended protection of accident insurance coverage, up to \$500, over the same summer period.

The only students exempt from paying this mandatory fee are graduate students who pay regular tuition during the summer months.

During the summer vacation, graduate and undergraduate students pay a fee of \$2.00 per visit to the Health Center, plus cost of medicine and laboratory services.

#### **RESPONSIBILITY OF THE STUDENT**

The responsibility for securing adequate medical attention in any contingency, whether an 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 medical advice and attention in any case are entirely the responsibility of the student, except as specified above.

## 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) 1963-64 .....                           | \$1,575.00                       |
| General Deposit .....                                     | 25.00                            |
| Student Body Dues, including <i>California Tech</i> ..... | 22.00                            |
| Assessment for <i>Big T</i> .....                         | 6.00                             |
|   | 1,628.00                         |
| Books and Supplies (approx.) .....                        | 80.00                            |
| Student House Living Expenses (21 meals per week)         |                                  |
| Board .....   | \$560.00                         |
| Room .....  | <u>365.00<sup>1</sup></u> 925.00 |
| Dues .....  | <u>21.00</u> 946.00              |
|   | 2,654.00                         |

The following is a list of undergraduate student expenses at the California Institute of Technology for the Academic Year 1963-64, together with the dates on which the various fees are due. These charges are subject to change at the discretion of the Institute.

|                                | <i>First Term</i>                  | <i>Fee</i>          |
|--------------------------------|------------------------------------|---------------------|
| Sept. 26, 1963                 | General Breakage Deposit .....     | \$ 25.00            |
| Freshmen and transfer students | Tuition .....                      | 525.00              |
| Sept. 30, 1963                 | Board and Room .....               | 330.00 <sup>1</sup> |
| All others                     |                                    |                     |
|                                | <i>Incidental Fees:</i>            |                     |
|                                | Associated Student Body Dues ..... | \$ 7.00             |
|                                | Assessment for <i>Big T</i> .....  | 2.00                |
|                                | Student House Dues .....           | 7.00                |
|                                | <i>Second Term</i>                 |                     |
| January 6, 1964                | Tuition .....                      | 525.00              |
|                                | Board and Room .....               | 303.00 <sup>1</sup> |
|                                | <i>Incidental Fees:</i>            |                     |
|                                | Associated Student Body Dues ..... | 7.50                |
|                                | Assessment for <i>Big T</i> .....  | 2.00                |
|                                | Student House Dues .....           | 7.00                |
|                                | <i>Third Term</i>                  |                     |
| March 30, 1964                 | Tuition .....                      | 525.00              |
|                                | Board and Room .....               | 292.00 <sup>1</sup> |
|                                | <i>Incidental Fees:</i>            |                     |
|                                | Associated Student Body Dues ..... | 7.50                |
|                                | Assessment for <i>Big T</i> .....  | 2.00                |
|                                | Student House Dues .....           | 7.00                |

<sup>1</sup>There are a few large rooms available which will rent for \$425.00 per year. Rates for room and board subject to revision prior to beginning of any term upon notice to student.

Tuition Fees for fewer than normal number of units:

|                        |                                    |
|------------------------|------------------------------------|
| Over 32 units .....    | Full Tuition <sup>1</sup>          |
| 32 to 25 units .....   | \$400.00 per term                  |
| 24 to 10 units .....   | \$16.00 per unit per term          |
| Minimum per term ..... | \$160.00                           |
| Auditor's Fee (p. 162) |                                    |
|                        | \$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.<sup>2</sup> 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 150).

*Special Fees.* Students taking the Spring Field Trip in Geology (Ge 122) and the Summer Field Geology course (Ge 123) are charged for travel at an estimated rate of one cent per automobile mile, plus reasonable subsistence expense.

The fee for auditing courses (see page 171) is \$25.00 per term, per lecture hour.

*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.

<sup>1</sup>Although the Institute charges full tuition for over 32 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. See footnote page 230.

<sup>2</sup>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.

**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. 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 \$1,000.

2. Federal loans under the National Defense Education Act are available 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.

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

**Deferred Payment Plan.** In addition to loans there is available a plan under which any student in good standing may defer up to \$1000 of his college bills each year to a total of \$4000 and may pay the deferred portion in installments after his graduation. The sum of \$39.00 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. The interest payments are as follows: during freshman year \$42.82, sophomore year \$99.90, junior year \$157.00, senior year \$214.08. Commencing November 1 following his class's graduation the student commences repayment on the deferred portion at the rate of \$55 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 HONORS AND SCHOLARSHIP GRANTS

In order that appropriate awards may be made to students as they most deserve or need them, the California Institute makes a clear distinction between recognition of academic honor and achievement and recognition of need for financial assistance. This distinction is made with two types of awards: Honors at Entrance and Scholarship Grants.

## HONORS AT ENTRANCE

In recognition of distinguished academic achievement Honors at Entrance are awarded to the top ten percent of those admitted to the freshman class. They are awarded without regard to financial need, and carry no monetary grant. No application for consideration for Honors at Entrance is needed.

## FRESHMAN SCHOLARSHIP GRANTS

The recipients of scholarship grants are selected by the Freshman Admissions Committee from the candidates who have stood sufficiently high on the entrance examinations, and have otherwise 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 grants will be found on pages 186 to 191.

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 161. 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 161) 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 College Scholarships, and the Regional Scholarships described below are given without consideration of financial need. All applicants for admission are automatically considered for the Sloan and General Motors College Scholarships. Candidates for Regional Scholarships are nominated by the principals or headmasters of their schools. 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 a rank in the upper half of the class. 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 freshmen 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 SCHOLARSHIPS

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.

### 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.

**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. will in 1962 award 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 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 in 1963-64.

**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.

**Bechtel Foundation Scholarships:** The Bechtel Foundation of San Francisco provided funds for two scholarships to be awarded to juniors or seniors in engineering.

**Meridan Hunt Bennett Scholarships and Fellowships:** Mrs. Russell M. Bennett of Minneapolis, in January 1946, made a gift of approximately \$50,000 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 Scholarship Federation Scholarship: The California Institute each year awards a scholarship to a C.S.F. member who is also a seal-bearer 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.

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.

Garrett Corporation Scholarships: The Garrett Corporation of Los Ange-

les gave \$3000 for scholarships to be awarded to juniors or seniors majoring in engineering or chemical engineering, and to fifth-year students in mechanical engineering and chemical engineering.

**General Motors Corporation Scholarship:** 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. Holders 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 at the California Institute a scholarship to be awarded to a student in the junior 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.

**Graham Brothers Foundation Scholarship:** The Graham Brothers Foundation of Long Beach made possible the award of a scholarship.

**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.

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

**Walter Humphry Scholarships:** Mr. Walter Humphry established a fund the interest from which is used for undergraduate scholarships.

**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.

**Earle M. Jorgensen Scholarship:** Mr. Earle M. Jorgensen 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 totaling \$2100 a year. 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 con-

tinue 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 established a tuition scholarship to be awarded to an undergraduate student in one 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.

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 courses.

Neely Enterprises Scholarships: Neely Enterprises gave \$2000 for scholarships for sophomore students majoring in physics or engineering whose homes are in Arizona, California, Nevada or New Mexico.

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 provided for two four-year undergraduate scholarships in the amount of \$1700 a year each. These four-year awards are open to entering freshmen only.

Radio Corporation of America Scholarship: The Radio Corporation of America provided funds for an undergraduate scholarship for 1961-62 in the amount of \$800. Freshmen are not eligible for this award.

Rayonier Foundation Scholarship: The Rayonier Foundation is providing

two scholarships of \$500 each for undergraduates majoring in chemical engineering or engineering.

**Regional Prize Scholarships:** A Regional Prize Scholarship is awarded to one entering freshman student each year in each of seven regions in the United States. The scholarship carries a stipend of \$1400 for the freshman year. Regional Scholarships are an academic honor and are awarded, without regard to financial need, on the basis of high scholastic grades, high scores on the College Board Examinations required for admission, the recommendations of teachers and principals or headmasters, and on the result of a personal interview with a member of the Admissions Committee. To be eligible to compete for these scholarships an applicant must be nominated by the principal or headmaster of his school and must be attending school in one of the following regions: Region I: California; Region II: Idaho, Montana, Oregon, Washington, Wyoming; Region III: Arizona, Colorado, Nevada, New Mexico, Texas, Utah; Region IV: Illinois, Iowa, Minnesota, Missouri, Nebraska, Wisconsin; Region V: Indiana, Michigan, Ohio; Region VI: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont; Region VII: Delaware, Maryland, New Jersey, New York, Pennsylvania. Nomination forms will be sent on request to principals or headmasters of schools in these regions.

**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 \$2000 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 a scholarship for an undergraduate majoring in chemical engineering and another scholarship for an undergraduate 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 in the amount of \$1700 each year. Preference is given to a student interested in geology or chemical engineering as applied to the petroleum industry.

**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.

**Timken-Sturgis Foundation Scholarship:** The Timken-Sturgis Foundation of San Diego made possible the award of one or more undergraduate scholarships.

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. C. A. 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.

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

#### 4. STUDENT AID LOAN FUNDS

##### *Institute Loan Funds (see page 182)*

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 182-183. 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  
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 & Loan Fund—Sundry Donors

*National Defense Student Loan Program* (see page 182)

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 182-183.

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 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.

During the second and third terms, schedules are arranged for students to be interviewed by representatives of organizations who visit the campus. 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.

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.

#### 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 \$1,000 provides for a first and second prize to be awarded at a public contest and announced at Commencement. 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.

# 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; the degrees of Aeronautical Engineer, Civil Engineer, Electrical Engineer, Geological Engineer, Geophysical Engineer, and Mechanical Engineer, after a minimum of two years of graduate work; and the degree of Doctor of Philosophy.
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 225) 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 164 and 177.
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. Foreign students who are admitted to graduate standing may be required to confine their work during their first term of residence to undergraduate courses when this is necessary in order to familiarize them with American teaching methods and vernacular English.

## II. GRADUATE RESIDENCE

One term of residence shall consist of one term's work of not fewer than 45 units of advanced work in which a passing grade is recorded. If fewer than 45 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 199, 201, 205 for special requirements for residence.

Graduate students will be required to carry at least 36 units during each of their first three terms of attendance at the Institute.

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.

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 between May 15 and June 15. Students who are registered for summer research will not in general be required to pay tuition for the research units, but will be required to pay minimum tuition of \$160 if Ph.D. or engineer's degree thesis requirements are completed during the summer.

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 Registrar, and must carry the recommendation of the student's major department before submission to the Graduate Office.

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.

## III. 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 172), the grade "P," which denotes passed,

may be used at the discretion of the instructor, in the case of seminar or other work which does not lend itself to more specific grading. In graduate research, only the grades "P" and "F" are given.

#### IV. TUITION FEES

The tuition charge for all students registering for graduate work is currently \$1575 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. 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. Students desiring permission to register for fewer than 33 units should petition therefor on a blank obtained from the Registrar. If reduced registration is permitted, the tuition is at the rate of \$400 a term for 32 to 25 units, and at the rate of \$16 a unit for fewer than 25 units, with a minimum of \$160.00 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.

The tuition includes the cost of the routine medical services available to students at the Health Center, as well as the sum of ten dollars which is credited annually to the Emergency Health Fund (see page 178). A summer accident fee of \$7.50 must be paid by graduate students who register for summer work (see page 179). 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 225 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, provided that they meet the same conditions that apply to undergraduate loans.

## GRADUATE EXPENSES

|  |                     |
|--|---------------------|
| Tuition (3 terms) 1963-64 .....  | \$1,575.00          |
| General Deposit .....  | 25.00               |
| Books and Supplies (approx.) .....   | \$1,600.00<br>80.00 |
| Graduate House Living Expenses (see page 224 for details)                      |                     |
| Room—\$382.50 to \$585.00 per Academic Year                                    |                     |
| Meals—Available at the Chandler Dining Hall<br>or the Athenaeum (members only) |                     |

*First Term*

|                    |                       |        |
|--------------------|-----------------------|--------|
| September 30, 1693 | Tuition .....         | 525.00 |
|                    | General Deposit ..... | 25.00  |

*Second Term*

|                 |               |        |
|-----------------|---------------|--------|
| January 6, 1964 | Tuition ..... | 525.00 |
|-----------------|---------------|--------|

*Third Term*

|                |               |        |
|----------------|---------------|--------|
| March 30, 1964 | Tuition ..... | 525.00 |
|----------------|---------------|--------|

\*Summer Accident Insurance Fee .....

Tuition fees for fewer than normal number of units:

|                            |                                    |
|----------------------------|------------------------------------|
| Over 32 units .....        | Full Tuition <sup>1</sup>          |
| 32 to 25 units .....       | \$400.00 per term                  |
| 24 to 10 units .....       | \$16.00 per unit per term          |
| Minimum per term .....     | \$160.00                           |
| Auditor's Fee (p. 162) ... | \$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.<sup>2</sup>

## B. REGULATIONS CONCERNING WORK FOR THE DEGREE OF MASTER OF SCIENCE

### I. GENERAL REQUIREMENTS

To receive the degree of Master of Science the student must complete in a satisfactory way the work indicated in the schedule of fifth-year courses (see pages 246-260) as well as in the schedule of the four-year course in science or in engineering, except that, in the case of students transferring from other institutions, equivalents will be accepted in subjects in which the student shows by examination or otherwise that he is proficient, and except in so far as substitutions may be approved by special vote of the committee in charge.

Senior students at the Institute desiring to return for a fifth year should consult with the faculty in the field in which they expect to do their major work, and apply for admission to work towards the master's degree on a form obtained from the Dean of Graduate Studies. Such students will be

<sup>1</sup>An Accident Insurance Fee of \$7.50 will be charged to all students taking summer research.

<sup>2</sup>Although the Institute charges full tuition for 32 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.

<sup>2</sup>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.

expected to present satisfactory scholarship qualifications, and to have demonstrated a capacity for doing advanced work.

All programs of study and applications for admission to candidacy for the degree of Master of Science shall be in the charge of the Curriculum Committee; and recommendations to the Faculty for the award of the degree shall be made by this committee, all such actions being taken in general after consideration of recommendations by the department concerned.

A student before entering upon work for the degree of Master of Science should, after consultation with the department concerned, submit a plan of study, and make application to the committee in charge for acceptance as a candidate for that degree. Application forms for admission to candidacy for these degrees may be obtained from the Registrar, and must be submitted not later than the sixth week of the academic year in which the degree is to be granted.

## II. REGISTRATION

1. The regulations governing registration and student responsibilities as given for undergraduate students on pages 170-171 of the catalog apply also to students working toward the master's degree.

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

3. A student will not receive credit for a course unless he is properly registered, and at the first meeting of each class should furnish the instructor with a regular assignment card for the course, obtained on registration.

4. Students registering for more than 50 units but fewer than 63 units in any term must have the approval of their department. Registration for more than 62 units must in addition have the approval of the Dean of Graduate Studies.

5. In the case of a student registered for the degree of Master of Science and holding a position as a graduate assistant, 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.

## III. SCHOLASTIC REQUIREMENTS

1. A minimum of 140 units of graduate residence at this Institute is required for the master's degree, but specific departmental requirements often exceed this number. All or any part of this residence may be acquired prior to the completion of the work for the bachelor's degree provided a total of fifteen terms of acceptable college work equivalent to 45 units per term is completed. 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.

2. Scholastic requirements for undergraduate students (see page 172) also apply to students working toward the master's degree. In meeting the graduation requirements on page 175, the following rule will apply for master's degree candidates: only those courses shown on the candidacy blank and approved by the department representative shall be counted in

figuring the grade-point average. Students who become ineligible to register, having failed to meet the scholastic requirements stated on pages 172-174 of the catalog, may submit to the Dean of Graduate Studies a petition for reinstatement. This petition should have the endorsement of the department in which the student is registered. The Dean of Graduate Studies will pass on this petition if he concurs with the departmental recommendation; otherwise the petition will be referred to the Committee on Graduate Study for final action. Changes on the candidacy blank which are not initiated by the proper authority are not to be recognized. No course which appears on the candidacy blank and for which the candidate is registered may be removed after the last date for dropping courses as listed in the catalog.

3. Students admitted to work toward the degree of Master of Science who have completed the senior year at the Institute are subject to the same regulations as are seniors, as listed on pages 172-174.

4. Students admitted to work toward the degree of Master of Science who have completed their undergraduate work at other institutions are subject to the scholastic regulations applying to new transfer students as listed on pages 166-169.

5. 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 249.

6. 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 electric circuit theory (EE101abc), electromagnetic fields and waves (EE115abc), and engineering mathematics and complex variables (AM95abc). 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.

7. A written placement examination is required of incoming graduate students in the Division of Geological Sciences. For details see page 215. 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.

8. 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 219.

#### IV. THESIS

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. Instruc-

tions 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 195. Regulations governing registration will be found on page 203. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a new 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 196) 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 a ribbon copy, a reproduced copy, and the vellum of a satisfactory individual thesis describing his research, including a one-page digest or summary of the main results obtained. In form, the thesis must satisfy the requirements for theses for the degree of Doctor of Philosophy. (See page 206.)

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 214, except that a grade of D in Ph 131 abc is acceptable.

*Special Requirements for the Degree of Mechanical Engineer.* Each student admitted to work for the degree of Mechanical Engineer shall be required to take an oral placement examination given by the faculty in mechanical engineering before his registration. The results will be used as a guide in 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, 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 259.

## 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 207-224.

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. 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 regular courses 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. 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.*

4. 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.

5. 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 shall 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.

6. Registration, with at least minimum tuition (see page 181), is required for the term or summer period in which the requirements for the Ph.D. degree are completed, including either the final examination or submission of thesis. Registration with minimum tuition will be allowed for at most one term.

7. Graduate students studying for the doctor's degree who are devoting their whole time to their studies will be allowed to register for not more than 60 units in any one term. (See pages 199, 201 with reference to total work load of graduate students.)

#### IV. 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 207-224, under special requirements adopted by the various divisions of the Institute. The

program must be approved by both major and minor divisions on a form obtainable from the Graduate Office. The candidate will be examined on this work (see page 206). 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 196 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 initiated 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 207-224. 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 ad-

mitted 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:

- I. 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.
- II. To pass with a grade of B- or better one of the following courses: L 1 abc in French, L 35 in German, or L 51 a in Russian.
- III. 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.

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 207-224.

6. *Thesis.* Two weeks before the degree is to be conferred, the candidate is required to submit to the Dean of Graduate Studies a ribbon copy, a reproduced copy, and the vellum of a satisfactory thesis describing his research. For special departmental regulations concerning theses, see pages 207-224.

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 202.

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.*

#### V. 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 IV, page 204, 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.

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          | Neurophysiology  |
| Biophysics            | Plant Physiology |
| Cell Biology          | Psychobiology    |
| Developmental Biology | Virology         |
| Genetics              |                  |

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 Virology 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.

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. In addition to the original typed copy of the thesis, the vellum copy and two reproduced copies are to be submitted. One of the two reproduced copies is retained by 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 in the fields of inorganic chemistry and organic chemistry (on Monday), and physical chemistry (on Tuesday). In addition, an optional chemical physics examination will also be given (on Tuesday). These examinations (except for the one in chemical physics) 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 informal 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. The placement examination in chemical physics 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 beyond the physics courses normally required for the undergraduate chemistry option at this Institute.

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. A student who takes the optional placement

examination in chemical physics and fails to show satisfactory performance may be required to register for a prescribed course or courses in chemistry, physics, or mathematics.

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 Engineering.* The requirements in chemical engineering are essentially the same as those in chemistry except that the placement examinations will be required in the fields of engineering thermodynamics of one-component systems and applied chemical thermodynamics (on the Wednesday before registration), transport phenomena and the unit operations of chemical engineering (on Thursday), and either industrial chemistry (on Monday) or physical chemistry (on Tuesday). Students who have in earlier residence at this Institute demonstrated proficiency in the subjects covered by the placement examinations may be excused from them.

The Division's requirements for candidacy in chemical engineering are to be completed by the end of the student's fifth term of graduate residence at the Institute. The candidacy examination covers thermodynamics, chemical engineering unit operations, physical chemistry, and industrial chemistry.

2. It is expected that the applicant 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 of Chemistry and Chemical Engineering 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 to the Chairman of the Division of Chemistry and Chemical Engineering four copies of his thesis, in final form (the original copy, a copy on vellum, and two copies reproduced from the vellum), at least two weeks before the date of his final examination. Three copies are returned to the candidate after his examination.

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 of the Division of Chemistry and Chemical Engineering 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

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 doctorate 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:

|            |                                     |
|------------|-------------------------------------|
| 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.*** To be recommended for admission to candidacy for the Ph.D. degree in Applied Mechanics, the general Institute requirements stated on page 203 are defined specifically as follows:

- a. 12 units of research must be completed.
- b. Not less than 50 units of advanced courses in the student's major field, as arranged by the student in conference with his advisor and approved by the faculty in Applied Mechanics, must be completed. 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. An advanced course in mathematics or applied mathematics, such as AM 125 abc or Ph 129 abc, acceptable to the faculty in Applied Mathematics must be completed. Such course shall be in addition to requirement (b) above.
- d. Not less than 45 units of advanced courses, either concentrated in one discipline other than the major field or distributed among two or more disciplines other than the major field, must be completed.
- e. A three-hour oral examination on the major subject must be passed. 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 faculty in Applied Mechanics, elect a discipline in the field of Applied Mechanics 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 a list of 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 (2 to 6 pages each), and (b) a brief statement of his proposed thesis research.

To be recommended for admission to candidacy the applicant must (a) pass the qualifying examination described above, (b) submit a satisfactory written progress report on his thesis research, (c) pass the courses required for the M.S. degree, and other advanced courses as required by the staff, and (d) 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 in Civil Engineering is to broaden the student's outlook by acquainting him with subject matter outside his major field and by introducing him to different approaches to problems closely related to his field. The student may follow either a subject minor or a general minor. For a subject minor, the work must be outside the Division of Engineering. For a general minor, at least a portion of the work should preferably be outside the Division, but none of it shall include any of those courses in the fifth-year Civil Engineering schedule of courses which are usually taken by M.S. candidates in Civil Engineering. The choice of program must be approved by the student's advisor and the faculty in Civil Engineering.

**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. If his course work and research during the 5th year show that he is capable of carrying on work at the doctorate level and if he satisfactorily passes a qualifying oral examination, he may then be admitted to work towards the doctor's degree.

**Note:** For students entering with a Bachelor of Science degree, placement examinations are required (see page 200).

To be recommended for candidacy the applicant must satisfactorily complete 18 units of research in his field of interest and pass the following subject with a grade of C or better:

Ph 131 abc      Electricity and Magnetism

and one of the following subjects:

|            |                                     |
|------------|-------------------------------------|
| Ma 108 abc | Advanced Calculus                   |
| AM 125 abc | Engineering Mathematical Principles |
| Ph 129 abc | Methods of Mathematical Physics     |

An applicant may also satisfy any of the course requirements described above 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.

Students working toward the doctorate are required to take three oral examinations. The first of these, which is normally given during the fifth year, may be waived at the discretion of the faculty. The second, normally taken in the third term of the second year of graduate study, must be taken prior to admission to candidacy and covers broadly his major field and his minor program of study. The third, which is taken after admission to candidacy, covers his doctorate 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 thesis has been presented in final form and prior to its approval.

**5. Engineering Science.** The program of study leading to advanced degrees in Engineering Science must be approved by the Engineering Science Committee. To be recommended for candidacy for the Ph.D. degree in Engineering Science the student must complete at least 12 units of research and pass a comprehensive candidacy examination, in addition to the general Institute requirements. The candidate must submit a satisfactory thesis and take a final examination. The final examination will cover the thesis and fields related to it.

**6. Materials Science.** To be recommended for candidacy for the Ph.D. degree in Materials Science, the student must, in addition to the general Institute requirements:

- a. Complete 12 units of research.
- b. Complete not less than 50 units of advanced courses arranged by the student in conference with his advisor and approved by the faculty in Materials Science. 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, acceptable to the faculty in Materials Science. Such course shall be in addition to requirement (b) above.
- d. 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 faculty in Materials Science, elect a discipline in the field of Materials Science as a minor subject, consisting of a group of courses that differ markedly from the major subject of study or research.

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

- a. Complete 12 units of research.
- b. Complete not less than 50 units of advanced courses arranged by the student in conference with his advisor and approved by the faculty in Me-

chanical 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, acceptable to the faculty in Mechanical Engineering. Such course shall be in addition to requirement (b) above.
- d. 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 faculty in Mechanical Engineering, elect a discipline in the field of Mechanical Engineering as a minor subject, consisting of a group of courses that differ markedly from the major subject of study or research. Such a group may consist of fluid mechanics, thermodynamics, jet propulsion, physical metallurgy, or nuclear energy.

#### DIVISION OF GEOLOGICAL SCIENCES

The following statement summarizes the regulations governing the doctorate 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, as to 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  
Geobiology

Planetary Science

Geochemistry  
Geophysics

*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 204-205 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 if possible.

### *5. 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 107 abc, Ph 108 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 geochemi-

cal 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 strongly 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 206). An examining committee will then be appointed and a date which is mutually agreeable to those concerned will be set for the examina-

tion. 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 205, 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

### 1. MAJOR AND MINOR FIELDS

The disciplines offered by the Division in which major or minor work may be undertaken, as specified on page 204, are Astronomy, Mathematics, and Physics.

### 2. PHYSICS

*a. Placement Examinations.* On Thursday and Friday preceding the beginning of instruction for his first term of graduate study, a student admitted to work for an advanced degree in physics is required to take placement examinations to be used as a guide in selecting the proper course of study. These examinations will cover material treated in Theoretical Mechanics, Atomic and Nuclear Physics, Quantum Mechanics, and Advanced Calculus, approximately as covered in Ph 108, 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 c, 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 |                                      | <i>Units</i> |
|---------------------------|--------------------------------------|--------------|
| Ph 129                    | Methods of Mathematical Physics      | 18           |
| Ph 205                    | Principles of Quantum Mechanics      | 18           |
| Ph 209                    | Electromagnetism and Electron Theory | 27           |

GROUP II, ELECTIVE COURSES

|        |  |
|--------|--|
| Ph 131 | Electricity and Magnetism                                |
| Ph 201 | Analytical Mechanics                                     |
| Ph 203 | Nuclear Physics  |
| Ph 204 | Low Temperature 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  |
| Ay 131 | Astrophysics I<br>or<br>Ay 132 Astrophysics II           |

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 63 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 63 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 63 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 (see page 204) in Physics will be approved by the minor division if it includes Ph 112 abc and 18 units of Physics courses from Groups I and II, excluding Ph 129 ab, Ay 131 ab, Ay 132 ab, and any specified course in Physics required for the major.

### 3. 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.

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 printed copy of his completed thesis, in final form, to his supervisor. 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.

#### 4. 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 students' 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

|        |  |
|--------|--|
| Ma 105 | Introduction to Numerical Analysis         |
| Ma 109 | Operational Calculus                       |
| Ma 137 | Introduction to Lebesgue Integrals         |
| Ma 143 | Functional Analysis and Integral Equations |
| Ma 144 | Probability                                |
| AM 180 | Matrix Algebra                             |

*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           |
| AM 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 to 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.

### 5. ASTRONOMY

The Placement Examinations in Physics, page 218, Section 2a, covering the material of Ph 107, Ph 108, Ph 112, and an additional oral examination in astronomy, covering the material in Ay 2, 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 complete satisfactorily (a) 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) 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 ab, Ay 210 and Ay 211, substituting Ay 136, and 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 taken include physics, geology or engineering, dependent on the student's field of specialization.

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.

### 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, 1201 E. California, Pasadena, 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 daily from 7 A.M. to 7 P.M., serving breakfast, lunch, dinner and snacks cafeteria style.

#### 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.

#### 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 note-books 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.

#### 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.

\*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.

**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.

**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.

**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.

**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.

**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.

**Meridan Hunt Bennett Scholarships:** The scholarships for graduate students are granted from the Meridan Hunt Bennett Fund as stated on pages 177-178.

**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.

**Frederick Roeser Scholarship:** This scholarship is granted from the Frederick Roeser Loan, Scholarship, and Research Fund. The recipient is designated as the Roeser Scholar.

**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.

**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.

**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 Section.

**Lucy Mason Clark Fellowship:** This fellowship, in the field of plant physiology, is supported by a fund contributed by Miss Lucy Mason Clark.

**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.

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.

Von Kármán Scholarship Fund: Given by Dr. William Bollay for scholarships for sons or daughters of Aerophysics Development Corporation employees. The recipients are designated as von Kármán Scholars.

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 Ray G. Coates Scholar.

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.

Earle C. Anthony Scholarship: A fund has been established by Mr. Earle C. Anthony for scholarships for graduate students.

Elbert G. Richardson Scholarship and Fellowship Fund: The income of this fund is used to maintain scholarships and fellowships for graduate students.

Eben G. Rutherford Scholarship Fund: The income derived from this fund is used for graduate scholarships.

Samuel H. and Dorothy Breed Clinidinst Foundation: The income of this fund is designated for graduate scholarship aid.

#### 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:

Allied Chemical and Dye Corporation  
 R. C. Baker Foundation  
 Barry Wright Corporation  
 The Boeing Company  
 California Research Corporation  
 Consolidated Electrodynamics Corporation  
 Convair  
 Corning Glass Works Foundation  
 Douglas Aircraft Company  
 E. L. DuPont de Nemours and Company  
 Eastman Kodak Company  
 Electro-Optical Systems, Inc.  
 Fluor Foundation  
 Garrett Corporation  
 General Atomic  
 General Electric Foundation

Librascope Division of General Precision, Inc.  
 Gillette Paper-Mate Manufacturing Company  
 Hughes Aircraft Company  
 Inland Steel-Ryerson Foundation  
 International Business Machines Corporation  
 International Nickel Company, Inc.  
 Kaiser Aluminum & Chemical Corporation  
 Kennecott Copper Corporation  
 Paul E. Lloyd  
 Lockheed Leadership Fund  
 Arthur McCallum Fund  
 Mobil Oil Company  
 Pacific Scientific Company  
 Pan American Petroleum Foundation, Inc.

Radio Corporation of America  
 Rand Corporation  
 Richfield Oil Corporation  
 Schlumberger Foundation  
 Shell Companies Foundation  
 Sinclair Oil Corporation  
 Alfred P. Sloan Foundation  
 Space Technology Laboratories

Standard Oil Company of California  
 Stauffer Chemical Company  
 Stewart-Warner Corporation  
 Tektronix Foundation  
 Union Carbide Corporation  
 United States Rubber Company  
 United States Steel Foundation

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 257, and note under Engineering Science, pages 143-144.

#### 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 work. Applications 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.

#### 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 overall 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).<sup>1</sup>

Besides the subjects shown in the course schedules, students are required to take either military or physical education<sup>2</sup> in each term of the freshman and sophomore years.

### KEY TO ABBREVIATIONS

|                              |     |                              |    |
|------------------------------|-----|------------------------------|----|
| Aeronautics .....            | Ae  | English .....                | En |
| Air Science .....            | AS  | Geology .....                | Ge |
| Applied Mathematics .....    | AMa | History and Government ..... | H  |
| Applied Mechanics .....      | AM  | Hydraulics .....             | Hy |
| Astronomy .....              | Ay  | Jet Propulsion .....         | JP |
| Biology .....                | Bi  | Languages .....              | L  |
| Chemical Engineering .....   | ChE | Mathematics .....            | Ma |
| Chemistry .....              | Ch  | Mechanical Engineering ..... | ME |
| Civil Engineering .....      | CE  | Philosophy .....             | Pl |
| Economics .....              | Ec  | Physical Education .....     | PE |
| Electrical Engineering ..... | EE  | Physical Metallurgy .....    | PM |
| Engineering Graphics .....   | Gr  | Physics .....                | Ph |
| Engineering Science .....    | ES  |                              |    |

<sup>1</sup>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 ½.

<sup>2</sup>See page 177 for rule regarding excuses from physical education.

## FIRST YEAR, ALL OPTIONS

The subjects listed below are taken by all students during their first year. Differentiation into the various options begins in the second year.<sup>1</sup>

|                       |  |    | 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<br>Electric Forces (4-3-5) ..... | 12 | 12             | 12  |     |
| Ch 1 abc              | General and Quantitative Chemistry (3-6-3) .....                     | 12 | 12             | 12  |     |
| En 1 abc              | English Literature (3-0-3) .....                                     | 6  | 6              | 6   |     |
| H 1 abc               | History of European Civilization (2-0-3) .....                       | 5  | 5              | 5   |     |
| Gr 1                  | Basic Graphics (0-3-0) .....   | 3  | .              | .   |     |
| PE 1 abc <sup>2</sup> | Physical Education (0-3-0) .....                                     | 3  | 3              | 3   |     |
|                       |  | 53 | 50             | 50  |     |

## SENIOR HUMANITIES ELECTIVES

|        |   |       |  |
|--------|---|-------|--|
| PI 1   | Introduction to Philosophy                      | H 15  | Europe Since 1914                        |
| PI 2   | Logic   | H 16  | American Foreign Relations               |
| PI 3   | Contemporary European<br>Philosophies           | H 17  | The Far West and the Great<br>Plains     |
| PI 4   | Ethics  | H 19  | Modern America                           |
| PI 6   | Psychology                                      | H 21  | Medieval England                         |
| En 8   | Contemporary English and<br>European Literature | H 22  | Modern Britain                           |
| En 9   | American Literature                             | H 23  | Modern War                               |
| En 10  | Modern Drama                                    | H 25  | Political Parties and Pressure<br>Groups |
| En 11  | Literature of the Bible                         | H 26  | The Political Novel                      |
| En 18  | Modern Poetry                                   | H 28  | American Political Ideas                 |
| En 19  | Seminar in Literature                           | H 29  | American Philosophical Ideas             |
| L 5    | French Literature                               | H 30  | Individual and Society<br>in America     |
| L 40   | German Literature                               | H 31  | Making of the American<br>Republic       |
| Ec 48  | Introduction to Industrial<br>Relations         | H 35  | Modern India and Pakistan                |
| Ec 104 | Government Regulation                           | H 123 | Growth of Industrial<br>Civilization     |
| Ec 124 | Economic Problems of<br>Underdeveloped Areas    | H 124 | Seminar in Foreign Area<br>Problems      |
| Ec 125 | Technical Cooperation                           | H 125 | National Security                        |
| H 4    | The British Empire and the<br>Commonwealth      | H 150 | African Studies                          |
| H 7    | Modern and Contemporary<br>Germany              |       |  |
| H 8    | Modern and Contemporary<br>Russia               |       |  |

<sup>1</sup>Honor electives (3 units) to be given second and third terms. See page 176.

<sup>2</sup>AFROTC students will substitute AS 1 abc (0-1-1) first and third terms, (2-1-1) second term, for  
PE 1 abc.

**ASTRONOMY OPTION**  
*(For First Year see page 231)*

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 174.

| <b>SECOND YEAR</b>    |   | 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) . . . . .                               | 15-19          | 15-19     | 15-19     | 6-10 |
| PE 2 abc <sup>1</sup> | Physical Education (0-3-0) . . . . .                          | 3              | 3         | 3         |      |
|                       |   | <hr/>          | <hr/>     | <hr/>     |      |
|                       |   | 48-52          | 48-52     | 48-52     |      |

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.

| <b>THIRD YEAR</b> |  | Units per Term | 8     | 8     | 8 |
|-------------------|--|----------------|-------|-------|---|
| En 7 abc          | Advanced Literature (3-0-5) . . . . .        | 8              | 8     | 8     |   |
| Ph 109 a          | Analytical Mechanics (3-0-6) . . . . .       | 9              |       |       |   |
| Ph 114 bc         | Atomic and Nuclear Physics (3-0-6) . . . . . | . . . . .      | 9     | 9     |   |
| Ph 125 abc        | Quantum Mechanics (3-0-6) . . . . .          | 9              | 9     | 9     |   |
| Ay 2 abc          | General Astronomy (3-3-3) . . . . .          | 9              | 9     | 9     |   |
|                   | Electives (see below) . . . . .              | 6-12           | 6-12  | 6-12  |   |
|                   |  | <hr/>          | <hr/> | <hr/> |   |
|                   |  | 44-50          | 44-50 | 44-50 |   |

| <b>FOURTH YEAR</b> |   | Units per Term | 9     | 9     | 9 |
|--------------------|---|----------------|-------|-------|---|
|                    | <i>(For 1963-64 only)</i>                           |                |       |       |   |
| Ec 4 ab            | Humanities Electives <sup>2</sup> (3-0-6) . . . . . | 9              | 9     | 9     |   |
| H 5 abc            | Economic Principles and Problems (3-0-3) . . . . .  | . . . . .      | 6     | 6     |   |
| Ph 108 abc         | Public Affairs (1-0-1) . . . . .                    | 2              | 2     | 2     |   |
| Ph 112 abc         | Theoretical Mechanics (3-0-6) . . . . .             | 9              | 9     | 9     |   |
|                    | Atomic and Nuclear Physics (4-0-8) . . . . .        | 12             | 12    | 12    |   |
|                    | Electives (see below) . . . . .                     | 8-15           | 6-8   | 6-8   |   |
|                    |   | <hr/>          | <hr/> | <hr/> |   |
|                    |   | 43-50          | 47-49 | 47-49 |   |

*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  |
| ME 17 ab               | Thermodynamics (3-0-6) . . . . .                   | 9         | 9         |    |
| AM 95 abc <sup>3</sup> | Engineering Mathematics (4-0-8) . . . . .          | 12        | 12        | 12 |

|                     |  |    |    |    |
|---------------------|--|----|----|----|
| Ma 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 1 abc            | Basic Electrical Engineering (3-0-6) .....                                   | 9  | 9  | 9  |
| EE 2 ab             | Basic Electrical Engineering Laboratory (0-3-0) ...                          | .  | 3  | 3  |
| EE 101 abc          | Electric Circuit Theory (3-0-6) .....  | 9  | 9  | 9  |
| EE 106 ab           | Electronic Circuits (3-0-6) .....  | 9  | 9  | .  |
| Ph 115 ab           | Geometrical and Physical Optics (3-0-6) .....                                | 9  | 9  | .  |
| Ay 108 ab           | Astronomical Instruments and Radiation<br>Measurement (3-1-5), (3-2-4) ..... | 9  | 9  | .  |
| Ay 133 ab           | Radio Astronomy (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  |
| Ay 135 <sup>3</sup> | Topics in Modern Astronomy (3-0-6) .....                                     | .  | 9  | .  |
| Ay 136 <sup>3</sup> | Planetary Physics (3-0-6) .....  | .  | .  | 9  |
| Ay 141 abc          | Research Conference in Astronomy (1-0-1) .....                               | 2  | 2  | 2  |

<sup>1</sup>AFROTC students will substitute AS 2 abc (2-1-1) first and third terms, (0-1-1) second terms, for PE 2 abc.

<sup>2</sup>For list of Humanities electives, see page 231.

<sup>3</sup>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 231)*

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 174.

**SECOND YEAR**

|                       |   | Units per Term | 1st   | 2nd   | 3rd   |
|-----------------------|---|----------------|-------|-------|-------|
| Ma 2 abc              | Sophomore Mathematics (4-0-8) .....                       | 12             | 12    | 12    | 12    |
| Ph 2 abc              | Electricity, Fields, and Atomic Structure (4-3-5) .....   | 12             | 12    | 12    | 12    |
| H 2 abc               | History and Government of the United States (2-0-4) ..... | 6              | 6     | 6     | 6     |
| PE 2 abc <sup>1</sup> | Physical Education (0-3-0) .....                          | 3              | 3     | 3     | 3     |
|                       | Electives .....   | 19             | 19    | 19    | 19    |
|                       |   | <hr/>          | <hr/> | <hr/> | <hr/> |
|                       |   | 52             | 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 | Basic Organic Chemistry (2-0-2) .....            | 10 | 4 | 4 |
| Ch 46 ab  | Basic Organic Chemistry Laboratory (1-5-0) ..... | .  | 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 ab 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; 3-3-4; 3-5-2) ..... | 10    | 10    | 10    |
| Bi 3       | Plant Biology (3-6-3) .....              | 12    | .     | .     |
| Bi 10      | Animal Biology (3-6-3) .....             | .     | 12    | .     |
|            | Electives .....                          | 7     | 7     | 19    |
|            |  | <hr/> | <hr/> | <hr/> |
|            |  | 49    | 49    | 49    |

*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   | Embryology (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 |

## FOURTH YEAR

|                     |   | Units per Term |     |     |
|---------------------|---|----------------|-----|-----|
|                     |   | 1st            | 2nd | 3rd |
| H 5 abc             | Humanities Electives <sup>2</sup> ..... | 15             | 15  | 9   |
| Bi 118              | Public Affairs (1-0-1) .....            | 2              | 2   | 2   |
| Bi 122 <sup>3</sup> | General Physiology (3-3-4) .....        | 10             | .   | .   |
|                     | Genetics (3-3-4) .....                  | 10             | .   | .   |
|                     | Electives .....                         | 9              | 29  | 35  |
|                     |   | —              | 49  | 49  |
|                     |   |                | 49  | 49  |

*Electives*

In addition to those listed for the third year:

|            |   |      |      |   |
|------------|---|------|------|---|
| 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 | Experimental Embryology (2-0-4) .....                     | 6    | 6    | 6 |
| 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 |

Any advanced course offered by other Divisions

subject to approval by the student's advisor.

<sup>1</sup>AFROTC students will substitute AS 2 abc (2-1-1) first and third terms, (0-1-1) second term, for PE 2 abc.

<sup>2</sup>For list of Humanities electives see page 231.

<sup>3</sup>Required of Biology majors unless Bi 22 or Bi 122 has been taken earlier.

## CHEMICAL ENGINEERING OPTION

(For First Year see page 231)

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 | Basic Organic Chemistry (3-0-7; 2-0-2) .....                 | 10 | 4              | 4   |     |
| Ch 46 ab  | Basic Organic Chemistry Laboratory (1-5-0) .....             | .  | 6              | 6   |     |
| PE 2 abc  | Electives in Science and/or Engineering <sup>1,2</sup> ..... | 9  | 9              | 9   |     |
|           | Physical Education (0-3-0) <sup>3</sup> .....                | 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  |
| 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<br>(3-0-6; 2-0-4) ..... | 9  | 6  | .  |
| AM 8 c    | Mechanics of Solids I (3-0-6) .....                         | .  | .  | 9  |
| AM 95 ab  | Engineering Mathematics (4-0-8) .....                       | 12 | 12 | .  |
| EE 5      | Introductory Electronics (3-0-6) .....                      | .  | .  | 9  |
|           |   | 48 | 49 | 49 |

## FOURTH YEAR

|            |   |       |       |       |
|------------|---|-------|-------|-------|
| H 5 abc    | Humanities Electives (3-0-6) <sup>4</sup> ..... | 9     | 9     | 9     |
| AM 9 a     | Public Affairs (1-0-1) .....                    | 2     | 2     | 2     |
| ChE 61 ab  | Mechanics of Solids II (3-0-6) .....            | 9     | .     | .     |
| ChE 64     | Industrial Chemistry (3-0-6) .....              | 9     | 9     | .     |
| ChE 66 abc | Applied Chemical Thermodynamics (3-0-6) .....   | .     | .     | 9     |
| ChE 67 ab  | Chemical Engineering Operations (3-0-9) .....   | 12    | 12    | 12    |
|            | Chemical Engineering Laboratory (0-7-2) .....   | .     | 9     | 9     |
|            | Electives <sup>2,5</sup> .....                  | 6-10  | 6-10  | 6-10  |
|            |   | 47-51 | 47-51 | 47-51 |

<sup>1</sup>No more than 9 units in chemical engineering and no units in chemistry courses may be elected.

<sup>2</sup>If ChE 80 units are to be used as electives in the Chemical Engineering 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 chemical engineering electives without special permission.

<sup>3</sup>AFROTC students will substitute AS 2 abc (2-1-1) first and third terms, (0-1-1) second term, for PE 2 abc.

<sup>4</sup>For list of Humanities electives, see page 231.

<sup>5</sup>These elective units must be approved by the advisor. If Ch 41 abc and Ch 46 ab have not been taken, they must be substituted in place of these electives.

**CHEMISTRY OPTION**  
*(For First Year see page 231)*

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)*

|           |  | 1st   | Units per Term | 2nd   | 3rd   |
|-----------|--|-------|----------------|-------|-------|
| H 2 abc   | History and Government of the United States (2-0-4)          | 6     | 6              | 6     | 6     |
| Ma 2 abc  | Sophomore Mathematics (4-0-8) .....                          | 12    | 12             | 12    | 12    |
| Ph 2 abc  | Electricity, Fields, and Atomic Structure (4-3-5) .....      | 12    | 12             | 12    | 12    |
| Ch 41 abc | Basic Organic Chemistry (3-0-7; 2-0-2) .....                 | 10    | 4              | 4     | 4     |
| Ch 46 ab  | Basic Organic Chemistry Laboratory (1-5-0) .....             | .     | 6              | 6     | 6     |
| PE 2 abc  | Electives in Science and/or Engineering <sup>1,2</sup> ..... | 9     | 9              | 9     | 9     |
|           | Physical Education (0-3-0) <sup>3</sup> .....                | 3     | 3              | 3     | 3     |
|           |  | <hr/> | <hr/>          | <hr/> | <hr/> |
|           |  | 52    | 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 <sup>4</sup> (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 <sup>2,5</sup> .....                 | 8-12  | 6-10  | 6-10  |
|           |  | <hr/> | <hr/> | <hr/> |
|           |  | 47-51 | 47-51 | 47-51 |

**FOURTH YEAR**

|         |   |       |       |       |
|---------|---|-------|-------|-------|
| H 5 abc | Humanities Electives (3-0-6) <sup>6</sup> ..... | 9     | 9     | 9     |
|         | Public Affairs (1-0-1) .....                    | 2     | 2     | 2     |
|         | Electives <sup>2,7</sup> .....                  | 36-40 | 36-40 | 36-40 |
|         |   | <hr/> | <hr/> | <hr/> |
|         |   | 47-51 | 47-51 | 47-51 |

<sup>1</sup>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.

<sup>2</sup>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.

<sup>3</sup>AFROTC students will substitute AS 2 abc (2-1-1) first and third terms, (0-1-1) second term, for PE 2 abc.

<sup>4</sup>May be taken in either third or fourth year.

<sup>5</sup>In addition to approved elective courses listed on page 238 any science and engineering course will be accepted if approved by the advisor. If Ch 41 abc and Ch 46 ab have not been taken, they must be substituted in place of these electives.

<sup>6</sup>For list of Humanities electives see page 231.

<sup>7</sup>Approved elective courses listed on page 238.

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.

|            |  |  | 1st | Units per Term | 2nd | 3rd |
|------------|--|--|-----|----------------|-----|-----|
| Ch 13 abc  | Inorganic Chemistry (2-0-4) .....                                    |  | 6   | 6              | 6   |     |
| Ch 16      | Chemical Instrumentation (0-6-2) .....                               |  | 8   | .              | .   |     |
| Ch 80      | Chemical Research (units to be arranged) .....                       |  | .   | .              | .   |     |
| Ch 81      | Special Topics in Chemistry (units to be arranged) ..                |  | .   | .              | .   |     |
| 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 abc | Radioactivity and Isotopes (2-0-4) .....                             |  | 6   | 6              | 6   |     |
| 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 abc | Characterization of Organic Compounds (2-0-2) ..                     |  | 4   | 4              | 4   |     |
| Ch 149 abc | Laboratory in Characterization of Organic<br>Compounds (0-6-0) ..... |  | 6   | 6              | 6   |     |
| ChE 61 ab  | Industrial Chemistry (3-0-6) .....                                   |  | 9   | 9              | .   |     |
| Ch 63 ab   | Chemical Engineering Thermodynamics<br>(3-0-6; 2-0-4) .....          |  | 9   | 6              | .   |     |
| ChE 64     | Applied Chemical Thermodynamics (3-0-6) .....                        |  | .   | .              | 9   |     |
| ChE 65     | Economics of Chemical Technology (1-0-8) .....                       |  | .   | 9              | .   |     |
| ChE 66 abc | Chemical Engineering Operations (3-0-9) .....                        |  | 12  | 12             | 12  |     |
| ChE 68     | Introductory Chemical Engineering Kinetics (3-0-6) ..                |  | 9   | .              | .   |     |
| ChE 80     | Undergraduate Research (units to be arranged) .....                  |  | .   | .              | .   |     |
| ChE 170    | Chemical Process Dynamics (2-0-7) .....                              |  | .   | .              | 9   |     |
| Ph 107 abc | Electricity and Magnetism (3-0-6) .....                              |  | 9   | 9              | 9   |     |
| Ph 108 abc | Theoretical Mechanics (3-0-6) .....                                  |  | 9   | 9              | 9   |     |
| Ph 109     | Analytical Mechanics (3-0-6) .....                                   |  | 9   | .              | .   |     |
| Ph 111 abc | Structure of Matter (3-0-6) .....                                    |  | 9   | 9              | 9   |     |
| Ph 112 abc | Atomic and Nuclear Physics (4-0-8) .....                             |  | 12  | 12             | 12  |     |
| Ph 114 bc  | Introduction to Atomic and Nuclear Physics (3-0-6) ..                |  | .   | 9              | 9   |     |
| Ph 125 abc | Quantum Mechanics (3-0-6) .....                                      |  | 9   | 9              | 9   |     |
| Ma 108 abc | Advanced Calculus (4-0-8) .....                                      |  | 12  | 12             | 12  |     |
| AM 95 ab   | Engineering Mathematics (4-0-8) <sup>1</sup> .....                   |  | .   | .              | .   |     |
| AM 102 abc | Applied Nuclear Physics (2-0-4) .....                                |  | 6   | 6              | 6   |     |
| Bi 107 abc | Biochemistry (3-0-7; 3-3-4; 3-5-2) .....                             |  | 10  | 10             | 10  |     |
| Bi 110     | General Microbiology (3-4-5) .....                                   |  | .   | .              | 12  |     |
| Bi 127     | Biochemical Genetics (2-4-4) .....                                   |  | .   | .              | 10  |     |
| Ge 3       | Mineralogy (3-3-3) .....   |  | .   | 9              | .   |     |
| Ge 30 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 (4-0-6) .....                                      |  | 10  | .              | .   |     |

<sup>1</sup>May be taken first and second or second and third terms.

**ENGINEERING OPTION**  
*(For First Year see page 231)*

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 174.

|                          |   | <b>SECOND YEAR</b> |       |       | 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 <sup>1</sup>    | Physical Education (0-3-0) .....                          | 3                  | 3     | 3     |                |
|                          | Science or Engineering Electives .....                    | 9                  | 9     | 9     |                |
|                          | Electives <sup>2</sup> .....                              | 6-12               | 6-12  | 6-12  |                |
|                          |   | 48-54              | 48-54 | 48-54 |                |
| <b>THIRD YEAR</b>        |   |                    |       |       |                |
| En 7 abc                 | Advanced Literature (3-0-5) .....                         | 8                  | 8     | 8     |                |
| AM 95 abc                | Engineering Mathematics .....                             | or                 | 12    | 12    | 12             |
| Ma 108 abc               | Introduction to Real & Complex Analysis (4-0-8) .....     |                    |       |       |                |
|                          | Electives <sup>2</sup> .....                              | 22-28              | 22-28 | 22-28 |                |
|                          |   | 45-51              | 45-51 | 45-51 |                |
| <b>FOURTH YEAR</b>       |   |                    |       |       |                |
| H 5 abc                  | Humanities Elective <sup>3</sup> (3-0-6) .....            | 9                  | 9     | 9     |                |
| E 10 ab<br>or<br>E 11 ab | Public Affairs (1-0-1) .....                              | 2                  | 2     | 2     |                |
|                          | Technical Presentations (1-0-1) .....                     | 2                  | 2     | .     |                |
|                          | Electives <sup>2</sup> .....                              | 29-35              | 29-35 | 29-35 |                |
|                          |   | 45-51              | 45-51 | 43-49 |                |

<sup>1</sup>AFROTC students will substitute AS 2 abc (2-1-1) first and third terms, (0-1-1) second term, for PE 2 abc.

<sup>2</sup>The electives must include Ec 4 ab and at least 99 units of Engineering Division courses (Ae, AM, CE, EE, Cr, Hy, JP, ME, PM) 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 7, 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.

<sup>3</sup>For list of Humanities electives, see page 231.

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.

**GEOLOGICAL SCIENCES OPTION**  
*(For First Year see page 231)*

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.

|                       |   | <b>SECOND YEAR</b> | 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 <sup>1</sup> | Physical Education (0-3-0) .....                          |                    | 3              | 3     | 3     |
|                       | Electives (see suggested Electives listed below)* ...     |                    | 10             | 9     | 18    |
|                       |   |                    | <hr/>          | <hr/> | <hr/> |
|                       |   |                    | 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.

|       |                                     |    |   |   |
|-------|-------------------------------------|----|---|---|
| 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 | Basic Organic Chemistry (3-0-7; 2-0-2) .....     | 10    | 4     | 4     |
| Ch 46 ab  | Basic Organic Chemistry Laboratory (1-5-0) ..... | .     | 6     | 6     |
|           |  | <hr/> | <hr/> | <hr/> |
|           |  | 52    | 52    | 52    |

<sup>1</sup>AFROTC students will substitute AS 2 abc (2-1-1) first and third terms, (0-1-1) second term, 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) ....   | .     | .     | 12    |
| Ch 24 ab | Physical Chemistry for Geologists (4-0-6) .....      | 10    | 10    | .     |
|          | Electives (select from Electives listed below) ..... | 9     | 9     | 9     |
|          |  | <hr/> | <hr/> | <hr/> |
|          |  | 49    | 49    | 49    |

*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) ....         | .     | .     | 12    |
| 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    |
|           |  | <hr/> | <hr/> | <hr/> |
|           |  | 49    | 49    | 49    |

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, 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 107 abc | Electricity and Magnetism (3-0-6) .....              | 9     | 9     | 9     |
|            | Electives (select from Electives listed below) ..... | 17    | 17    | 17    |
|            |  | <hr/> | <hr/> | <hr/> |
|            |  | 47    | 47    | 47    |

Add electives to bring unit load up to a minimum of 47 units but not to exceed the allowable limit, selected with the advice and consent of the advisor from the following courses for which prerequisites have been completed. Any Ge course, Ay 1, AM 95 abc, Ch 21 abc, EE 160, EE 140, Ma 108 abc, Ph 108 abc. Special attention is called to the opportunity to take L 32 abc or L 50 abc. Ec 4 ab must be elected by or before the fourth year.

**FOURTH YEAR***Common to All Options in the Division*

|                            |                                   |    |    |    |
|----------------------------|-----------------------------------|----|----|----|
| L 32 abc<br>or<br>L 50 abc | Elementary German (4-0-6) .....   | 10 | 10 | 10 |
| H 5 abc                    | Elementary Russian                |    |    |    |
| Ge 102                     | Public Affairs (1-0-1) .....      | 2  | 2  | 2  |
| Ge 100                     | Oral Presentation (1-0-1) .....   | 2  | .  | .  |
|                            | Geology Club (1-0-0) .....        | 1  | 1  | 1  |
|                            | Humanities Elective (3-0-6) ..... | 9  | 9  | 9  |

(Elect from selection listed on page 231)

*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*

|          |   |    |    |    |
|----------|---|----|----|----|
| Ch 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 abc, Ch 127 ab, Ch 129, and Ge 151 a. |    |    |    |

48   48   48*Geophysics Option*

|            |   |      |      |      |
|------------|---|------|------|------|
| Ph 108 abc | Theoretical Mechanics (3-0-6) .....   | 9    | 9    | 9    |
|            | Geology Electives .....   | 7-10 | 7-10 | 7-10 |
|            | General Electives .....   | .    | .    | .    |
|            | Add other electives in Physics, Mathematics, Chemistry, Astronomy, or Engineering to bring unit load to a minimum of 42 units, but not to exceed the allowable limit. Elective courses must be approved by the student's advisor. |      |      |      |

42-47   42-47   42-47

**MATHEMATICS OPTION**  
*(For First Year see page 231)*

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 174.

|                       |  | <b>SECOND YEAR</b> |             |             |
|-----------------------|--|--------------------|-------------|-------------|
|                       |  | 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<br>of Mathematics .....   | 9                  | 9           | 9           |
| PE 2 abc <sup>1</sup> | Physical Education (0-3-0) .....   | 3                  | 3           | 3           |
|                       |  | <hr/> 51           | <hr/> 51    | <hr/> 51    |
|                       |  | <b>THIRD YEAR</b>  |             |             |
| En 7 abc              | Advanced Literature (3-0-5) .....  | 8                  | 8           | 8           |
| Ec 4 ab               | Economic Principles and Problems or a selected<br>course in the Humanities <sup>2</sup> (can be taken in senior<br>year) ..... | Minimum<br>6       | 6           | .           |
| Ma 108 abc            | Advanced Calculus (4-0-8) .....  | 12                 | 12          | 12          |
|                       | Selected courses in Mathematics .....  | Minimum<br>9       | 9           | 9           |
|                       | Electives <sup>3</sup> .....   | Minimum<br>6       | 6           | 6           |
|                       | For each term the total number of units is required to<br>fall within range .....  | <hr/> 44-49        | <hr/> 44-49 | <hr/> 44-49 |
|                       |  | <hr/> 44-49        | <hr/> 44-49 | <hr/> 44-49 |
|                       |  | <b>FOURTH YEAR</b> |             |             |
| H 5 abc               | Public Affairs (1-0-1) .....   | 2                  | 2           | 2           |
| Ec 4 ab               | Economic Principles and Problems or a selected<br>course in the Humanities <sup>2</sup> (if not taken in junior<br>year) ..... | Minimum<br>6       | 6           | .           |
|                       | Selected courses in Mathematics .....  | Minimum<br>9       | 9           | 9           |
|                       | Selected courses in the Humanities <sup>2</sup> .....  | Minimum<br>9       | 9           | 9           |
|                       | Electives <sup>3</sup> .....   | Minimum<br>5       | 5           | 5           |
|                       | For each term the total number of units is required to<br>fall within range .....  | <hr/> 38-48        | <hr/> 38-48 | <hr/> 38-48 |

Normally a junior will select 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.

<sup>1</sup>AFROTC students will substitute AS 2 abc (2-1-1) first and third terms, (0-1-1) second term, for PE 2 abc.

<sup>2</sup>For list of electives in the Humanities, see page 231.

<sup>3</sup>An elective is any course in any subject other than Mathematics.

**PHYSICS OPTION**  
*(For First Year see page 231)*

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 174.

**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     |
| PE 2 abc <sup>2</sup> | Electives <sup>1</sup> . . . . .                              | 15-19          | 15-19 | 15-19 |
|                       | Physical Education (0-3-0) . . . . .                          | 3              | 3     | 3     |
|                       |   | <hr/>          | <hr/> | <hr/> |
|                       |   | 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.

|           |  |      |      |    |
|-----------|--|------|------|----|
| 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 | Basic Organic Chemistry (2-0-2) . . . . .            | 4    | 4    | 4  |
| Ch 46 abc | Basic Organic Chemistry Laboratory (1-5-0) . . . . . | 6    | 6    | 6  |
| ChE 50    | Applications of Chemistry (3-0-6) . . . . .          | .    | 9    | .  |
| L 32 abc  | Elementary German (4-0-6) . . . . .                  | 10   | 10   | 10 |

**THIRD YEAR**

|            |  |       |       |       |
|------------|--|-------|-------|-------|
| Ph 109     | Analytical Mechanics . . . . .                       | 9     | .     | .     |
| Ph 114 ab  | Introduction to Atomic and Nuclear Physics . . . . . | .     | 9     | 9     |
| Ph 125 abc | Quantum Mechanics . . . . .                          | 9     | 9     | 9     |
| En 7 abc   | Advanced Literature (3-0-5) . . . . .                | 8     | 8     | 8     |
|            | Electives <sup>3</sup> . . . . .                     | 15-21 | 15-21 | 15-21 |
|            |  | <hr/> | <hr/> | <hr/> |
|            |  | 44-48 | 44-48 | 44-48 |

*Suggested Electives*

|            |   |    |    |    |
|------------|---|----|----|----|
| 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 (4-2-4) . . . . .      | .  | .  | 10 |
| Bi 9       | Cell Biology (3-3-3) . . . . .            | .  | .  | 9  |
| Ay 2 abc   | General Astronomy (3-3-3) . . . . .       | 9  | 9  | 9  |

<sup>1</sup>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.

<sup>2</sup>AFROTC students will substitute AS 2 abc (2-1-1) first and third terms, (0-1-1) second term, for PE 2 abc.

<sup>3</sup>Students should note that EE 1 abc is prerequisite to most advanced electrical engineering courses, and that Ma 108 abc is prerequisite to most advanced mathematical courses.

|           |   |    |    |    |
|-----------|---|----|----|----|
| EE 1 abc  | Basic Electrical Engineering (3-0-6) .....            | 9  | 9  | 9  |
| EE 2 ab   | Basic Electrical Engineering Laboratory (0-3-0) ..... | .  | 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 108 abc | Theoretical Mechanics (3-0-6) .....            | 9       | 9     | 9     |
| Ph 112 abc | Atomic and Nuclear Physics (4-0-8) .....       | 12      | 12    | 12    |
|            | Laboratory Course .....                        | Minimum | 6     | .     |
| Ec 4 ab    | Economic Principles and Problems (3-0-3) ..... | .       | 6     | 6     |
| H 5 abc    | Public Affairs (1-0-1) .....                   | 2       | 2     | 2     |
|            | Humanities elective <sup>1</sup> .....         | 9       | 9     | 9     |
|            | Electives .....                                | 6-8     | 6-8   | 6-8   |
|            |  | 47-49   | 47-49 | 47-49 |

## Laboratory Courses

|          |   |     |    |     |   |
|----------|---|-----|----|-----|---|
| Ph 77    | Experimental Physics Laboratory .....   | 6-9 | or | 6-9 | . |
| EE 7 abc | Experimental Techniques in Electrical<br>Engineering (0-3-2) .....            | 5   |    | 5   | 5 |
| Ph 172   | Experimental Research in Physics (units as<br>arranged with instructor) ..... | .   |    | .   | . |

## Suggested Electives

|            |  |    |    |    |    |
|------------|--|----|----|----|----|
| Ma 112     | Elementary Statistics (3-0-6) .....  | 9  | or | 9  | .  |
| Ma 105 ab  | Introduction to Numerical Analysis (3-2-6) .....                                       | .  |    | 11 | 11 |
| Ma 137     | Introduction to Lebesgue Integrals (3-0-6) .....                                       | 9  |    | .  | .  |
| EE 101 abc | Electric Circuit Theory (3-0-6) .....  | 9  |    | 9  | 9  |
| EE 106 ab  | Electronic Circuits (3-0-6) .....  | 9  |    | 9  | .  |
| EE 107     | Principles of Feedback (3-0-6) .....   | .  |    | .  | 9  |
| Ph 129 abc | Methods of Mathematical Physics (3-0-6) .....  | 9  |    | 9  | 9  |
| Ph 171     | Reading and Independent Study in Physics<br>(units arranged, maximum 9 units per term) |    |    |    |    |
| Ph 172     | Experimental Research in Physics (units arranged) .....                                | .  |    | .  | .  |
| L 51 abc   | Intermediate Russian (4-0-6) .....   | 10 |    | 10 | 10 |

<sup>1</sup>For list of Humanities electives, see page 231.

**SCHEDULES OF FIFTH- AND SIXTH-YEAR COURSES**  
**GRADUATE HUMANITIES ELECTIVES**

|            |  |
|------------|--|
| H 100 abc  | Seminar in History and Government      |
| En 100 abc | Seminar in Literature                  |
| Pl 100 abc | Philosophy of Science                  |
| Pl 101 abc | History of Thought                     |
| Pl 102 abc | Philosophy and Literature              |
| Ec 100 abc | Business Economics                     |
| Ec 110     | Industrial Relations                   |
| Ec 111     | Business Cycles and Government Policy  |
| Ec 112     | Modern Schools of Economic Thought     |
| Ec 126 abc | Economic Analysis and Policy (Seminar) |
| H 123      | The Growth of Industrial Civilization  |
| H 124      | Seminar in Foreign Area Problems       |
| Ec 124     | Economics of Underdeveloped Areas      |
| H 125 abc  | Seminar on National Security           |
| Ec 104     | Government Regulation                  |
| Ec 125     | Technical Cooperation                  |
| H 150      | African Studies                        |

**AERONAUTICS**

**FIFTH YEAR**

*(Leading to the Degree of Master of Science in Aeronautics)*

|             |   | Units per Term | 1st         | 2nd         | 3rd  |
|-------------|---|----------------|-------------|-------------|------|
|             | Humanities Electives .....  |                | 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<br>of Aircraft and Spacecraft ..... |                | 9           | 9           | 9    |
| Ae 104 abc  | Experimental Methods in Aeronautics .....                           |                |             |             |      |
| or          |   |                |             |             |      |
| Ae 104a and |   |                |             |             |      |
| Ae 105 bc   | Research Laboratory in Fluid Mechanics .....                        |                |             |             |      |
| AM 116,     |   |                |             |             |      |
| AM 113 ab   | Complex Variable, Engineering Mathematics .....                     |                | 9           | 9           | 9    |
| Ae 150 abc  | Seminar .....   |                | 1           | 1           | 1    |
|             |   | <hr/> 55-56    | <hr/> 55-56 | <hr/> 55-56 |      |

NOTE: The above program represents the minimum level of work for the M.S. degree in Aeronautics. If any of the subjects listed have been taken as an undergraduate, more advanced subjects may be substituted for them.

**AERONAUTICS**

**SIXTH YEAR**

*(Leading to the degree of Aeronautical Engineer)*

|            |   | Units per Term | 1st      | 2nd      | 3rd |
|------------|---|----------------|----------|----------|-----|
| Ae 200 abc | Research in Aeronautics .....             |                | 20       | 20       | 20  |
| Ae 201 abc | Fundamentals of Fluid Mechanics .....     |                |          |          |     |
| or         |   |                |          |          |     |
| Ae 210 abc | Fundamentals of Solid Mechanics .....     |                |          |          |     |
| Ae 208 abc | Fluid Mechanics Seminar .....             |                |          |          |     |
| or         |   |                |          |          |     |
| Ae 209 abc | Solid Mechanics Seminar .....             |                |          |          |     |
| or         |   |                |          |          |     |
| JP 290 abc | Jet Propulsion Seminar .....              |                |          |          |     |
| AM 125 abc | Engineering Mathematical Principles ..... |                | 9        | 9        | 9   |
|            | Elective .....                            |                | 9        | 9        | 9   |
|            |   | <hr/> 48       | <hr/> 48 | <hr/> 48 |     |

## AERONAUTICS (JET PROPULSION OPTION)

## SIXTH YEAR

|            |  |       |       |       |
|------------|--|-------|-------|-------|
| JP 208     | Research in Jet Propulsion .....   | 20    | 20    | 20    |
| Ae 201 abc | Fundamentals of Fluid Mechanics .....  |       |       |       |
| or         |  | 9     | 9     | 9     |
| Ae 210 abc | Fundamentals of Solid Mechanics .....  |       |       |       |
| JP 290 abc | Jet Propulsion Seminar .....   | 1     | 1     | 1     |
|            | Electives, as below <sup>2</sup> (minimum total for year,<br>81 units) ..... | 27-30 | 27-30 | 27-30 |
|            |  | 48    | 48    | 48    |

## APPLIED MECHANICS

## FIFTH YEAR

*(Leading to the degree of Master of Science in Applied Mechanics)*

|            |  | Units per Term | 1st   | 2nd   | 3rd   |
|------------|--|----------------|-------|-------|-------|
|            | Humanities Elective .....  | 9-10           | 9-10  | 9-10  | 9-10  |
| E 150 abc  | Seminar (1-0-1) .....  |                | 2     | 2     | 2     |
| AM 125 abc | Engineering Mathematical Principles <sup>1</sup> .....                       | 9              | 9     | 9     | 9     |
|            | Electives, as below <sup>2</sup> (minimum total for year,<br>81 units) ..... | 27             | 27    | 27    | 27    |
|            |  | 47-48          | 47-48 | 47-48 | 47-48 |

*Suggested Electives<sup>2</sup>*

|             |   |   |    |    |
|-------------|---|---|----|----|
| AM 101 abc  | Nuclear Reactor Theory .....                          | 9 | 9  | 9  |
| AM 103 a    | Nuclear Radiation Measurements Laboratory .....       | 9 | .  | .  |
| AM 103 b    | Nuclear Energy Laboratory .....                       | . | 9  | .  |
| AM 110 abc  | Theory of Elasticity, etc. .....                      | 6 | 6  | 6  |
| AM 111      | Experimental Stress Analysis .....                    | . | 9  | .  |
| AM 130 abc  | Applications of Classical Theoretical Physics I ..... | 9 | 9  | 9  |
| AM 140      | Plasticity .....                                      | 6 | .  | .  |
| AM 141 ab   | Wave Propagation in Solids .....                      | . | 6  | 6  |
| AM 150 abc  | Mechanical Vibrations .....                           | 6 | 6  | 6  |
| AM 155      | Dynamic Measurements Laboratory .....                 | 9 | .  | .  |
| AM 160      | Vibrations Laboratory .....                           | . | .  | 6  |
| AM 174,6 ab | Advanced Dynamics I, II .....                         | 6 | 6  | 6  |
| AM 180      | Matrix Algebra .....                                  | 9 | .  | .  |
| Ae 101 abc  | Elements of Gasdynamics .....                         | 9 | 9  | 9  |
| Ae 104 abc  | Experimental Methods in Aeronautics .....             | 9 | 9  | 9  |
| Ae 105 bc   | Research Laboratory in Fluid Mechanics .....          | . | 9  | 9  |
| Ae 210 abc  | Fundamentals of Solid Mechanics .....                 | 9 | 9  | 9  |
| Ae 216      | Structural Dynamics .....                             | . | 9  | .  |
| Ae 217      | Aeroelasticity .....                                  | . | .  | 9  |
| CE 123      | Dynamics of Structures .....                          | . | .  | 9  |
| EE 180      | Digital Computer Design .....                         | 9 | .  | .  |
| EE 181 ab   | Principles of Analog Computation .....                |   | 12 | 12 |
| Hy 101 abc  | Fluid Mechanics .....                                 | 9 | 9  | 9  |
| Hy 134      | Flow in Porous Media .....                            | . | .  | 9  |
| JP 121 abc  | Rockets and Air Breathing Engines .....               | 9 | 9  | 9  |
| Ma 105 ab   | Introduction to Numerical Analysis .....              | . | 11 | 11 |
| ME 126      | Fluid Mechanics and Heat Transfer Laboratory .....    | . | .  | 9  |
| Ph 108 abc  | Theoretical Mechanics .....                           | 9 | 9  | 9  |

<sup>1</sup>Students who have not had the equivalent of AM 95 abc (Engineering Mathematics) should replace AM 125 abc by AM 113 ab and AM 116. With staff approval, AM 125 abc can be replaced by Ma 108 abc (Advanced Calculus), Ph 129 abc (Methods of Mathematical Physics), or other satisfactory substitute.

<sup>2</sup>Note that a total of 140 units is required for the M.S. degree. Courses not on the above list of suggestions may be elected with staff approval.

## ASTRONOMY

## FIFTH YEAR

*(Leading to the degree of Master of Science in Astronomy)*

|  |         | 1st     | 2nd     | 3rd |
|--|---------|---------|---------|-----|
| Humanities Electives (3-0-6; 4-0-6) <sup>1</sup> . . . . .   | 9 or 10 | 9 or 10 | 9 or 10 |     |
| Ay 131 ab, or Ay 132 ab (3-0-6) . . . . .                    | 9       | 9 or 9  | 9       |     |
| Choice of 18 units from Ay 133, 135, 136, 210, 211 . . . . . | 9 or 9  | 9 or 9  | 9       |     |
| Electives to total . . . . .                                 | 47-50   | 47-50   | 47-50   |     |

Elective subjects program, to be approved by the department, from advanced subjects in astronomy and physics. Placement examination will be required. See page 219, section 2(a). Ay 112, Ph 107, Ph 109, Ph 114, and Ph 125 may be required of those students whose previous training in some of these subjects proves to be insufficient.

<sup>1</sup>For list of Humanities electives, see page 246.

## BIOLOGY

As nearly all biology majors are working for the doctor's degree and following programs arranged by the students in consultation with members of the Division, no specific graduate curricula can be outlined.

## CHEMICAL ENGINEERING

## FIFTH YEAR

*(Leading to the degree of Master of Science in Chemical Engineering)*

|   | 1st     | 2nd     | 3rd     |
|---|---------|---------|---------|
| Humanities Electives (3-0-6; 4-0-6) <sup>1</sup> . . . . .                  | 9 or 10 | 9 or 10 | 9 or 10 |
| ChE 167 abc Chemical Engineering Laboratory (0-15-0) <sup>2</sup> . . . . . | 15      | 15      | 15      |
| Electives <sup>3</sup> at least . . . . .                                   | 23      | 23      | 23      |
|   | 47-48   | 47-48   | 47-48   |

<sup>1</sup>For list of Humanities electives, see page 246.

<sup>2</sup>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.

<sup>3</sup>Selective subjects are to be approved by a member of the Division and must include AM 113 ab if equivalent has not been taken. A minimum of 27 units of these electives must be in advanced chemical engineering subjects, the remainder are to be chosen from other advanced subjects.

A minimum of 141 units of approved graduate subjects, with three terms of residence (at least 45 units per term), is required for the Master's degree.

Students admitted for work toward the M.S. in Chemical Engineering will be required to take the placement examinations in engineering thermodynamics, the unit operations of chemical engineering, and industrial chemistry. If desired the student can substitute physical chemistry for industrial chemistry.

**CHEMISTRY**  
**FIFTH YEAR**

*(Leading to the 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.

A total of at least 27 units in the Humanities is required for a master's degree. Not fewer than 30 units of courses of science subjects chosen from advanced courses and not fewer than 40 units of Chemical Research must be offered for the master's degree. 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**  
**FIFTH YEAR**

*(Leading to the degree of Master of Science in Civil Engineering)*

|                            |   | Units per Term |         |         |
|----------------------------|---|----------------|---------|---------|
|                            |   | 1st            | 2nd     | 3rd     |
| CE 130 abc                 | Humanities Electives (3-0-6; 4-0-6) <sup>1</sup> .....      | 9 or 10        | 9 or 10 | 9 or 10 |
|                            | Civil Engineering Seminar (1-0-0) .....                     | 1              | 1       | 1       |
|                            | Electives (minimum total for year 108) <sup>2,3</sup> ..... | 36-39          | 36-39   | 36-39   |
| <i>Suggested Electives</i> |   | <hr/>          | <hr/>   | <hr/>   |
|                            |   | 46-50          | 46-50   | 46-50   |

(Courses are grouped into general areas for ready reference; however, the student is encouraged to select electives from several areas in order to avoid overspecialization).

**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<br>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 | 9 | 9 |

## 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 |

## HYDRAULICS AND WATER RESOURCES

|            |  |   |   |   |
|------------|--|---|---|---|
| CE 155     | Hydrology (3-0-6) .....                                      | 9 | . | . |
| CE 160     | Advanced Hydrology <sup>1</sup> .....                        | . | . | . |
| Hy 101 abc | Advanced Fluid Mechanics (3-0-6) .....                       | 9 | 9 | 9 |
| Hy 103 ab  | Advanced Hydraulics (3-0-6) .....                            | 9 | 9 | . |
| Hy 103 c   | Hydraulic Structures (3-0-6) .....                           | . | . | 9 |
| Hy 105     | Analysis and Design of Hydraulic Projects <sup>4</sup> ..... | . | . | . |
| Hy 121     | Advanced Hydraulics Laboratory <sup>4</sup> .....            | . | . | . |
| Hy 134     | Flow in Porous Media (3-0-6) .....                           | . | . | 9 |

## ENVIRONMENTAL HEALTH ENGINEERING

|            |  |   |   |   |
|------------|--|---|---|---|
| CE 137 abc | Water Supply & Waste-Water Disposal<br>(3-0-6; 1-6-2) .....  | 9 | 9 | 9 |
| CE 138 abc | Sanitary Sciences (2-3-4) .....                              | 9 | 9 | 9 |
| CE 151 abc | Air Resources Engineering (2-3-4) .....                      | 9 | 9 | 9 |
| CE 152 ab  | Environmental Radiation (2-3-4) .....                        | . | 9 | 9 |
| CE 153     | Seminar in Environmental Health<br>Engineering (2-0-1) ..... | . | . | 3 |
| CE 156     | Industrial Wastes (3-0-6) .....                              | . | . | 9 |

## APPLIED MATHEMATICS

|           |  |        |    |    |
|-----------|--|--------|----|----|
| AM 113 ab | Engineering Mathematics (4-0-8) .....          | .      | 12 | 12 |
| AM 116    | Complex Variables & Applications (4-0-8) ..... | 12     | .  | .  |
| AM 180    | Matrix Algebra (3-0-6) .....                   | 9      | .  | .  |
| Ma 105 ab | Intro. to Numerical Analysis (3-2-6) .....     | .      | 11 | 11 |
| Ma 112    | Elementary Statistics (3-0-6) .....            | 9 or 9 | .  | .  |

<sup>1</sup>For list of Humanities electives, see page 246.<sup>2</sup>Students who have not had AM 95 ab or its equivalent will be required to include AM 113 as part of their elective units.<sup>3</sup>Electives must be approved by Civil Engineering faculty.<sup>4</sup>Six or more units as arranged

## ELECTRICAL ENGINEERING

## FIFTH YEAR

*(Leading to the degree of Master of Science in Electrical Engineering)*

|            |  |              |              |              |
|------------|--|--------------|--------------|--------------|
| EE 220 abc | Humanities Electives (3-0-6; 4-0-6) <sup>1</sup> ..... | 9 or 10      | 9 or 10      | 9 or 10      |
|            | Research Seminar in Electrical Engineering .....       | 2            | 2            | 2            |
|            | Electives, <sup>2</sup> as approved by advisor .....   | 36-39        | 36-39        | 36-39        |
|            | <b>TOTAL</b> .....                                     | <b>47-51</b> | <b>47-51</b> | <b>47-51</b> |

## Suggested Electives

|            |  |   |    |    |
|------------|--|---|----|----|
| EE 132 abc | Network Synthesis (3-0-6) .....                  | 9 | 9  | 9  |
| EE 140 abc | Electric Communication (3-0-6) .....             | 9 | 9  | 9  |
| EE 150 abc | Electromagnetic Fields (3-0-6) .....             | 9 | 9  | 9  |
| EE 164 abc | Microwave Electronics and Circuits (3-0-6) ..... | 9 | 9  | 9  |
| EE 165 ab  | Microwave Laboratory (1-3-2) .....               | . | 6  | 6  |
| EE 170 abc | Feedback Control Systems (3-0-6) (3-3-6) .....   | 9 | 12 | 12 |
| EE 180 abc | Digital Computer Design (3-3-3) .....            | 9 | .  | .  |
| EE 181 ab  | Principles of Analog Computation (3-3-6) .....   | . | 12 | 12 |
| EE 190 abc | Advanced Electronics (3-0-6) .....               | 9 | 9  | 9  |

<sup>1</sup>For list of Humanities electives, see page 246.<sup>2</sup>A total of 140 units is required for the M.S. degree. If, as a result of the placement examinations (see p. 191), a student is required to take any of the following courses: AM 113 ab, AM 116, EE 101 abc, EE 115 abc; no more than 30 units from these courses may be offered for the M.S. degree.

|            |   |    |    |    |
|------------|---|----|----|----|
| EE 191 abc | Physics of Semiconductors and Semiconductor Devices (3-0-6) ..... | 9  | 9  | 9  |
| EE 195 abc | Electronic Processes in Solids (3-0-6) .....                      | 9  | 9  | 9  |
| EE 292 ab  | Magnetic Properties of Solids (2-0-4) .....                       | 6  | 6  | .  |
| Ph 112 abc | Atomic and Nuclear Physics (4-0-8) .....                          | 12 | 12 | 12 |
| Ph 129 abc | Methods of Mathematical Physics (3-0-6) .....                     | 9  | 9  | 9  |
| Ph 131 abc | Electricity and Magnetism (3-0-6) .....                           | 9  | 9  | 9  |
| AM 125 abc | Engineering Mathematical Principles (3-0-6) ..                    | 9  | 9  | 9  |
| AM 180     | Matrix Algebra (3-0-6) .....                                      | 9  | .  | .  |
| Ma 105 ab  | Introduction to Numerical Analysis (3-2-6) ...                    | .  | 11 | 11 |
|            | Other electives as approved by Electrical Engineering Faculty     |    |    |    |

### SIXTH YEAR

(Leading to the degree of Electrical Engineer)

*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 213, except that a grade of D in Ph 131 is acceptable.

### ENGINEERING SCIENCE

(Leading to the degree of Master of Science in Engineering Science)

|   |  | Units per Term | 1st     | 2nd     | 3rd     |
|---|--|----------------|---------|---------|---------|
|   | Humanities Electives .....                 | 9 or 10        | 9 or 10 | 9 or 10 | 9 or 10 |
| AM 125 abc  | Engineering Mathematical Principles* ..... | 9              | 9       | 9       | 9       |
| <i>One of the following:</i>  |  |                |         |         |         |
| AM 101 abc  | Nuclear Reactor Theory .....               | 9              | 9       | 9       | 9       |
| AM 130 abc  | Classical Theoretical Physics I .....      | 9              | 9       | 9       | 9       |
| AM 131 abc  | Classical Theoretical Physics II .....     | 9              | 9       | 9       | 9       |
| JP 201 abc  | Physical Mechanics .....                   | 9              | 9       | 9       | 9       |
| Add electives to bring total to 140 units. Electives must be approved by advisor. |  |                |         |         |         |

\*Students who have not had the equivalent of AM 95 abc (Engineering Mathematics) should replace the Applied Mathematics course by AM 113 ab and AM 116. With the approval of the student's advisor equivalent courses in mathematics, or applied mathematics, may be substituted for AM 125 or Ph 129.

### GEOLOGY

#### FIFTH YEAR

*Option leading to degree of Master of Science in Geology*

|   | Units per Term  | 1st | 2nd  | 3rd  |
|---|---|-----|------|------|
|   | Humanities Elective (3-0-6; 4-0-6) (select from electives listed on page 246) ..... | 9   | 9    | 9    |
| Ge 100  | Geology Club .....  | 1   | 1    | 1    |
| Ge 102  | Oral Presentation (1-0-1) .....   | 2   | or 2 | or 2 |
| Ge 114  | Mineralogy II Optical Mineralogy (3-8-1) .....                                      | 12  | .    | .    |
| Ge 115a   | Igneous Petrology and Petrography (3-6-3) .....                                     | .   | 12   | .    |
| Ge 115b   | Sedimentary Petrology and Petrography (3-4-3) .....                                 | .   | .    | 12   |
| Ge 121 abc  | Advanced Field Geology .....  | 14  | 10   | 11   |
| Ge 123  | Summer Field Geology (30 units) .....   | .   | .    | .    |
| Ch 124 ab   | Physical Chemistry for Geologists .....   | 6   | 6    | .    |
| Add electives to bring total to 140 units. Electives must be approved by advisor. |   |     |      |      |

*Option leading to degree of Master of Science in Geophysics*

|        |   |   |      |      |
|--------|---|---|------|------|
|        | Humanities Elective (3-0-6; 4-0-6) (select from electives listed on page 235) ..... | 9 | 9    | 9    |
| Ge 100 | Geology Club .....  | 1 | 1    | 1    |
| Ge 102 | Oral Presentation (1-0-1) .....   | 2 | or 2 | or 2 |

## 252 Graduate Courses

|            |                                       |    |    |    |
|------------|---------------------------------------|----|----|----|
| Ge 120 abc | Elementary Field Geology .....        | 10 | 10 | 10 |
| Ge 282 abc | Geophysics-Geochemistry Seminar ..... | 1  | 1  | 1  |
| Ph 107 abc | Electricity and Magnetism .....       | 9  | 9  | 9  |
| Ph 108 abc | Theoretical Mechanics .....           | 9  | 9  | 9  |

Add electives to bring total to 140 units. Electives  
must be approved by advisor.

*Option leading to degree of Master of Science in Geochemistry*  
Humanities Elective (3-0-6; 4-0-6) (select from

|            |   |    |    |    |
|------------|---|----|----|----|
|            | Electives listed on page 235) .....                 | 9  | 9  | 9  |
| Ge 100     | Geology Club .....                                  | 1  | 1  | 1  |
| Ge 102     | Oral Presentation (1-0-1) .....                     | 2  | or | 2  |
| Ge 114     | Mineralogy II Optical Mineralogy (3-8-1) .....      | 12 | .  | .  |
| Ge 115a    | Igneous Petrology and Petrography (3-6-3) .....     | .  | 12 | .  |
| Ge 115b    | Sedimentary Petrology and Petrography (3-4-3) ..... | .  | .  | 12 |
| Ge 120 abc | Elementary Field Geology .....                      | 10 | 10 | 10 |
| Ge 130 ab  | Introduction to Geochemistry .....                  | 4  | 4  | .  |
| Ch 124 ab  | Physical Chemistry for Geologists .....             | 6  | 6  | .  |

Add electives to bring total to 140 units, including at least 30 additional units of advanced courses in Chemistry and Geochemistry, and at least 30 units of research in Geochemistry. Equivalent or previous courses may be substituted for Ge 114, Ge 115 ab, Ge 120, Ge 130 ab, and Ch 124. Substitutions and Electives must be approved by advisor.

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

## FIFTH YEAR

(Leading to the degree of Master of Science in Materials Science)

| E 150 abc |   |  |  | Units per Term |         |         |
|-----------|---|--|--|----------------|---------|---------|
|           |   |  |  | 1st            | 2nd     | 3rd     |
|           |   |  |  | 9 or 10        | 9 or 10 | 9 or 10 |
|           |   |  |  | 2              | 2       | 2       |
|           | Humanities Electives (3-0-6; 4-0-6)*          |  |  | 9              | 9       | 9       |
|           | Seminar (1-0-1)                               |  |  | 2              | 2       | 2       |
|           | Electives (Minimum total for year, 108 units) |  |  | 36             | 36      | 36      |
|           |   |  |  | 47-48          | 47-48   | 47-48   |

## Electives (See Notes 1 and 2 below)

|            |   |       |          |      |    |  |
|------------|---|-------|----------|------|----|--|
| 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 |      |    |  |
| Ae 222     | Polymer Mechanics (3-0-6)                                     | ..... | Any term |      |    |  |
| 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 ab  | Nuclear Engineering Laboratory (1-6-2)                        | ..... | 9        | 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<br>(3-0-6)    | ..... | 9        | 9    | 9  |  |
| AM 131 abc | Applications of Classical Theoretical Physics II<br>(3-0-6)   | ..... | 9        | 9    | 9  |  |
| AM 140     | Plasticity (2-0-4)  | ..... | 6        | .    | .  |  |
| AM 141 ab  | Wave Propagation in Solids (2-0-4)                            | ..... | .        | 6    | 6  |  |
| AM 150 abc | Mechanical Vibrations (2-0-4)                                 | ..... | 6        | 6    | 6  |  |
| AM 155     | Dynamic Measurements Laboratory (1-6-2)                       | ....  | 9        | .    | .  |  |
| Ch 121 ab  | The Nature of the Chemical Bond (2-0-4)                       | ..... | .        | 6    | 6  |  |
| CE 115 ab  | Soil Mechanics (3-0-6)  | ..... | 9        | 9    | .  |  |
| EE 162 abc | Physics of Electronic Devices (2-0-4)                         | ..... | 6        | 6    | 6  |  |
| EE 190 abc | Advanced Electronics (3-0-6)                                  | ..... | 9        | 9    | 9  |  |
| EE 191     | Physics of Semiconductor and Semiconductor<br>Devices (3-0-6) | ..... | .        | 9    | .  |  |
| Ma 105 ab  | Introduction to Numerical Analysis (3-2-6)                    | ...   | .        | 11   | 11 |  |
| 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<br>Transfer (3-0-6)        | ..... | 9        | 9    | 9  |  |
| ME 126     | Fluid Mechanics and Heat Transfer Laboratory<br>(0-6-3)       | ..... | .        | .    | 9  |  |
| ME 127     | High Frequency Measurements in Fluids and<br>Solids (2-6-1)   | ..... | .        | 9    | .  |  |
| Ph 107 abc | Electricity and Magnetism (3-0-6)                             | ..... | 9        | 9    | 9  |  |
| Ph 112 abc | Atomic and Nuclear Physics (4-0-8)                            | ..... | 12       | 12   | 12 |  |
| PM 102     | Pyrometry (1-6-2)   | ..... | .        | .    | 9  |  |
| PM 103 ab  | Physical Metallurgy Laboratory (0-9-0) (0-6-0)                | 9     | 6        | .    | .  |  |
| PM 104     | Photography (1-6-2)   | ..... | 9        | .    | .  |  |

\*For list of Humanities electives, see page 246.

Note 1: Students who have not had a course in Engineering Mathematics, Advanced Calculus, or the equivalent in their undergraduate work, are required to include AM 113 ab and AM 116 among the elective units.

Note 2: Substitution for electives listed above may be made with the specific approval of the faculty in Materials Science.

|           |  |   |   |   |
|-----------|--|---|---|---|
| PM 105    | Mechanical Behavior of Metals (2-0-4) .....                            | 6 | . | . |
| PM 112 ab | Advanced Physical Metallurgy (3-0-6) .....                             | . | 9 | 9 |
| PM 115 ab | Crystal Structure and Properties of Metals and<br>Alloys (3-0-6) ..... | . | 9 | 9 |
| PM 116    | X-Ray Metallography Laboratory I (0-6-3) .....                         | . | . | 9 |
| PM 120    | Physics of Solids (3-0-6) .....  | 9 | . | . |

### MATHEMATICS AND APPLIED MATHEMATICS

As nearly all mathematics and applied mathematics majors are working for the doctor's degree and follow programs arranged by the student in consultation with members of the Divisions, no specific fifth year curriculum is outlined.

### MECHANICAL ENGINEERING OPTION

#### FIFTH YEAR

*(Leading to the degree of Master of Science in Mechanical Engineering)*

|            |   |          | Units per Term |          |     |
|------------|---|----------|----------------|----------|-----|
|            |   |          | 1st            | 2nd      | 3rd |
| E 150 abc  | Humanities Electives (3-0-6; 4-0-6) <sup>1</sup> .....            | 9 or 10  | 9 or 10        | 9 or 10  |     |
|            | Seminar (1-0-1) .....   | 2        | 2              | 2        |     |
|            | Electives as below. See Notes 1 & 2, page 258                     |          |                |          |     |
|            | (Minimum total for year 108) .....                                | 36       | 36             | 36       |     |
|            |   | <hr/>    | <hr/>          | <hr/>    |     |
|            |   | 47 or 48 | 47 or 48       | 47 or 48 |     |
|            | <i>Electives (See Notes 1 and 2, page 258)</i>                    |          |                |          |     |
| 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<br>(1-4-4) .....        | 9        | .              | .        |     |
| AM 103 b   | Nuclear Energy 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 150 abc | Mechanical Vibrations (2-0-4) .....                               | 6        | 6              | 6        |     |
| AM 155     | Dynamic Measurements Laboratory (1-6-2) .....                     | 9        | .              | .        |     |
| AM 180     | Matrix Algebra (3-0-6) .....                                      | 9        | .              | .        |     |
| Hy 101 abc | Advanced Fluid Mechanics (3-0-6) .....                            | 9        | 9              | 9        |     |
| JP 170     | Jet Propulsion Laboratory (0-9-0) .....                           | .        | .              | 9        |     |
| Ma 105 ab  | Introduction to Numerical Analysis (3-2-6) .....                  | .        | 11             | 11       |     |
| 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<br>Transfer (3-0-6) .....      | 9        | 9              | 9        |     |
| ME 126     | Fluid Mechanics and Heat Transfer<br>Laboratory (0-6-3) .....     | .        | .              | .        | 9   |
| ME 127     | High Frequency Measurements in Fluids and<br>Solids (2-6-1) ..... | .        | 9              | .        |     |
| Ph 107 abc | Electricity and Magnetism (3-0-6) .....                           | 9        | 9              | 9        |     |
| PM 102     | Pyrometry (1-6-2) .....   | .        | .              | .        | 9   |
| PM 104     | Photography (1-6-2) .....   | 9        | .              | .        |     |

<sup>1</sup>For list of Humanities electives, see page 246.

**MECHANICAL ENGINEERING**  
**(JET PROPULSION OPTION)**

**FIFTH YEAR**

*(Leading to the degree of Master of Science in Mechanical Engineering)*

|            |  | 1st      | Units per Term | 2nd      | 3rd |
|------------|--|----------|----------------|----------|-----|
| E 150 abc  | Humanities Electives (3-0-6; 4-0-6) <sup>1</sup> . . . . . | 9 or 10  | 9 or 10        | 9 or 10  |     |
| JP 120 abc | Seminar (1-0-1) . . . . .                                  | 2        | 2              | 2        |     |
| 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. See Notes 1 & 2, page 258              |          |                |          |     |
|            | (Minimum total for year 54) . . . . .                      | 18       | 18             | 18       |     |
|            |  | <hr/>    | <hr/>          | <hr/>    |     |
|            |  | 47 or 48 | 47 or 48       | 47 or 48 |     |

*Electives (See Notes 1 and 2, page 258)*

|            |  |          |    |    |
|------------|--|----------|----|----|
| 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<br>(1-4-4) . . . . .                   | 9        | .  | .  |
| AM 103 b   | Nuclear Energy 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 (3-0-6) . . . . .                                | 9        | 9  | 9  |
| AM 150 abc | Mechanical Vibrations (2-0-4) . . . . .  | 6        | 6  | 6  |
| AM 155     | Dynamic Measurements Laboratory (1-6-2) . . . . .                                | 9        | .  | .  |
| AM 180     | Matrix Algebra (3-0-6) . . . . .   | 9        | .  | .  |
| Hy 101 abc | Advanced Fluid Mechanics (3-0-6) . . . . .                                       | 9        | 9  | 9  |
| JP 170     | Jet Propulsion Laboratory (0-9-0) . . . . .                                      | .        | .  | 9  |
| JP 221 abc | Rocket Trajectories and Orbital Mechanics<br>(2-0-4) . . . . .                   | 6        | 6  | 6  |
| JP 240 a   | Heat Transfer in Propulsion Systems—Radiative<br>Heat Transfer (3-0-6) . . . . . | Any term |    |    |
| Ma 105 ab  | Introduction to Numerical Analysis (3-2-6) . . . . .                             | .        | 11 | 11 |
| 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<br>Transfer (3-0-6) . . . . .                 | 9        | 9  | 9  |
| ME 126     | Fluid Mechanics and Heat Transfer<br>Laboratory (0-6-3) . . . . .                | .        | .  | 9  |
| ME 127     | High Frequency Measurements in Fluids and<br>Solids (2-6-1) . . . . .            | .        | 9  | .  |
| Ph 107 abc | Electricity and Magnetism (3-0-6) . . . . .                                      | 9        | 9  | 9  |
| PM 102     | Pyrometry (1-6-2) . . . . .  | .        | .  | 9  |
| PM 104     | Photography (1-6-2) . . . . .  | 9        | .  | .  |

<sup>1</sup>For list of Humanities electives, see page 246.

MECHANICAL ENGINEERING  
(NUCLEAR ENERGY OPTION)

## FIFTH YEAR

*(Leading to the degree of Master of Science in Mechanical Engineering)*

|            |  |       | Units per Term | 1st      | 2nd      | 3rd |
|------------|--|-------|----------------|----------|----------|-----|
|            | Humanities Electives (3-0-6; 4-0-6) <sup>1</sup>                             | ..... | 9 or 10        | 9 or 10  | 9 or 10  |     |
| E 150 abc  | Seminar (1-0-1)  | ..... | 2              | 2        | 2        |     |
| AM 101 abc | Nuclear Reactor Theory (3-0-6)   | ..... | 9              | 9        | 9        |     |
| AM 102 abc | Applied Nuclear Physics (2-0-4) <sup>2</sup>                                 | ..... | 6              | 6        | 6        |     |
|            | Electives as below. See Notes 1 & 2, page 258<br>(minimum total for year 63) | ..... | 21             | 21       | 21       |     |
|            |  |       | 47 or 48       | 47 or 48 | 47 or 48 |     |

*Electives (See Notes 1 and 2, page 258)*

|            |  |       |        |    |    |  |
|------------|--|-------|--------|----|----|--|
| AM 103 a   | Nuclear Radiation Measurements Laboratory<br>(1-4-4)             | ..... | 9      | .  | .  |  |
| AM 103 b   | Nuclear Energy 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 (3-0-6)                          | ..    | 9      | 9  | 9  |  |
| AM 155     | Dynamic Measurements Laboratory (2-0-4)                          | ..    | 9      | .  | .  |  |
| AM 180     | Matrix Algebra (3-0-6)   | ..... | 9      | .  | .  |  |
| Hy 101 abc | Advanced Fluid Mechanics (3-0-6)                                 | ..... | 9      | 9  | 9  |  |
| JP 170     | Jet Propulsion Laboratory (0-9-0)                                | ..... | .      | .  | 9  |  |
| Ma 105 ab  | Introduction to Numerical Analysis (3-2-6)                       | ..    | .      | 11 | 11 |  |
| Ma 112     | Elementary Statistics (3-0-6)                                    | ..... | 9 or 9 | 9  | .  |  |
| ME 118 abc | Advanced Thermodynamics and Energy<br>Transfer (3-0-6)           | ..... | 9      | 9  | 9  |  |
| ME 126     | Fluid Mechanics and Heat Transfer<br>Laboratory (0-6-3)          | ..... | .      | .  | 9  |  |
| ME 127     | High Frequency Measurements in Fluids and<br>Solids (2-6-1)      | ..... | .      | 9  | .  |  |
| Ph 107 abc | Electricity and Magnetism (3-0-6)                                | ..... | 9      | 9  | 9  |  |
| PM 102     | Pyrometry (1-6-2)  | ..... | .      | .  | 9  |  |
| PM 104     | Photography (1-6-2)  | ..... | 9      | .  | .  |  |
| PM 115 ab  | Crystal Structure and Properties of Metals and<br>Alloys (3-0-6) | ..... | .      | 9  | 9  |  |
| PM 116     | X-Ray Metallography and Laboratory I (0-6-3)                     | ..    | .      | .  | 9  |  |
| PM 120     | Physics of Solids (3-0-6)  | ..... | 9      | .  | .  |  |

<sup>1</sup>For list of Humanities electives, see page 246.<sup>2</sup>Ph 112 abc may be substituted for AM 102 abc, and the number of elective units for the year reduced to a minimum total of 45 units.

**MECHANICAL ENGINEERING**  
**(PHYSICAL METALLURGY OPTION)**

**FIFTH YEAR**

*(Leading to the degree of Master of Science in Mechanical Engineering)*

|           |  |       | Units per Term |                |                |
|-----------|--|-------|----------------|----------------|----------------|
|           |  |       | 1st            | 2nd            | 3rd            |
| E 150 abc | Humanities Electives (3-0-6; 4-0-6) <sup>1</sup>                                   | ..... | 9 or 10        | 9 or 10        | 9 or 10        |
| AM 110 a  | Seminar (1-0-1) .....  | 2     | 2              | 2              |                |
| AM 110 a  | Introduction to the Theory of Elasticity (2-0-4) .....                             | 6     | .              | .              |                |
| PM 103 ab | Physical Metallurgy Laboratory (0-9-0; 0-6-0) .....                                | 9     | 6              |                |                |
| PM 112 ab | Advanced Physical Metallurgy (3-0-6) .....   | .     | 9              | 9              |                |
| PM 116    | X-Ray Metallography I (0-6-3) <sup>2</sup> .....                                   | .     | .              | .              | 9              |
|           | Electives as below. See Notes 1 & 2, page 258<br>(minimum total for year 63) ..... | 21    | 21             | 21             |                |
|           |  |       | <hr/> 47 or 48 | <hr/> 47 or 48 | <hr/> 47 or 48 |

*Electives (See Notes 1 and 2, page 258)*

|            |   |   |    |    |
|------------|---|---|----|----|
| 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<br>(1-4-4) .....                    | 9 | .  | .  |
| AM 103 b   | Nuclear Energy Laboratory (1-4-4) .....                                       | . | 9  | .  |
| 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 (3-0-6) ..                                    | 9 | 9  | 9  |
| AM 150 abc | Mechanical Vibrations (2-0-4) .....   | 6 | 6  | 6  |
| AM 155     | Dynamic Measurements Laboratory (1-6-2) ..                                    | 9 | .  | .  |
| Ch 226 abc | Introduction to Quantum Mechanics with<br>Chemical Applications (3-0-6) ..... | 9 | 9  | 9  |
| JP 170     | Jet Propulsion Laboratory (0-9-0) .....                                       | . | .  | 9  |
| Ma 105 ab  | Introduction to Numerical Analysis (3-2-6) ..                                 | . | 11 | 11 |
| 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<br>Transfer (3-0-6) .....                  | 9 | 9  | 9  |
| ME 126     | Fluid Mechanics and Heat Transfer<br>Laboratory (0-6-3) .....                 | . | .  | 9  |
| ME 127     | High Frequency Measurements in Fluids and<br>Solids (2-6-1) .....             | . | 9  |    |
| Ph 107 abc | Electricity and Magnetism (3-0-6) .....                                       | 9 | 9  | .  |
| Ph 205 abc | Principles of Quantum Mechanics (3-0-6) ..                                    | 9 | 9  | 9  |
| PM 102     | Pyrometry (1-6-2) .....   | . | .  | 9  |
| PM 104     | Photography (1-6-2) .....   | 9 | .  | .  |

<sup>1</sup>For list of Humanities electives, see page 246.

<sup>2</sup>Students who have not had PM 115 a or the equivalent will take PM 115 a as one of the electives in the second term.

## 258 Graduate Courses

Notes applying to all options in Mechanical Engineering:

*Note 1:* Students who have not had a course in Engineering Mathematics, Advanced Calculus, or the equivalent in their undergraduate work are required to include AM 113 ab and AM 116 among the elective units.

*Note 2:* Substitutions for the scheduled electives may be made upon specific approval of the faculty in Mechanical Engineering. The following are examples of substitutions that have been made in some instances and may be used as a guide by those desiring to make substitutions:

|            |  |
|------------|--|
| AM 105     | Advanced Strength of Materials, 6 units second term  |
| AM 106     | Problems in Buckling, 6 units third term             |
| Ae 101 abc | Elements of Gasdynamics, 9 units each term           |
| EE 101 abc | Electric Circuit Theory, 9 units each term           |
| EE 106 ab  | Electronic Circuits, 9 units first and second terms  |
| EE 170 abc | Feedback Control Systems, 9 units each term          |
| JP 121 abc | Rockets and Air Breathing Engines, 9 units each term |
| PM 105     | Mechanical Behavior of Metals, 6 units first term    |

## MECHANICAL ENGINEERING

## SIXTH YEAR

(Leading to the degree of Mechanical Engineer)

Specific requirements for the degree of Mechanical Engineer are given on page 202. 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 163 ab Chemical Engineering Thermodynamics  
 Ch 226 abc Introduction to Quantum Mechanics  
 Ch 227 abc The Structure of Crystals  
 Ch 229 Diffraction Methods of Determining the Structure of Molecules  
 Ch 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  
 ME 200 Advanced Work in Mechanical Engineering  
 ME 300 Thesis—Research  
 PM 103 ab Physical Metallurgy Laboratory  
 PM 112 ab Advanced Physical Metallurgy  
 PM 205 Theory of Mechanical Behavior of Metals  
 PM 217 X-Ray Metallography II  
 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)

## SIXTH YEAR

(Leading to the degree of Mechanical Engineer)

|            |  | 1st | Units per Term | 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****FIFTH YEAR***(Leading to the degree of Master of Science in Physics)*

|   |  |  | 1st      | 2nd      | 3rd      | Units per Term |
|---|--|--|----------|----------|----------|----------------|
| Humanities Electives (3-0-6; 4-0-6) <sup>2</sup> . . . . .  |  |  | 9 or 10  | 9 or 10  | 9 or 10  |                |
| Electives as below (At least 54 of these units<br>must be from courses in Groups I and II<br>as listed on page 220) . . . . . |  |  | 39       | 39       | 39       |                |
|   |  |  | <hr/>    | <hr/>    | <hr/>    |                |
|   |  |  | 48 or 49 | 48 or 49 | 48 or 49 |                |
| Ph 108 abc  | Theoretical Mechanics (3-0-3) <sup>1</sup> . . . . . |  | 6        | 6        | 6        |                |
| Ph 112 abc  | Atomic and Nuclear Physics <sup>1</sup> . . . . .    |  | 12       | 12       | 12       |                |
| Ph 115 ab   | Geometrical and Physical Optics (3-0-6) . . . . .    |  | .        | 9        | 9        |                |
| Ph 129 abc  | Methods of Mathematical Physics (3-0-6) . . . . .    |  | 9        | 9        | 9        |                |
| Ph 131 abc  | Electricity and Magnetism (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 217  | Spectroscopy (3-0-6) . . . . .                       |  | .        | .        | 9        |                |
| Ma 108 abc  | Advanced Calculus (4-0-8) <sup>3</sup> . . . . .     |  | 12       | 12       | 12       |                |
| Ma 118 abc  | Functions of a Complex Variable (3-0-6) . . . . .    |  | 9        | 9        | 9        |                |

<sup>1</sup>Prerequisite for most other fifth-year courses.<sup>2</sup>For list of Humanities electives, see page 246.<sup>3</sup>Prerequisite for Ma 118.

**NOTE:** With the department's approval, students who have the proper preparation may substitute other graduate courses in Electrical Engineering, Mathematics, or Physics for some of those listed above. Students who have received credit for Ph 131 abc, Ph 129 abc, or Ph 205 abc as undergraduates may use these credits towards a master of science degree provided they replace them with undergraduate credits in L 32 abc (4-0-6), or L 50 abc (4-0-6) earned during the fifth year.

# Section VI

## S U B J E C T S O F I N S T R U C T I O N

### 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 5, AM 8, AM 9.* 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. *Texts: 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.* Equations of motion for aircraft and spacecraft. Performance of conventional aircraft and rocket powered vehicles. Engines, propellers, range and endurance, lifting and non-lifting reentry, satellite performance, staging, application of restricted three-body problem to trajectories in the solar system. Optimization of performance. Static and dynamic stability and control. Determination of response characteristics. Effects of non-linear aerodynamics, roll coupling, variable density and velocity, auto-pilot. Estimation of aerodynamic forces and moments on complete aircraft and their dependence on Mach number. Airfoil lift, drag, and moment characteristics. Boundary layers. Calculation of spanwise lift distribution on finite wings. Slender body theory. Similarity. *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 (2-3-4); 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.

**Ae 203 abc. Flight Mechanics and Applied Aerodynamics. 6 units (2-0-4); 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, thermo-elasticity, 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, Papkovitch, Neuber functions; integral transformations. Instructor: Fung.

**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. Instructor: Williams.

*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.

**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 non-metallic. 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. Instructor: Williams.

**Ae 214. Special Problems of Space Environment.** *9 units (3-0-6). Offered first term 1963-64.* The effect of space environment on living bodies, materials, and structures. Hard vacuum, ionizing and particle radiation. Micrometeoroid impact, damage, and protection. Radiation shielding. Differences between short time and long time missions. Solar radiation, 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); one term. 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. Instructors: Fung, Schmidt.

**Ae 217. Aeroelasticity.** 9 units (3-0-6); one term. 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 formulation of aeroelastic problems. Texts: *An Introduction to the Theory of Aeroelasticity*, Fung. *Aeroelasticity*, Bispinghoff, Ashley, and Halfman. Instructors: Fung, Schmidt.

**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. Non-linear Problems in Structures and Aeroelasticity.** 9 units (3-0-6): Offered third term 1963-64. Large deflection of beams and plates. Edge layer theories. Post-buckling behavior of plates. Non-linear vibrations of plates and shells. Buckling of arches and shells. Non-linear problems in static aeroelasticity. Flutter of buckled plates. Flutter of airfoils with non-linear stiffness and damping characteristics. Stall flutter. Instructors: Fung, Schmidt.

**Ae 221. Theory of Viscoelasticity.** 9 units (3-0-6): Offered second term 1963-64. 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. Instructor: Williams.

**Ae 222. Polymer Mechanics.** 9 units (3-0-6); one term, 1962-63. Microscopic description of filled and unfilled polymers in terms of the topology of linear and cross-linked networks. Mechanisms of polymer chain formation and rupture. Relation of the micro- and macro-properties in terms of continuum mechanics, and the analysis of voids and defects utilizing theories of finite and infinitesimal deformations. Basis for the time-temperature shift factor. Finite element model or spectral representation of viscoelastic stress-strain behavior.

**Ae 223. Design Criteria for Missiles, Boosters, and Spacecraft.** 9 units (3-0-6): Offered first term 1963-64. A review of the static and dynamic design criteria for structural components relating to the missile and space program. Items effecting 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 1963-64 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, Lees, Liepmann.

**Ae 232. Gasdynamics of Upper Atmosphere Flight.** 9 units (3-0-6); one term. *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: Lees.

**Ae 233. Mathematical Fluid Dynamics.** 9 units (3-0-6); one term. *Prerequisites: Ae 101, AM 125.* Topics chosen from characteristic theory, simple waves, shock waves, interactions, similarity solutions, singular perturbation theory, with applications to one-dimensional unsteady flow, supersonic flow, blast wave theory, Stokes flow, and boundary layer theory. Instructors: Lagerstrom, Cole, Kaplan.

**Ae 234. Hypersonic Aerodynamics.** 9 units (3-0-6); one term. *Prerequisites: Ae 101, Ae 201 a, AM 125.* An advanced course dealing with aerodynamic problems of flight at hypersonic speeds. Topics are selected from: Hypersonic small-disturbance theory, blunt body theory, boundary layers and shock waves in real gases, heat and mass transfer, testing facilities and experiments. Text: *Hypersonic Flow Theory*, Hayes and Probstein. Instructor: Kubota. (Offered third term 1963-64).

**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. Instructor: Cole. (Offered first term 1963-64).

**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. Instructor: Watts. (Offered second term 1963-64).

**Ae 237. Shock Tube Theory and Techniques.** 9 units (3-0-6); one term. *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 charge. Driver types and characteristics. Non-ideal behavior in shock tubes; diaphragm opening effects, boundary layer effects. Shock tube techniques and meas-

urements. 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. Instructors: Roshko, Sturtevant.

**Ae 238. Stochastic Processes in Fluid Mechanics.** 9 units (3-0-6); one term. *Prerequisites: AM 125, Ae 201.* Fundamental concepts; probability, random variables, statistical distributions. Stochastic processes; fluctuations in thermodynamic systems, shot effect, Brownian motion. Spectra and correlation functions. Kinematics and dynamics of isotropic homogeneous turbulence. Experimental methods and results: Instructors: Lagerstrom, Liepmann, Coles.

**Ae 239. Turbulent Shear Flows.** 9 units (3-0-6): Offered third term 1963-64. *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). Instructors: Coles, Liepmann, Roshko.

#### AERONAUTICS—JET PROPULSION (For Jet Propulsion see pages 313-315)

#### AIR SCIENCE

**\*AS 1 abc. Foundations of Aerospace Power.** 2 units (0-1-1) first and third term and 4 units (2-1-1) second term. (*The freshman year.*) 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, role and attributes of the professional officer in American democracy, 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. Fundamentals of Aerospace Weapon Systems.** 4 units (2-1-1) first and third terms and 2 units (0-1-1) second term. (*The sophomore year.*) An introductory survey of aerospace missiles and craft, and their propulsion and guidance systems; target intelligence and electronic warfare; nuclear, chemical, and biological warhead agents; defensive, strategic, and tactical operations; problems, mechanics, and military implications of space operations; and a survey of contemporary military thought. Instructors: Air Force Staff.

**\*\*AS 3 abc. Air Force Officer Development.** 8 units (4-1-3.) (*The junior year.*) Staff organization and functions and the skills required for effective staff work, to include oral and written communication and problem solving; basic psychological and sociological principles of leadership and their application to leadership practices and problems; and an introduction to military justice. Instructors: Air Force Staff.

<sup>\*</sup>During the first and third terms of the freshman year and the second term of the sophomore year, no military classroom instruction will be provided. During these terms certain Institute courses are substituted for the military classroom phase. The substitute courses are courses which contribute to precommission officer education requirements and are Institute required courses for all freshmen and sophomores. During these terms the cadet will participate only in the leadership Laboratory, one hour per week.

<sup>\*\*</sup>During the junior and senior years certain Institute courses may be substituted for some of the areas of instruction depicted above. When this occurs, and no military classroom instruction is provided, only three units will be granted for Air Science that term.

**\*\*AS 4 abc. Global Relations.** 8 units (4-1-3). (*The senior year.*) An intensive study of global relations of special concern to the Air Force officer, with emphasis on international relations and geography, and briefing for commissioned service. Instructors: Air Force Staff.

### ANTHROPOLOGY

**An 1. Social Anthropology.** 9 units (3-0-6); *Senior Elective.* A study of the forms and social functions of economic, sexual, familial, political, and religious institutions among selected tribal peoples of Africa, Asia, Oceania, and the Americas. Empirical material on these topics will be analyzed in such a way as to provide a rounded introduction to the data, methods, and problems of contemporary social anthropology. Instructor: Atkins.

**An 2. The Human Animal.** 9 units (3-0-6); *Senior Elective.* An introduction to modern physical anthropology. Man as a mammal and as a primate; the living varieties of *homo sapiens*; natural and cultural selection in the evolution of living races; Biological factors in human personality, society, and culture. Instructor: Atkins.

**An 3. Human Language.** 9 units (3-0-6); *Senior Elective.* A review of current psychological and anthropological research on human language as a vehicle of communication. The methods and findings of general structural linguistics and of the new field of psycho-linguistics, with special stress throughout on application of modern American English. Instructor: Atkins.

### 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. Instructors: Erdelyi, Whitham.

**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. Not offered in 1963-64. Instructors: De Prima, Wu.

**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 non-linear vibrations, orbital problems, viscous flow, elasticity. Given as a two-term course in the second and third terms 1963-64. Instructor: Cole.

<sup>\*\*</sup>During the junior and senior years certain Institute courses may be substituted for some of the areas of instruction depicted above. When this occurs, and no military classroom instruction is provided, only three units will be granted for Air Science that term.

**AMa 152 abc. Linear and Non-Linear Wave Propagation.** 9 units (3-0-6); three terms. Prerequisite: *AMa 101 or equivalent*. Mathematical formulation, hyperbolic equations, characteristics, shocks. Combined effect of non-linearity and diffusion. Wave propagation with relaxation effects. Dispersive waves, group velocity, geometry of waves, non-linear 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. Given as a two-term course in the first and second terms 1963-64. Instructors: Whitman, Erdelyi.

**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 non-linear oscillator problems. General theory of Markoff processes. Instructors: Liepmann, Caughey, Lagerstrom.

**AMa 170 abc. Linear and Non-Linear 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 non-linear 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. Instructor: Knowles.

**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) and of their representations. The course will be partly based on material in *Group Theory* by Wigner and *The Theory of Groups and Quantum Mechanics* by Weyl. Instructors: Lagerstrom, Kaplun.

**AMa 190. Reading and Independent study.** Units by arrangement.

**AMa 290. Applied Mathematics Colloquium.** 2 units. Three terms.

**AMa 291. Seminar in Applied Mathematics.** 6 units. Three terms.

**AMa 300. Research in Applied Mathematics.** Units by arrangement.

Other courses particularly suitable in making up a program in Applied Mathematics include:

|        |  |
|--------|--|
| Ma 109 | Operational Calculus                       |
| Ma 137 | Introduction to Lebesgue Integrals         |
| Ma 143 | Functional Analysis and Integral Equations |
| Ma 144 | Probability                                |

|        |   |
|--------|---|
| Ma 105 | Introduction to Numerical Analysis                        |
| Ma 205 | Numerical Analysis  |
| AM 174 | Advanced Dynamics I                                       |
| AM 180 | Matrix Algebra  |
| 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 140 | 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. *Text: Mechanics*, Landau and Lifshitz. *Instructors: Caughey, Crede, Hudson.*

**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. Instructors: Lune, Shapiro.

**AM 103 a. Nuclear Radiation Measurements Laboratory.** 9 units (1-4-4); first term. *Prerequisite: Ph 2 abc.* A one-term laboratory course designed to familiarize students with basic nuclear detecting and measuring techniques. The instruments are used to determine the properties of various types of radiation and to observe the nature of their interaction with matter. Instructors: Lune, Shapiro.

**AM 103 b. Nuclear Energy Laboratory.** 9 units (1-4-4); second 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. Instructors: Lune, 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. Photo-elastic method of stress measurements. Analysis of stress and strain in three dimensions. Solution of torsion problems. Wave propagation in elastic solids. Instructors: Housner, Miklowitz.

**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. Instructors: Housner, Miklowitz.

**AM 110 c. Mechanics of Materials.** 6 units (2-0-4); third term. *Prerequisite: AM 110 a.* Use of tensors in elastic theory. Non-linear stress-strain relations. Theory of plasticity. Theories of failures of stressed materials. Instructors: Housner, Miklowitz.

**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. Instructor: Staff.

**AM 113 ab. Engineering Mathematics.** 9 units (4-0-5); first and second, or 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, Miklowitz, 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: Miklowitz, Wayland, and Staff.

**AM 125 abc. Engineering Mathematical Principles.** 9 units (3-0-6); each term. Prerequisites: AM 95 abc, Ma 108, or equivalent. Topics from ordinary and partial differential equations with applications to vibrations, elasticity, theory of sound, fluid mechanics, and diffusion. Instructor: Cole.

**AM 126 abc. Applied Engineering Mathematics.** 12 units (3-0-9); each term. Prerequisites: AM 95 abc, Ma 108, or equivalent. A problem and lecture course in engineering mathematics. Preparation of approximately six reports per term on problems taken from all branches of engineering. First term lectures cover topics in ordinary differential equations including: Lagrange's equations, normal modes of vibration, and nonlinear systems. Second and third term lectures cover topics in partial differential equations including: characteristics, vibration theory, Rayleigh-Ritz method, conformal mapping, Laplace transforms, difference equations, relaxation methods. Instructor: Lindvall.

**AM 130 abc. Applications of Classical Theoretical Physics I.** 9 units (3-0-6); first, second, and third terms. Prerequisite: AM 95 abc, or equivalent. Analytical mechanics of systems of particles, heat conduction, thermodynamics, mechanics of continuous media. Instructors: Plesset, Wu, Hsieh.

**AM 131 abc. Applications of Classical Theoretical Physics II.** 9 units (3-0-6); first, second, and third terms. Prerequisite: AM 95 abc, or equivalent. Kinetic theory, classical and quantum statistical mechanics, electrodynamics, and special relativity. Instructors: Plesset, Wu, Hsieh.

**AM 140. Plasticity.** 6 units (2-0-4); first term. Prerequisites: AM 95 abc, AM 110 ac. Further study in theory of plasticity and applications. Yield criteria and strain hardening in metals. Rules of flow and the general stress-strain laws. Application to problems of combined stress. Creep and relaxation in metals and polymers. Plastico-viscous solid. Introduction to theory of visco-elasticity. Instructor: Miklowitz.

**AM 141 ab. Wave Propagation in Solids.** 6 units (2-0-4); second and third terms. Prerequisites: AM 95 abc, AM 110 a. Theory of wave propagation in solids with applica-

tion to problems. Waves in elastic media. Dispersion of waves in bounded solids. Approximate elasticity theories governing waves in rods, beams, plates and shells. Use of Laplace transform techniques, asymptotic expansion of integrals in deriving wave solutions for these theories. Related experiments. Waves in plastic and viscoelastic media. Damage due to wave action. Instructor: Miklowitz.

**AM 150 abc. Mechanical Vibrations.** 6 units (2-0-4); first, second and third terms. *Prerequisites: AM 95 abc and AM 98 abc, or permission of the instructor.* Theory of vibrating systems with applications to problems of 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 continuing systems. The third term is an introduction to non-linear vibration theory. Instructors: Caughey, Crede, Hudson.

**AM 155. Dynamic Measurements Laboratory.** 9 units (1-6-2); first term. Theory and technique of making measurements encountered in engineering practice and research, with special reference to dynamic measurements. Experiments in vibrations and stability using the latest electro-mechanical and electronic instruments are performed. Instructors: Caughey, Crede, Hudson.

**AM 160. Vibrations Laboratory.** 6 units (0-3-3). *Prerequisite: AM 150 abc.* The experimental analysis of typical problems involving vibrations in mechanical systems, such as a study of the characteristics of a vibration isolation system, or a determination of the transient strains in a machine member subjected to impact loads. The measurements 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, Crede, Hudson.

**AM 174 abc. Advanced Dynamics I.** 6 units (3-0-3). *Prerequisites: AM 125 abc and AM 150 abc or equivalents.* The first two terms will cover topics in advanced linear vibration theory with special emphasis on approximate methods of analysis of complex systems and topics in non-linear vibration theory with special emphasis on systems with strong non-linearities. 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. Given 1960-61. Instructor: Caughey.

**AM 176 abc. Advanced Dynamics II.** 6 units (3-0-3). *Prerequisites: AM 125 abc and AM 150 abc or equivalents.* The first term will be devoted to topics in engineering applications of acoustics. The second and third terms will cover topics in stability of dynamic mechanical systems and in control of mechanical-electrical systems. This course will be given every other year to alternate with AM 174. Instructor: Caughey.

**AM 180. 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.

**AM 181 ab. Linear Programming.** 9 units (3-0-6); second and third terms. *Prerequisite: AM 180 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. Instructor: Franklin.

**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. Given in alternate years. Not offered in 1963-64. Instructor: Cohen.

**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. 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-Schrieffer theory of superconductivity Instructor: Willens.

**AM 225 abc. Advanced Topics in Applied Mathematics.** 9 units (3-0-6). Prerequisite: *AM 125 abc, or equivalent.* Advanced mathematical techniques used in Engineering and Physics. Special emphasis on a systematic theory of partial differential equations. This will include theory of characteristics, Green's functions, tensor analysis, perturbation methods, similarity, Wiener-Hopf method. Selected advanced topics, such as Calculus of Variation, Integral Equations, will be included. The connections between physical and mathematical problems will be emphasized. Instructors: Cole, Lagerstrom, Kaplan.

**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 is intended to give the student sufficient familiarity with astronomy, spectroscopy and astrophysics to enable him to read with profit all but the more technical books and articles dealing with this subject. Reading in a text is supplemented by lectures on current astrophysical topics. Instructor: Greenstein.

**Ay 2 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 interiors and atmospheres. Instructors: Oke, Eggen, Schmidt.

## ADVANCED SUBJECTS

**Ay 108 abc. 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 in alternate years. Not given in 1963-64.

**Ay 112 abc. General Astronomy.** 6 units (3-2-1); *first, second, and third terms.* This subject is the same as Ay 2, with reduced credit for graduate students. Instructors: Oke, Eggen, Schmidt.

**Ay 131 ab. Stellar Atmospheres.** 9 units (3-0-6); *first and second terms.* Prerequisites: Ay 2 abc, Ph 112 abc. Atomic spectroscopy. Stellar spectra. The theory of radiative equilibrium in stellar atmospheres. The continuous absorption by atoms of the continuous spectrum of the stars; the line absorption coefficient and spectral lines. The solar atmosphere. Analysis of stellar spectra. Abundances of the elements. Nucleo-synthesis. Given in alternate years. Not given in 1963-64.

**Ay 132 ab. Stellar Interiors.** 9 units (3-0-6); *second and third terms.* Prerequisites: Ay 2 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.* 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, Field.

**Ay 135. Topics in Modern Astronomy.** 9 units (3-0-6); *second term.* Lecture and seminar course on recent developments and trends in current research. Instructor: Greenstein.

**Ay 136 ab. Planetary Dynamics and Physics.** 9 units (3-0-6); *second, third terms.* Introduction to planetary dynamics for undergraduates. Physical properties of the planets and satellites, their atmospheres and interiors. Interplanetary matter and fields. Comets. The second term will, in 1963-64, be especially for undergraduate students interested in planetary dynamics, orbits, trajectories. Ay 136 b will not be given in 1963-64. Instructor: Münch.

**Ay 140 abc. Seminar in Astrophysics.** 4-12 units; *first, second, 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. Students and visiting research personnel are admitted to the seminar who have the time, inclination and ability to engage in active, constructive work on problems that will be formulated in this seminar. 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 204. Advanced Stellar Spectroscopy.** *9 units (3-0-6); second term.* Spectral classification and review of quantitative analysis. Atmospheric turbulence, stellar rotation. Emission line objects, shell stars and peculiar A stars. Pulsating and red giant variable stars. Mass loss and stellar winds. Instructor: Deutsch.

**Ay 206. Variable Stars.** *9 units (3-0-6); third term.* Observations. Eclipsing stars and the physical properties of the stars. Intrinsic variables, cepheids, long-period and others. Galactic distribution, luminosities. Instructor: Eggen.

**Ay 208. Laboratory in Stellar Astronomy.** *10 units (2-6-2); first term.* Use of astronomical observational and laboratory equipment. Measurement and reduction of research materials. Projects undertaken by the group will involve research on star positions, motions, brightness, color, variability and spectra. Instructor: Eggen.

**Ay 210. Interstellar Matter.** *9 units (3-0-6); third 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); first 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 212. Content and Evolution of Our Own and Other Galaxies.** *6 units (2-0-4); first term.* Analysis of stellar content of galaxies. Photometry and color-magnitude diagrams. Study of star clusters. Age-dating. Chemical composition. Comparison of extra-galactic nebulae and our galaxy. Evolutionary considerations. Distance scale, masses, ages; choice of model universes. Not given in 1963-64.

**Ay 215. Seminar in Astrophysics.** *4 units (1-0-3); second term.* *Prerequisites: Ay 131 and/or Ay 132.* Seminar on recent developments for advanced students. The current observational and theoretical literature will be discussed by the students. Not given in 1963-64. Instructor: Münch.

**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 in alternate years. Not given in 1963-64.

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

**Ay 202. The Solar Atmosphere.**

**Ay 203. Stellar Electromagnetism.**

**Ay 204. Advanced Stellar Spectroscopy.**

**Ay 207. Stellar Luminosities and Colors.**

**Ay 209. Planetary and Diffuse Nebulae.**

**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, Staff.

**Bi 3. Plant Biology.** 12 units (3-6-3); first term. Prerequisite: Bi 1, Bi 9, or consent of instructor. Principles of plant structure, plant diversity, and plant function. Instructor: Lang.

**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: Hodge, Staff.

**Bi 10. Animal Biology.** 12 units (3-6-3); second 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. Embryology.** 12 units (2-6-4); third term. Prerequisite: Bi 10. The subject deals mainly with vertebrate embryology and includes some invertebrate, experimental and cytological material. Instructor: Tyler.

**Bi 107 abc. Biochemistry.** 10 units (3-0-7; 3-3-4; 3-5-2); first, second, and third terms. Prerequisite: Ch 41. A lecture course on the chemical constitution of living matter and the chemical changes in animals, with laboratory work illustrating principles and methods in current use. In the third quarter emphasis is placed upon the application of physical methods to biochemical problems. Instructors: Borsook, Mitchell, Delbrück.

**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: 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. Offered 1963-64 and alternate years. Instructors: Attardi, Staff.

**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 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. (This course was previously listed as Bi 2.) 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: Emerson, Edgar, 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 to be reviewed include genetic determination of protein structure, gene-enzyme relationships, genetic control of metabolism and biosynthetic pathways, and genes and development. 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 1962-63 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: Carusi.

**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: van Harreveld, Lang, Sinsheimer.

**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 ab. 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. Offered in 1962-63 and alternate years. Instructors: Attardi, Staff.

**Bi 220 abc. Experimental Embryology.** 6 units (2-0-4); first, second, and third terms. Lectures and discussion of the problems of embryonic development, including such topics as growth of the ovary, breeding habits of animals, fertilization, cleavage, organ formation, metamorphosis, regeneration, tissue culture, embryonic metabolism, etc. The subject may be taken for two consecutive years since the subject matter will be duplicated only in alternate years. Instructor: Tyler.

**Bi 221. Experimental Embryology Laboratory.** *Units to be arranged; all terms.* The work will include certain classical experiments and instruction in the methods of studying embryonic metabolism, transplantation, vital staining, cytochemistry, 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. Not offered 1963-64. Instructor: Bonner.

**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: 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), virology (290).

## CHEMICAL ENGINEERING

### UNDERGRADUATE SUBJECTS

**ChE 50. Applications of Chemistry.** *9 units (3-0-6); second term.* Consideration of the most recent developments in the field of chemical engineering viewed from the quantitative backgrounds of physics, mathematics, chemistry, and economics. Instructor: Corcoran.

**ChE 61 ab. Industrial Chemistry.** *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 abc.* A study of the more important industrial chemical processes, taking into consideration energy and material balances, chemical equilibria, chemical kinetics, and economics. Instructors: Rinker and Corcoran.

**ChE 63 abc. Chemical Engineering Thermodynamics.** *9 units (3-0-6) first term; 6 units (2-0-4) second term.* Lectures, class exercises, and problems in the engineering thermodynamics of one-component systems. 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 multi-component thermodynamics. Study of the thermodynamics of chemical equilibrium with engineering applications. Instructor: Pings.

**ChE 65. Economics of Chemical Technology.** *9 units (1-0-8); second term.* Detailed studies of the technology and its relation to the economic feasibility of exemplary chemical processes. Offered to seniors in the chemical engineering option as an elective. Instructors: Staff.

**ChE 66 abc. Chemical Engineering Operations.** 12 units (3-0-9); first, second, third terms. **Prerequisite:** ChE 63 abc. Calculations and discussions on the quantitative problems encountered in carrying out chemical processes efficiently on a commercial scale. The unit operations of chemical engineering are studied both as to principle and practice. **Texts:** *Transport Phenomena*, Bird, Stewart, and Lightfoot; *Principles of Unit Operations*, Foust. **Instructor:** Pings.

**ChE 67 ab. Chemical Engineering Laboratory.** 9 units (0-7-2); second, third terms. **Prerequisites:** Ch 21 abc, ChE 63 abc. Instruction and practice in making engineering measurements, and illustration of some of the principles encountered in engineering courses. **Instructor:** Richter.

**ChE 68. Introductory Chemical Engineering Kinetics.** 9 units (3-0-6); first term. **Prerequisite:** Ch 21 abc. A quantitative treatment of the design of chemical reactors. **Instructors:** Corcoran and Rinker.

**ChE 80. Undergraduate Research.** Research in chemical engineering and industrial chemistry offered as an elective in each of three terms. If ChE 80 units are to be used as electives in the Chemical Engineering 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 problem, 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 Chemical Engineering Option without special permission.

**ChE 81. Special Topics in Chemical Engineering.** 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 as electives in the Chemical Engineering Option.

#### ADVANCED SUBJECTS

**ChE 163 abc. Chemical Engineering Thermodynamics.** 6 units (3-0-3) first, third terms; 4 units (2-0-2) second term. This subject is the same as ChE 63 abc for third-year students, but with reduced credit for graduate students. No graduate credit is given for this subject to students in chemical engineering.

**ChE 166 abc. Chemical Engineering Operations.** 8 units (3-0-5); first, second, third terms. **Prerequisite:** ChE 63 abc. This subject is the same as ChE 66 abc, but with reduced credit for graduate students. No graduate credit is given for this subject to students in chemical engineering.

**ChE 167 abc. Chemical Engineering Laboratory.** 15 units (0-15-0); first, second, third terms. **Prerequisites:** Ch 21 abc, ChE 61 ab, ChE 63 abc. A laboratory course providing fundamental training in the methods and techniques of engineering measurements and in research encountered by the chemical engineer. **Instructor:** Richter.

**ChE 168 ab. Mechanics of Fluid Flow.** 9 units (2-0-7); second, third terms. **Prerequisites:** ChE 66 a, AM 95 ab, or taking AM 113 ab concurrently. A study of the flow of fluids in situations of interest to chemical engineers, with emphasis on estimation of velocity and pressure distribution. Subjects include the conservation of momentum and the Navier-Stokes equations, boundary layer theory, turbulence, non-Newtonian fluids, and flow in porous media. **Instructor:** Longwell.

**ChE 169. Advanced Industrial Chemistry.** 9 units (2-0-7); first term. *Prerequisites: ChE 61 ab, ChE 63 abc.* An extension of ChE 61 with emphasis on quantitative approaches to industrial chemical problems. Consideration is given to the more important chemical reactions of industrial interest. Chemical kinetics and material and energy balances are treated. Instructor: Corcoran.

**ChE 170. Chemical Process Dynamics.** 9 units (2-0-7); third term. *Prerequisite: Ma 2 abc.* A treatment of automatic control of chemical processes with emphasis on theory and dynamic response. Instructor: Richter.

**ChE 171 ab. Chemical Engineering Applied Mathematics.** 9 units (2-0-7); first, second terms. *Prerequisite: AM 95 ab.* Handling and interpretation of data including elementary statistical treatment, Laplace transforms and other methods of solution of linear partial differential equations, numerical solution of ordinary and partial differential equations, calculus of finite differences. Instructor: Longwell.

**ChE 172. Heat Transfer.** 9 units (2-0-7); third term. *Prerequisite: ChE 66 abc.* Detailed consideration of problems in thermal transfer. Instructor: Sage or Corcoran.

**ChE 262 abc. Thermodynamics of Multi-Component Systems.** 9 units (2-0-7); first, second, third terms. *Prerequisites: ChE 61 ab, ChE 63 abc, AM 95 ab, or taking AM 113 ab concurrently.* A presentation of the background necessary for a working knowledge of multi-component open systems from the engineering viewpoint. A discussion of the volumetric and phase behavior of pure substances, and of binary, ternary, and multi-component fluid systems at physical and chemical equilibrium is included as a part of this thermodynamic treatment. The solution of numerous problems relating to the application of these principles to industrial practice constitutes a part of this course. Texts: *Volumetric and Phase Behavior of Hydrocarbons*, Sage and Lacey; *Thermodynamics of Multi-Component Systems*, Sage. Instructor: Sage.

**ChE 263 abc. Transfers in Fluid Systems.** 12 units (2-0-10); first, second, third terms. *Prerequisites: ChE 66 abc, ChE 168 ab, AM 95 ab, or taking AM 113 ab concurrently.* A consideration of thermal and material transfers in fluid systems under conditions encountered in practice. Emphasis is placed upon point conditions and upon the analogies between momentum, thermal, and material transfers in turbulent flow. The greater part of the effort in the course is devoted to the solution of transfer problems, many of which require the use of graphical or numerical methods for solution of the differential equations involved. Given in alternate years. Offered in 1963-64. Instructor: Sage.

**ChE 266 abc. Applied Chemical Kinetics.** 9 units (2-0-7); first, second, third terms. *Prerequisite: ChE 66 abc.* Both homogeneous and heterogeneous kinetics are studied. Design of various types of reactors is treated on the basis of the associated phenomena of material, energy and momentum transfer. In the third term an extended problem in the design of a chemical reactor wherein there is simultaneous energy, material and momentum transfer is considered, and the Datatron 220 digital computer is used in the solution of the problem. Given in alternate years. Offered in 1962-63. Instructor: Corcoran.

**ChE 280. Chemical Engineering Research.** Offered to Ph.D. candidates in Chemical Engineering. The main lines of research now in progress are:

Influence of turbulence upon heat transfer in fluids.

Influence of turbulence on the transfer of material through fluids.

Phase and thermodynamic behavior of hydrocarbons and other fluids.

Studies of non-equilibrium behavior of fluid systems at elevated pressure.

Reaction kinetics in flow and non-flow systems.

Study of gas chromatography in analytical chemistry and mass transfer.

Application of mathematics to complex chemical engineering problems.

Liquid state physics.

Chemical thermodynamics.

Thermodynamics of irreversible processes.

**ChE 291 abc. Chemical Engineering Conference.** 2 units (1-0-1); first, second, third terms.

Oral presentations on industrial chemistry and chemical engineering problems of current interest. 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, and electrical 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: *General Chemistry*, Pauling; *Quantitative Chemistry*, Waser; and *Qualitative Elemental Analysis*, Swift and Schaefer. Instructors: Swift, Schaefer, other staff members, and assistants.

**Ch 13 abc. Inorganic Chemistry.** 6 units (2-0-4); first, second, third terms. *Prerequisites:*

*Ch 1 abc, Ch 21 ab.* The chemical and physical properties of the elements are discussed with reference to the periodic system and from the viewpoints of atomic structure and radiation effects. Such topics as coordination compounds, the liquid ammonia system, the compounds of nitrogen, the halides, and selected groups of metals are taken up in some detail. The class work is supplemented by problems which require a study of current literature. Instructor: Yost.

**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. 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 thermodynamics, statistical mechanics, and atomic theory, and their application to the quantitative interpretation of the properties of matter. Instructors: Robinson and Dickerson.

**Ch 24 ab. Physical Chemistry for Geologists.** 10 units (4-0-6); first, second terms. *Prerequisites:* *Ch 1 abc; Ma 2 abc; Ph 2 abc.* A discussion of selected topics in physical chemistry, adapted to the needs of Science Course students in the Geology Option. Instructor: Hughes.

**Ch 26 ab. Physical Chemistry Laboratory.** 8 units (0-6-2); second, third terms. *Prerequisites:* *Ch 1 abc; Ch 21 a.* Text: *Experiments in Physical Chemistry*, Badger. Instructors: Badger and Chan.

**Ch 41 abc. Basic Organic Chemistry.** 10 units (3-0-7) first term; 4 units (2-0-2) second, third terms. Prerequisite: Ch 1 abc. Lectures and recitations relating to the classification of carbon compounds, development of fundamental theories, and preparation and characteristic properties of the principal classes of carbon compounds. Text: *Basic Principles of Organic Chemistry*, Roberts and Caserio. Instructor: Roberts.

**Ch 46 ab. Basic Organic Chemistry Laboratory.** 6 units (1-5-0); second, third terms. Prerequisite: Ch 1 abc. Laboratory exercises to accompany Ch 41 abc. The preparation and purification of carbon compounds and the study of their characteristic properties. Qualified students may pursue research work. 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 abc. Inorganic Chemistry.** 4 units (2-0-2); first, second, third terms. Selected groups of inorganic compounds will be considered from modern physicochemical viewpoints; thus with reference to their physical properties, their thermodynamic constants (their heat-contents, free-energies, and entropies), their rates of conversion into one another (including effects of catalysis and energy radiations), and their molecular structure and valence relations. Instructor: Yost.

**Ch 117. Electroanalytical Chemistry.** 4 units (2-0-2); second term. The theory and practice of selected electroanalytical techniques are presented. Topics covered include potentiometry, diffusion currents, polarography, amperometry, coulometry, chronopotentiometry, and other electrochemical methods. Text: *Electroanalytical Chemistry*, Lingane. Not offered in 1963-64. Instructor: Anson.

**Ch 118 ab. Electroanalytical Chemistry Laboratory.** 6 units (0-6-0); second, third terms. Laboratory experiments involving the use of electroanalytical instruments. Not offered in 1963-64. Instructor: Anson.

**Ch 120. Electric and Magnetic Properties of Molecules.** 6 units (2-0-4); third term. Topics discussed are index of refraction and birefringence of substances, electronic polarizability of molecules, dielectric constant, diamagnetism, paramagnetism, ferromagnetism, ferrimagnetism, antiferromagnetism, Kerr effect, electric dipole moments, magnetic moments, and other molecular properties, especially in relation to the structure of molecules and crystals and the nature of the chemical bond. Not offered in 1963-64. Instructor: Pauling.

**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. Given in alternate years. Not offered in 1963-64. Instructor: Marsh.

**Ch 124 ab. Physical Chemistry for Geologists.** 6 units (4-0-2); first, second terms. This course is the same as Ch 24 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 brief but quantitative introduction to quantum mechanics, and is otherwise devoted primarily to both theoretical and experimental aspects of the electronic wave functions of molecules and solids. Illustrative topics are: molecular orbital and valence bond theories of molecules, Bloch states in solids, and applications of electron and nuclear magnetic resonance to electronic structure problems. Instructor: McConnell.

**Ch 127 abc. Radioactivity and Isotopes.** 6 units (2-0-4); first, second, third terms. The fundamental particles and isotopes. Nuclear structure. Natural and artificial radioactivity. Instrumentation in nuclear studies. Techniques of radiochemistry. The applications of stable and radioactive isotopes to various chemical studies. Instructor: Yost.

**Ch 128 ab. Electronic Structure of Molecules.** 6 units (2-0-4); second, third terms. *Prerequisite: Ch 21 abc.* Molecular electronic structure is treated with particular reference to chemical and geometric properties of molecules and the variation of these properties with electronic excitation. An elementary introduction to group theoretical methods in molecular problems is presented. A generally descriptive treatment follows of the electronic structure of organic and inorganic prototype molecules, free radicals, and ions, starting from the molecular orbital and valence bond approximations. The nature and chemical importance of the coupling of electronic motions with other kinds of molecular motions are stressed, and a discussion of inter-molecular interactions is given. Given in alternate years. Offered in 1963-64. Instructor: Robinson.

**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 1963-64. 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: Carusi.

**Ch 135. Chemical Kinetics.** 6 units (2-0-4); third term. The mechanics of chemical reactions as revealed by various methods, especially rate measurements and photochemical experiments, are discussed. Both theoretical and experimental aspects of the subject are studied. Topics include the transition state theory and the collision theory, unimolecular reactions, ionic reactions, modern experimental approaches to the nature of transient intermediates and elementary reactions, molecular structure and reactivity, tracer studies, hydrodynamics and kinetics. Text: *Foundations of Chemical Kinetics*, Benson. Offered in 1963-64. Instructor: Davidson.

**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. 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: Hammond.

**Ch 145. Advanced Organic Chemistry Laboratory.** 7 units (1-5-1); first term. Prerequisites: Ch 41 c, Ch 46 b. Advanced laboratory practice, synthetic experiments, use of kinetics in mechanistic studies, and selected optional work. Instructors: Hammond, Brown, and assistants.

**Ch 148 abc. Characterization of Organic Compounds.** 4 units (2-0-2); first, second, third terms. Prerequisites: Ch 41 abc, Ch 46 ab. 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: Niemann.

**Ch 149 abc. Laboratory in Characterization of Organic Compounds.** 6 units (0-6-0); first, second, third terms. Prerequisites: Ch 41 abc, Ch 46 ab, and consent of instructor. Laboratory exercises to accompany Ch 148. The isolation, purification, and identification of organic compounds with special reference to the manipulation of milligram and decigram quantities. Qualified students may pursue research work. Instructors: Niemann and assistant.

**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 abc. Statistical Mechanics.** 9 units (3-0-6); first, second, third terms. After a survey of the principles of classical and quantum mechanics and of the theory of probability, the equilibrium theory of statistical mechanics is developed and used to interpret the laws of thermodynamics from the molecular standpoint. A detailed study of the relationships between the thermodynamic functions of gases, liquids, and solids and their structure on the molecular scale follows. Given in alternate years. Offered in 1963-64. Instructor: Kuppermann.

**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 1963-64. Instructor: Badger.

**Ch 226 abc. Introduction to Quantum Mechanics, with Chemical Applications.** 9 units (3-0-6); first, second, third terms. *Prerequisite: Ch 125 abc, or Ph 112 abc, or the equivalent.* A review of the physical and historical background of the quantum theory is followed by a treatment of the mathematical formalism. Some exactly soluble problems are discussed and approximate methods for more complicated problems are developed. The structure of atoms and molecules, the theory of spectra, and if time permits other special topics will be treated. Offered in 1963-64. Instructor: Pitzer.

**Ch 227 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 1963-64. Instructor: Sturdivant.

**Ch 229 ab. X-Ray Diffraction Methods.** 6 units (2-0-4); second, third terms. *Prerequisite: Ch 227 abc or equivalent.* An advanced discussion of the techniques of structure analysis by X-ray diffraction. Given in alternate years. Not offered in 1963-64. Instructors: Hughes, Marsh.

**Ch 233 ab. The Metallic State.** 6 units (2-0-4); first, second terms. The physical, electrical, and magnetic as well as the structural, chemical, and thermodynamic properties of metals and alloys considered from modern viewpoints. Instructor: Yost.

**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. Not offered in 1963-64. 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. The course is given as a continuing cycle such that each of the major areas is presented once every three years. Instructor: Richards.

**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 1963-64. Instructor: Roberts.

**Ch 247 ab. Organic Reaction Mechanisms.** 6 units (2-0-4); first, second terms. Prerequisite: Ch 144 or equivalent. Various tools for the study of organic reaction mechanisms will be discussed with major emphasis on kinetic methods. Given in alternate years. Not offered in 1963-64. 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 1963-64. Instructor: Niemann.

**Ch 254 ab. The Chemistry of Amino Acids and Proteins.** 3 units (1-0-2); first, second terms. Prerequisites: Ch 41 abc, Ch 46 ab. A consideration of the physical and chemical properties of the amino acids, peptides, and proteins. Given in alternate years. Offered in 1963-64. Instructor: Niemann.

**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: *Experimental Immunochemistry*, Kabat and Mayer, *Principles of Immunology*, Cushing and Campbell, *Fundamentals of Immunology*, Boyd, and *The Proteins*, Neurath and Bailey. 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 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 mechanisms of electrode reactions. Inorganic analytical methods.

In organic chemistry—

Mechanism of organic reactions in relation to electronic theory.

Isolation of alkaloids and determination of their structure.

Structural elucidation and biosynthesis of natural products.

Chemistry and reaction mechanisms of metallocenes.

Isotope effects in organic and biochemical reactions.

Chemistry of amino acids and peptides.

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.

Enzymatic cleavage and formation of amide bonds.

Chemical analysis of proteins and determination of the order of amino-acid residues in polypeptide chains.

Physical chemical studies of nucleic acids.

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.

Nature of sickle cell anemia and other hemolytic diseases.

Behavior of biological macromolecules in the ultracentrifuge.

Chemistry in relation to mental disease.

**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, physical chemistry, 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 8 and AM 9 (may be taken concurrently).* 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. Instructor: Staff.

#### ADVANCED SUBJECTS

**CE 105. Introduction to Soil Mechanics.** 9 units (2-3-4); first term. Prerequisites: AM 8, AM 9. 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. Instructors: Housner, 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. Instructors: Housner, 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. Applied Microbiology.** 10 units (2-4-4), second term; 9 units (2-3-4), third term. *Prerequisites: Ch 4-1 abc, Bi 1, and Bi 9, or equivalents. (Ch 41 abc may be taken concurrently).* An investigation of the various groups of microorganisms, particularly bacteria; their morphology, cytology, taxonomy, physiology, nutrition, ecology, and pathogenesis. The influence of microorganisms upon man and his environment. The course includes topics on epidemiology, industrial microbiology, aquatic and marine microbiology, and the microbiology of water and sewage. 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, Ch 21 abc, AM 113 ab, CE 145 ab, and CE 155, or equivalents. (CE 145 ab 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, Samples, 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 151 abc. Air Resources Engineering.** 9 units (2-3-4); first, second, and third terms. *Prerequisites: Ch 1 abc, Ph 2 abc, Ma 2 abc, ME 17 ab, ME 19 ab.* The application of engineering analysis and scientific phenomena to problems of atmospheric pollution; evaluations of source emissions, meteorologic and climatologic factors, air quality measurements, aerosol properties and behavior, photochemical reactions, effects on animate and inanimate receptors; and principles of engineering control. Instructor: Friedlander.

**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. Instructor: 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. Prerequisites: CE 137 ab, CE 138 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. Instructors: McKee, Samples.

**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 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

The following courses in computers and their application to applied mathematics and engineering analysis are offered under the various options indicated.

**EE 180 abc. Digital Computer Design.** See Electrical Engineering Section for description.

**EE 181 ab. Principles of Analog Computation.** See Electrical Engineering Section.

**EE 280 abc. Advanced Course in Machine Computing Methods for Engineering Analysis.** See Electrical Engineering Section.

**AM 180. Matrix Algebra.** See Applied Mechanics Section.

**Ma 105 ab. Introduction to Numerical Analysis.** See Mathematics Section.

**Ma 205. Advanced Topics in Numerical Analysis.** See Mathematics Section.

#### ECONOMICS

##### UNDERGRADUATE SUBJECTS

**Ec 4 ab. Economic Principles and Problems.** 6 units (3-0-3); first term, and either second or third term. A course in economic life, institutions, and problems, stressing the national income approach. Subjects studied parallel those of Ec 2 ab, with such difference in emphasis as is necessary to make this shorter course complete in itself. Instructors: Sweezy, Brockie, Untereiner, Sherman.

**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.** 10 units (4-0-6); *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) business organization, 2) industrial promotion and finance, 3) factory management, 4) industrial sales, 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.* 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 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.

\*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 AM 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 fulfillment of requirements for a Ph.D. minor in Economics.

**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); *first 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); *second 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 124. Economic Problems of Underdeveloped Areas.\*** 9 units (3-0-6); *third term*. *Senior elective*. An examination of economic conditions in low income countries. Modern techniques of promoting development are studied, including international assistance programs and national economic planning. Instructor: Oliver.

**Ec 125 abc. Technical Cooperation (Seminar).** 9 units (3-0-6). *Senior elective*. This special seminar will be conducted experimentally during the year 1961-1962 as a part of the Carnegie Science and Public Affairs program. The primary objectives of the seminar are to prepare students for participation in technical cooperation programs, both in the United States and overseas, and to provide an opportunity for an intensive examination of the technical problems of raising living standards in newly developing countries. Guest lecturers and faculty from other divisions will participate in the seminar. Research projects will be undertaken by the students. Instructor: Oliver.

**Ec 126 abc. Economic Analysis and Policy\* (Seminar).** 9 units (3-0-6); *first, second, third term*. *Senior elective*. Open to students who have taken Ec 2 ab or Ec 4 ab and to other qualified students with the consent of the instructor: Instructors: Sweezy, Sherman.

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

## ELECTRICAL ENGINEERING

## UNDERGRADUATE SUBJECTS

**EE 1 abc. Basic Electrical Engineering.** 9 units (3-0-6); first, second, third terms. Prerequisites: *Ma 1 abc; Ph 1 abc*. An introductory course in circuit analysis, energy conversion, electromechanical devices, vacuum and solid-state devices and circuits. Instructors: Staff.

**EE 2 ab. Basic Electrical Engineering Laboratory.**

**EE 2 a. Laboratory in Electrical Circuits.** 3 units (0-3-0); second term. Prerequisite: *EE 1 a*. This course is the laboratory for *EE 1 a*. The experiments are designed to acquaint the student with techniques of electrical measurements and to provide experimental verification of the behavior of passive electrical circuits. Instructor: Nicolet.

**EE 2 b. Laboratory in Electronics.** 3 units (0-3-0); third term. Prerequisites: *EE 1 ab, EE 2 a*. This course is the laboratory for *EE 1 b*. The experiments are designed to acquaint the student with techniques of electrical measurements and to provide experimental verification of the properties of electron devices and simple electronic circuits. Instructor: Nicolet.

**EE 5. Introductory Electronics.** 9 units (3-0-6); third term. Prerequisite: *Ph 1 abc*. 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 amplifiers and switching circuits. Instructor: Langmuir.

**EE 7 abc. Experimental Techniques in Electrical Engineering.** 5 units (0-3-2); first, second and third terms. A general laboratory program designed primarily to prepare the student to participate in current experimental research in the fields of electrical engineering and physical electronics. Emphasis is placed not only upon careful laboratory procedure but also upon selection of significant projects and interpretation of data. Formal laboratory experiments are available for students whose experimental background is insufficient to permit them to carry on original work. Text: *Literature references*. Instructor: Mead.

## ADVANCED SUBJECTS

**EE 101 abc. Electric Circuit Theory.** 9 units (3-0-6); first, second and third terms. Prerequisites: *EE 1 abc; AM 116*. Steady state and transient analysis of linear electric circuits. Application of transform methods. Elementary principles of circuit synthesis, filter theory, distributed systems including transmission lines. Instructor: Hertel.

**EE 106 ab. Electronic Circuits.** 9 units (3-0-6); first and second terms. Prerequisite: *EE 1 abc*. A course covering the general areas of nonlinear electronics. Diode circuits, rectifiers, clippers, clamps, mixers. Transistor and vacuum tube amplifiers treated from the equivalent circuit point of view; biasing, gain, frequency response, class A, B and C power output and limitations. Transistor switching, saturation, power converters, transistor choppers, direct coupled transistor logic. Oscillators; relaxation and harmonic, using 3 terminal and negative resistance devices. Modulation (AM and FM) methods. Texts: *Transistor Circuit Analysis*, Joyce and Clarke; *Electronic and Radio Engineering*, Terman. Instructor: Mead.

**EE 107. Principles of Feedback.** 9 units (3-0-6); third term. Prerequisite: *EE 101 ab*. Basic principles of linear feedback theory. Automatic control systems, feedback amplifiers, oscillators.

**EE 115 abc. Electromagnetism.** 9 units (3-0-6); first, second, third terms. Prerequisites: *Ph 2 abc; Ma 2 abc; AM 95 a, b.* A course in theoretical electricity and magnetism, primarily for electrical engineering students. Topics covered include electrostatics, magnetostatics, Maxwell's equations, wave-guides, cavity resonators, and antennas. EE 115 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: Langmuir.

**EE 132 abc. Network Synthesis.** 9 units (3-0-6); first, second, third terms. Prerequisite: *EE 101 ab.* 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. Text: *Synthesis of Passive Networks*, Guillemin; *Principles of Microwave Circuits*, Montgomery et al. Instructor: George.

**EE 140 abc. Communication Theory.** 9 units (3-0-6); first, second, third terms. Prerequisite: *EE 101 ab.* Modern methods in the statistical theory of communication systems. A review of probability theory and statistical methods. Sampling theorems, autocorrelation and cross correlation functions, spectral densities. Noise, its description, properties and effects. Optimum linear circuits (Wiener filters) for smoothing or prediction of statistical signals in noise. Information and decision theoretic models for the communication of information in the presence of noise. Entropy of a finite source, channel capacity, and coding theorems. Modulation and estimation methods for continuous signals. Instructor: Grettberg.

**EE 150 abc. Electromagnetic Fields.** 9 units (3-0-6); first, second, third terms. Prerequisites: *EE 115 ab or Ph 107.* 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 162 abc. Physics of Electronic Devices.** 6 units (2-0-4); first, second, third terms. Prerequisite: *EE 1 ab.* A course in the physical principles of electron devices and an introduction to atomic and molecular physics. Motion of charged particles in electric and magnetic fields and applications. Electronic phenomena in metals; conduction, emission, contact potential. Electrical conduction in gases; breakdown, plasmas, gas tubes. Electronic phenomena in semiconductors; transistors. Instructor: Mason.

**EE 164 abc. Microwave Electronics and Magnetics.** 9 units (3-0-6); first, second, third terms. Prerequisites: *EE 115 ab or Ph 107.* Principles of interaction between the electronic charge and spin with microwave electromagnetic fields. Generation and focusing of high-current electron beams with electric and magnetic fields. Velocity modulation, transit time effects, plasma oscillation and space charge wave propagation, and traveling wave interaction with electron beams with application to microwave amplifiers and oscillators. The electromagnetic theory of slow-wave circuits and noise in electron beams will also be considered. Electron spin resonance and relaxation phenomena will be discussed. The interaction of electromagnetic fields with magnetic materials with application to the behavior of quantum amplifiers such as Masers and Lasers, microwave ferrite devices, and thin magnetic films will be treated in detail. Instructor: Soohoo.

**EE 165. Microwave Laboratory.** 6 units (1-3-2); second term. Prerequisite: EE 132 or EE 150 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: George.

**EE 170 abc. Feedback Control Systems.** 9 units (3-0-6); first term; 12 units (3-3-6); second and third terms. Prerequisites: EE 101 ab, EE 107. A study of automatic feedback control systems. Basic theory and methods of analysis and synthesis; root locus methods, the Nyquist criterion, and analog computer techniques. Multiple loop systems. Non-linear systems with emphasis on phase plane and describing function techniques. Sampled-data systems. The laboratory experiments are designed to acquaint the student with characteristics of practical components, but emphasis is placed on a correlation of observed response with predictions based on the various theoretical methods.

**EE 171 abc. Sampled-Data Systems.** 6 units (2-0-4). Prerequisites: EE 170, AM 116. A study of feedback systems which operate on pulsed-data. The analysis of sampled-data systems using the z-transform and the modified z-transform; root locus techniques and frequency response of sampled-data systems; difference equations applied to sampled-data systems. Compensation by discrete and continuous networks. The synthesis of optimum discrete systems using statistical techniques. Selected topics on non-linear sampled-data systems. Text: *Sampled-Data Control Systems*, Jury. Not offered in 1963-64.

**EE 180 abc. Data Processing Systems and Switching Theory.** EE 180 a, 9 units (3-3-3); EE 180 bc, 9 units (3-0-6). The first term is concerned with the basic principles of logical design and instrumentation of digital computers with an introduction to modern switching theory, pulse circuitry, and electronic instrumentation principles. The laboratory permits a study of the design and operating characteristics of the actual computers. The second and third terms are a more detailed treatment of switching theory and switching circuit synthesis as applied to modern concepts of instrumenting complex data processing systems, together with more advanced concepts of machine organization for data processing. Text: *Logical Design of Digital Computers*, Phister (first term); course notes (second and third terms).

**EE 181 ab. Principles of Analog Computation.** 12 units (3-3-6); second, third terms. Prerequisite: AM 180. General survey of the basic principles of electric analog computing techniques. Development and application of electronic differential analyzer and direct analogy principles. Synthesis of passive analogies—lumped parameter systems. Synthesis of passive analogies—distributed systems. Synthesis of active circuit analogies. Applications to solid mechanics, aeroelasticity, heat transfer, fluid mechanics, servomechanisms. Text: Course notes. Instructor: McCann.

**EE 190 abc. Advanced Electronics.** 9 units (3-0-6); first, second, third terms. An integrated treatment of the theory and application of vacuum and solid-state electronic devices. 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 vacuum and semiconductor triodes, and their static and incremental models. Design of bias networks. Practical design of feedback and d-c amplifiers. Instructor: Middlebrook.

**EE 191 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 filter, band theory of crystal electrons, holes, semiconductors, theory of p-n junctions and p-n junction transistors. Not offered in 1963-64. Instructor: Nicolet.

**EE 195 abc. Electronic Processes in Solids. 9 units (3-0-6); first, second, third terms.** *Prerequisite: EE 162 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: Mason, Nicolet, Mead, Wilts.

**EE 200. 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. The Institute is equipped to an unusual degree for the following lines of work: electronic devices and their application, physical electronics, microwave tubes, transistor applications, electromechanical devices, control systems, communications and information theory, electromagnetic wave propagation and antennas, analog and digital computers, engineering analysis requiring large scale computing techniques.

**EE 220. 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 240 abc. Advanced Communication Theory. 9 units (3-0-6); first, second, third terms.** *Prerequisite: EE 140 abc.* An advanced course in statistical communication theory dealing with optimum receivers for the detection of signals in noise, the noisy channel and its implications, and signal selection and coding. The course will emphasize the mathematical aspects of modern communication theory. Instructor: Braverman.

**EE 250 abc. Boundary-Value Problems of Electromagnetic Theory. 9 units (3-0-6); first, second, third terms.** *Prerequisite: EE 150 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. Not offered in 1963-64. Instructor: Papas.

**EE 260 abc. Topics in Physical Electronics. 4 units (1-0-3); first, second, and third terms.** *Prerequisite: EE 164 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 1963-64.

**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 290. Topics in Solid State Devices and Circuits.** *6 units (2-0-4); third term. Prerequisite: EE 190 ab.* Advanced treatment of a selection of topics including silicon controlled rectifiers, field-effect transistors, and their applications. A term paper will be required. Instructor: Middlebrook.

**EE 292. Magnetic Properties of Solids.** *6 units (2-0-4); first and second terms. Prerequisite: EE 162 or Ph 111 or equivalent.* The theory of diamagnetism, paramagnetism, and ferromagnetism are treated both classically and quantum mechanically, with application to the behavior of masers, ferrites and thin films. The topics covered include the following: magnetic susceptibility, paramagnetic and ferromagnetic resonance and relaxation, spin waves excitation and non-linear effects, anisotropy, coercive force, domain wall motion and magnetization reversal in ferromagnetic materials. Instructor: Soohoo.

### 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.** *2 units (1-0-1); 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: Welch, Kiceniok.

**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. Instructor: Welch.

**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. Instructor: Welch.

### ENGLISH

#### UNDERGRADUATE SUBJECTS

**En 1 abc. Literature.** 6 units (3-0-3); *first, second, third terms.* A study of literary documents illustrating Rationalism, Romanticism and the Modern Reaction with frequent analytical and critical papers assigned. Instructors: Bowerman, Clark, Eagleson, Langston, Mandel, Stanton, D. Smith.

**En 7 abc. Advanced Literature.** 8 units (3-0-5); *first, second, third terms.* Prerequisite: *En 1 abc.* 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. Instructors: Bowerman, Clark, Eagleson, Eaton, Langston, Mandel, Miller, D. Smith, Stanton.

**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: Stanton.

**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. Instructor: Stanton.

**En 12 abc. Debating.** 4 units (2-0-2). A study of the principles of argumentation; systematic practice in debating; preparation for intercollegiate debates.

**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.

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**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 19. Seminar in Literature.\*** 9 units (3-0-6); second term, Senior Elective. Prerequisite: En 7. The subject matter of this course arises from the interest of the students registered in any given term. Each student is required to give a long oral report to the class on some humanistic subject selected by himself with the approval of the instructor. The number registered for the course in any term is strictly limited and is by permission of the instructor. Hours by arrangement. Instructor: Eagleson.

**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). 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: H. Smith.

#### 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

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

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.* 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.

**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. In charge: Sharp (first term).

**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 109. Structural Geology.** 6 units (1-3-2); first term. *Prerequisites: Ge 1, Ge 2, Ge 3.* A problem course in the interpretation and description of geologic structures. Includes use of descriptive geometry and stereographic projection in solution of geologic problems; mechanical properties of rocks; geologic scale models. Instructor: Allen.

**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. Instructor: Degens.

**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 and 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 1963-64. 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. General Geophysics (and Planetary Interiors).** 6 units (3-0-3); third 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 171. Applied Geophysics I.** 10 units (4-2-4); second term. The use of gravity, magnetic and seismic methods applied to geological field problems. Theoretical background and field practice. Not offered in 1963-64. 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, Deby-Hückel 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. Instructor: Degens.

**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 occurring 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. (Offered in 1963-64). Instructor: Wasserburg.

**Ge 220 ab. Lunar and Planetary Surfaces.** 9 units (3-0-6); second term. 9 units (3-1-5); third term. Prerequisites: Ph 107 abc and Ge 115 ab desirable. Consult with instructor. Observational evidence pertaining to the surface geology and geophysics of the Moon and Mars 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 extra-terrestrial 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 propagation 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. Offered in 1962-63. 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 alternate years (1962-63). Instructors: Allen and 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 (1963-64). Instructors: Kamb and 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 tectonic 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. Not offered in 1963-64. Instructor: Richter.

**Ge 264 ab. Elastic Waves.** 8 units (4-0-4); first and second terms. Prerequisites: Ph 107 abc and Ph 108 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. Instructors: Press and Knopoff.

**Ge 265 ab. Advanced General Geophysics.** 9 units (3-0-6); second and third terms. Prerequisites: Ph 107 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. Instructors: Knopoff and Press.

**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. Not offered in 1963-64. 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, Phinney, 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
- (U) Planetary Science

## GERMAN

(See under *Languages*)

## HISTORY AND GOVERNMENT

## UNDERGRADUATE SUBJECTS

**H 1 abc. History of European Civilization.** 5 units (2-0-3); *first, second, third terms*. An introduction to the history of Europe from 1648 to the present. The course will include discussions of political, social, and economic problems, and of the more important theoretical concepts of the period. Instructors: Ellersieck, Elliot, Fay, Huttenback.

**H 2 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: Paul, Strout, Langdon, B. L. Jones.

**H 4. The British Empire and the 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 5 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 7. Modern and Contemporary Germany.\*** 9 units (3-0-6). *Senior Elective*. A study of what is sometimes called "The German Problem." Attention will be focused on the rise of Prussia, on Prussian leadership in the unification and direction of Germany, and on the place of Germany in the economy of Europe. Particular stress will be placed upon the German experience since the first World War.

**H 8. Modern and Contemporary 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 15. 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 these upheavals of the twentieth century and their effect on domestic and international organization. Instructor: Fay.

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**H 16. American Foreign Relations.\* 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 17. The Far West and the Great Plains.\* 9 units (3-0-6). Senior Elective.** A study of the development of the great regions that compose the western half of the United States. Especial attention will be paid to the influence of the natural environment on the men who settled the West, from pioneer days to the present time, and the exploitation of natural resources, through such industries as mining, ranching, oil and farming. Instructor: Paul.

**H 19. Modern America.\* 9 units (3-0-6). Senior Elective.** The great issues and personalities of Twentieth Century America. Instructor: B. L. Jones.

**H 20. Modern and Contemporary France.\* 9 units (3-0-6). Senior Elective.** A study of modern France in the light of her revolutionary tradition. A consideration of the French Revolution followed by an examination of selected episodes between 1815 and 1944 (the June Days, the Paris Commune, the Dreyfus affair, the Stavisky riots, the Vichy regime) which reflect continuing revolutionary strain. Instructor: Fay.

**H 21. Medieval England.\* 9 units (3-0-6). Senior Elective.** Feudalism as a political system, and its part in the early development of parliamentary democracy, approached principally through the study of selected political episodes in English history, 1066-1485. Instructor: Fay.

**H 22. Modern Britain.\* 9 units (3-0-6). Senior Elective.** A study of Britain's recent past with particular emphasis upon the development of the working class movement. Instructor: Elliot.

**H 23. 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 24 a. Political Behavior.\* 9 units (3-0-6). Senior Elective.** An examination of general behavior patterns and tendencies of individuals as related to their political behavior and to appropriate types of political institutions. Relevant psychological and sociological theory and research will be discussed in an effort to find the kinds of government suitable to people living in modern technological and industrial society. Instructor: J. Davies.

**H 24 b. Political Revolution. 9 units (3-0-6). Senior Elective.** An analysis of various revolutions in light of the basic psychic and social forces which impel individuals to fight for and support a drastic, sudden change in the political power structure of their society. Instructor: J. Davies.

**H 25. Political Parties and Pressure Groups.\* 9 units (3-0-6). Senior Elective.** A study of those institutions through which individuals and groups seek to control governmental policy and administration. Particular attention will be focused on parties as formulators of individuals' political wants, fears, and expectations and as transmitters of these programs to government. Instructor: J. Davies.

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**H 26. The Political Novel.\*** *9 units (3-0-6). Senior Elective.* A political and literary appraisal of modern novels that attempt to explain and to judge relationships between the individual and the state in both free and totalitarian societies. The class will meet under the joint supervision of a professor of English and a political scientist. Instructors: J. Davies, Stanton.

**H 28. American Political Ideas.\*** *9 units (3-0-6).* Historical and analytical examination of liberal, conservative and radical thought with an emphasis on reading in original sources. Instructor: Strout.

**H 29. American Philosophical Ideas.** *9 units (3-0-6).* A survey of American intellectual history in the 19th and 20th centuries, with particular emphasis on philosophical, literary, religious, artistic, and historical thought. Instructor: Strout.

**H 30. The Individual and Society in America.\*** *9 units (3-0-6).* Readings in some "classics" of American history, centered about the relation of the individual to the larger community at different periods. Problems such as status and social mobility, personal and group values and tensions, nonconformity and social criticism, and the development of the American character will be discussed. Instructor: Strout.

**H 31. The Making of the American Republic.\*** *9 units (3-0-6).* A study of the American Revolution and the emergence of the new nation, 1754-1800. Instructor: Langdon.

**H 32. The Seventeenth Century World.\*** *9 units (3-0-6).* England and her American colonies in the seventeenth century. Instructor: Langdon.

**H 35. Modern India and Pakistan.\*** *9 units (3-0-6).* The course will deal with 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 40. Reading in History.** *Units to be determined for the individual by the department. Elective, in any term. Approval of the Registration Committee is required where excess units are involved.* 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 100 abc. Seminar in History and Government.** *9 units (2-0-7).* Studies in English and American civilization. The reading will be chiefly in biographies of great men and women, famous novels, and suggestive essays in historical and political interpretation. Instructor: Fay.

**H 123. The Growth of Industrial Civilization.\*** *9 units (3-0-6). Senior Elective.* An analysis and study of some of the major factors affecting the past, present and future development of industrial civilization with emphasis on projections into the next century. Among the factors to be considered are population changes, material, food and energy resources and technical manpower. Lectures and discussions will be given by staff members from various Institute divisions. Instructors in charge: Weir, Bonner, Brown.

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**H 124. 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.

**H 125 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 defence policy, and the role of international organizations in the development of an orderly world society. Instructor: Elliot.

**H 140. Reading and Research in History and Government.** Units to be determined for the individual by the department.

**H 150 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.

## 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 (3-0-6); first, second, third terms. Prerequisites: ME 19 ab and Hy 111 or equivalent. Continuity, momentum, and energy equations for viscous, compressible fluids; circulation and the production of vorticity; potential flow and applications to flow around bodies; gravity waves; laminar flow; laminar boundary layers; turbulence and turbulent shear flow; transport of sediment; topics from gas dynamics and introduction to mechanics of compressible flow. 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, sedimentation, surface waves and coastal engineering, and unsteady flow in pipes and channels. Theory and design of hydraulic structures such as inlets, chutes, energy dissipators, canals, transitions and the like. 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.

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**Hy 111. Fluid Mechanics Laboratory.** 6 units (0-6-0); 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 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 ab or equivalent. AM 116 is also recommended. (AM 95 b 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, dewatering for excavations, dispersion, and salinity intrusion. Emphasis is placed on flow-net analysis and mathematical methods. 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. No prerequisite. A study of such rotating machinery as turbines, pumps, 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 ab 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, and density currents. 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 Engineering Division. The subject matter will be variable depending upon the needs and interests of the students. It may be taken any number of times with permission of the instructor. Instructors: Staff.

**Hy 300. Thesis.**

**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. Instructor: 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 overall 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. Instructors: Rannie, 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. Instructor: Penner.

**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. Instructor: 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, in-

elastic 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. Instructor: 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: Marble, Penner.

**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. Instructor: Rannie.

**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; limita-

tions 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. Instructor: Penner.

**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 Members.

**JP 280 abc. Research in Jet Propulsion.** Units to be arranged. Theoretical and experimental investigations of problems associated with propulsion and related fields. Instructors: Staff Members.

**JP 290 abc. Advanced Seminar in Jet Propulsion.** 2 units (1-0-1); each term. Seminar on current research problems in propulsion and related fields. Instructors: Staff Members.

#### LANGUAGES

##### UNDERGRADUATE SUBJECTS

**L 1 abc. Elementary French.** 10 units (3-1-6); first, second, third terms. A subject 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 the department of languages. Instructor: Stern.

**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.

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**L 32 abc. Elementary German.** *10 units (3-1-6); first, second, third terms.* This subject is presented in the same manner as the Elementary French. Students who have had German in the secondary school or junior college should not register for this subject without consulting the department of languages. One session in the language laboratory will be scheduled each week. *Instructors: Bowerman, 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.*

**L 50 abc. Elementary Russian.** *10 units (4-0-6); first, second, third terms.* A subject 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. *Instructor: Kosloff.*

**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.

#### 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 algebra; analytic geometry; the infinite series. *Professor in charge: Apostol.*

**Ma 1.5 abc. Advanced Placement Course.** *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 material of Ma 1 abc and Ma 2 ab. Students who complete this course take Ma 2 c either in the first or in the last quarter of their sophomore year. Alternately, they may be allowed to take a special course, Ma 1.5 d, concurrently with Ma 1.5 c.

**Ma 2 abc. Sophomore Mathematics.** *12 units (4-0-8); first, second, third terms.* A continuation of the freshman mathematics course including: an extension of the calculus to functions of several variables; introduction to probability; vector analysis; differential equations; numerical analysis. *Professor in charge: Lees.*

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**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. Their subsystems, factor systems and direct products are studied. The algebraic techniques of decomposition and extension are presented. A large portion of the course is devoted to linear algebra and matrix theory with applications to geometry. Included are determinants, characteristic roots, Hermitian matrices and canonical forms. Instructors: Block, Crawley, Dean, Halpern.

**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: Cryer.

**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 1963-64.)
- (c) Theory of elasticity. (Given in 1962-63.)
- (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:

**Ma 102. Differential Geometry.** 9 units (3-0-6); third term. Selected topics in metrical differential geometry. Given in 1964-65 and alternate years.

**Ma 103. Algebraic Geometry.** 9 units (3-0-6); first term. Prerequisite: Ma 5 abc. A study of the relations between geometric objects (varieties) and the algebraic structures attached to them. Instructor: Dade.

**Ma 104. Projective Geometry.** 9 units (3-0-6); first 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. Given in 1964-1965 and alternate years.

**Ma 105 ab. Introduction to Numerical Analysis.** 11 units (3-2-6); second and third terms. Prerequisites: Ma 108 or AM 15 or equivalent, Ma 5, Ma 31 or AM 180 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. Instructors: Todd, Cryer.

**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: Dixon, Fuller, Knuth, Garsia.

**Ma 109. Operational Calculus.** *9 units (3-0-6); third term.* Introduction to operational calculus and to delta functions. Applications to ordinary and partial differential equations. Instructor: Erdélyi.

**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. Instructor: Dilworth.

**Ma 116 ab. Mathematical Logic and Axiomatic Set Theory.** *9 units (3-0-6); first and second 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. Not offered in 1963-64.

**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. Not offered in 1963-64 (see AMa 101 abc).

**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: Hall.

**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 geometries. Offered in 1964-65 and alternate years.

**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. Instructor: Todd.

**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. Instructor: DePrima.

**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. Offered in 1964-65 and alternate years.

**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: Garsia.

**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. Offered in 1964-65 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, differentials. Offered in 1964-65 and alternate years.

**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. Instructor: Hall.

**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. In charge: Dilworth.

[B] The following courses are open primarily to graduate students.

**Ma 205 abc. Numerical Analysis.** 9 units (3-0-6); three terms. *Prerequisite: Ma 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. Instructors: Erdélyi, Fielder, Kreiss.

**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. Instructor: Collins.

**Ma 222 abc. Group Theory.** 9 units (3-0-6); three terms. *Prerequisite: Ma 120 or permission of instructor.* An introduction to the basic properties of finite and infinite

groups. Theorems on homomorphisms, the theory of abelian groups, permutation groups, free groups, automorphisms. The Sylow theorems. Study of solvable, supersolvable, and nilpotent groups. A large part of the second term will be devoted to the theory of group representation, and will include applications to theoretical physics. Instructor: Dade.

**Ma 223. Matrix Theory.** 9 units (3-0-6); second term. *Prerequisites: Ma 108, 1220 or equivalent.* Algebraic, arithmetic and analytic aspects of matrix theory. Not offered in 1963-64.

**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. Offered in 1964-65 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. 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. Instructors: Erdélyi, Luxemburg.

**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 1963-64.

**Ma 290. Reading.** Occasionally advanced work is given by a reading course under the direction of an instructor. Hours and units by arrangement.

**[C]** The following courses and seminars are intended for advanced graduate students. They are research courses and seminars, offered according to demand, and covering selected topics of current interest. The courses offered, and the topics covered will be announced at the beginning of each term.

**Ma 305 abc** Seminar in Numerical Analysis. 6 units. Three terms.

**Ma 320 abc** Special topics in Algebra. 9 units. Three terms.

**Ma 324 abc** Seminar in Matrix Theory. Units to be arranged. Three terms. Instructor: O. Todd.

**Ma 325 abc** Seminar in Algebra. 6 units. Three terms.

**Ma 340 abc** Special topics in Analysis. 9 units. Three terms. Instructor: Luxemburg.

**Ma 345 abc** Seminar in Analysis. 6 units. Three terms.

**Ma 350 ab** Special topics in Geometry. 9 units. First and second terms. Instructor: Garsia.

**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 (3-3-3); first, second or third 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. *Prerequisites: ME 1, ME 3, ME 17 ab, AM 8 abc, AM 95 ab.* 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, Welch.

**ME 17 ab. Thermodynamics.** 9 units (3-0-6); first and second terms. *Prerequisites: Ma 1 abc, Ph 1 abc.* Basic laws of thermodynamics, fundamental properties and inter-relationships between properties. Maxwell relations, Joule-Thomson effect, Clapeyron-Clausius equation. Application to gases as well as to other systems. Elements of kinetic theory. Analyses of energy conversion cycles and propulsion devices. One-dimensional flow in a duct, normal and oblique shocks, expansion through nozzles. Basic chemical thermodynamics and theory of equilibrium of a reacting mixture. Text: *Elements of Engineering Thermodynamics*, Sabersky. Instructor: Culick.

**ME 17 c. Heat Transfer.** 9 units (3-0-6); third term. *Prerequisites: Ma 2 ab, ME 17 ab or equivalent.* Conduction in solids. Solution of problems by analytical, graphical, and numerical methods. Basic equations governing convective heat transfer. Similarity requirements. Special problems in laminar and turbulent flow. Free convection. Heat transfer in condensing and boiling fluids. Energy exchange by radiation. Instructor: Culick.

**ME 19 ab. Fluid Mechanics and Gas Dynamics.** 9 units (3-0-6); first and second terms. *Prerequisites: Ma 2 abc, Ph 1 abc.* Basic equations of fluid mechanics, theorems of energy, linear and angular momentum, potential flow, elements of airfoil theory. Flow of real fluids, similarity parameters, flow in closed ducts. Boundary layer theory in laminar and turbulent flow. Flow and wave phenomena in open conduits. Instructor: Acosta.

**ME 19 c. Principles of Energy Conversion.** 9 units (3-0-6); third term. *Prerequisites: Ma 2 abc, ME 17 ab and ME 19 ab or equivalent.* Availability of chemical, nuclear, and solar energy. Systems for the conversion into mechanical or electrical power. Analysis of principal system components such as fans, compressors, pumps and turbines. To include topics from two- and three-dimensional design theories of turbomachines. Instructor: Acosta.

#### 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, Welch.

**ME 118 abc. Advanced Thermodynamics and Energy Transfer.** 9 units (3-0-6); first, second, and third terms. *Prerequisites: ME 18, ME 19 ab.* 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. Instructor: Sabersky.

**ME 126. Fluid Mechanics and Heat Transfer Laboratory.** 9 units (0-6-3); third term. *Prerequisites: ME 17 abc, ME 19 ab, or equivalent. Students with other background shall obtain instructor's permission.* 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 convection 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.* **Prerequisites:** *AM 8 abc, 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 269.

Hydraulics, page 311.

Jet Propulsion, page 313.

Physical Metallurgy, page 325.

### 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

**PI 1. Introduction to Philosophy.\*** *9 units (3-0-6). Senior Elective.* A study of the major problems of philosophy in terms of the most influential contemporary world views, including naturalism, idealism, theism, pragmatism, and positivism. Instructor: Bures.

**PI 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.

**PI 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.

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**PI 4. Ethics.\* 9 units (3-0-6). Senior Elective.** A study of ethical values in relation to human nature and culture. Among the major topics considered are: the moral systems of some representative cultures; the development of personality and values in these cultures; the possibility of a rational basis for ethics; competing views of human nature; ethical conflicts in American culture. Instructor: Bures.

**PI 6 a. Introduction to Personality and Culture.\* 9 units (3-0-6). Senior Elective; first term.** A study of selected aspects of contemporary psychology and anthropology, aimed at introducing the student to the wide diversity of approaches currently being employed in seeking a scientific understanding of man and his behavior. The complementary character of the various concepts and methods will be indicated. Instructor: Atkins.

**PI 6 b. The Psychology of Behavioral Processes.\* 9 units (3-0-6). Senior Elective; second 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.

**PI 6 c. The Psychology of Personality Development.\* 9 units (3-0-6). Senior Elective; third term.** A study of psychological development from birth to maturity. Attention is paid to stages of development, roles, emotional and motivational patterns. A positive conception of growth and creativity and factors inhibiting growth are emphasized in terms of a basic vocabulary. Instructor: Bures.

**PI 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.

**PI 13. Reading in Philosophy. Units to be determined for the individual by the department. Elective, with the approval of the Undergraduate Academic Standards and Honors Committee, in any term.** Reading in philosophy, supplementary to, but not substituted for, courses listed; supervised by members of the department.

#### ADVANCED SUBJECTS

**PI 100 abc. Philosophy of Science. 9 units (2-0-7).** A full-year sequence. The relation between science and philosophy. The functions of logical analysis in knowledge and the analysis of the language of science. A study of the nature of formal science (logic and mathematics) and of factual science, their methods and interrelationships. Concept formation in the sciences. Analysis of some basic problems in the philosophy of science: measurement, causality, probability, induction, space, time, reality. Scientific method and social problems. Instructor: Bures.

**PI 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.

\*The fourth-year Humanities electives to be offered in any given term will be scheduled before the close of the preceding term.

**PI 102 abc. Philosophy and Literature.** 9 units (2-0-7). *A full-year sequence.* 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.

**PI 110. Mathematical Models in Behavioral Science.** (9 units (3-0-6). *(Not usable as Senior Humanities or M.S. Humanities requirement.)* Applications of formal models and methods from symbolic logic and mathematics to selected problems in psychology, sociology, and social anthropology. An exploration of the potentials in behavioral science of models from relational logic, game theory, information theory, linear graph theory, and other such sources. The course presupposes a basic background and interest in mathematics, but no prior knowledge of the behavioral sciences. Instructor: Atkins.

**PI 113. Reading in Philosophy.** Same as PI 13 but for graduate credit.

### PHYSICAL METALLURGY UNDERGRADUATE SUBJECTS

**PM 5 abc. Principles of Engineering Materials.** 9 units (3-0-6); *first, second and third terms.* *Prerequisites: Ch 1 abc, Ph 2 abc, AM 8 c, (AM 8 c may be taken concurrently with PM 5 c).* The purpose of this course is to acquaint the student with the principles underlying the properties of solid materials. Elementary principles of quantum mechanics are employed to discuss the electronic structure of atoms, the types of bonds between atoms in molecules and crystals, and to develop the band theory of solids. An introduction to the principles of statistical thermodynamics also is given. These principles are employed as the basis for discussion of the electrical, magnetic, and thermal properties of solids. Rate processes such as diffusion and phase transformations also are considered. The concepts and theory of dislocations in crystals are introduced and are employed in the discussion of the processes of deformation and fracture of solids. Instructors: Buffington, Wood.

**PM 10. Engineering Physical Metallurgy.** 9 units (2-1-6); *first term.* *Prerequisite: PM 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.

**PM 11. Metallography Laboratory.** 9 units (0-6-3); *second term.* *Prerequisite: PM 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

**PM 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.

**PM 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. Instructor: Staff.

**PM 103 ab. Physical Metallurgy Laboratory.** 9 units (0-9-0); first term. 6 units (0-6-0); second term. Prerequisite: PM 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.

**PM 104. Photography.** 9 units (1-6-2). first term. Prerequisite: Ph 2 abc. Study and synthesis of optical systems in the use of photographic methods in research. Experiments will be conducted with various systems to illustrate the effectiveness of photographic methods as research tools. Instructors: Staff.

**PM 105. Mechanical Behavior of Metals.** 6 units (2-0-4); first term. Prerequisites: AM 9 abc, PM 5 abc. A study of the various types of behavior of metals under applied load which are of significance for engineering applications. Properties under simple tension and compression loading, hysteresis and damping capacity, the influence of temperature, behavior under rapidly applied and impact loads, fatigue, mechanical wear, behavior under combined stress, and selection of working stresses. Instructor: Wood.

**PM 112 ab. Advanced Physical Metallurgy.** 9 units (3-0-6); second and third terms. Prerequisites: PM 5 ab or PM 120, PM 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.

**PM 115 ab. Crystal Structure and Properties of Metals and Alloys.** 9 units (3-0-6); second and third terms. Prerequisite: PM 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.

**PM 116. X-Ray Metallography Laboratory I.** 9 units (0-6-3); third term. Prerequisite: PM 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.

**PM 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 PM 5 ab cannot receive credit for PM 120, since there exists some duplication of material. Additional study in physics of solids can be arranged under PM 100. Instructor: Buffington.

**PM 135. Radioisotopes Laboratory.** 9 units (0-9-0); third term. Prerequisites: AM 103 a, PM 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.

**PM 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.

**PM 205 ab. Theory of the Mechanical Behavior of Crystalline Solids.** 9 units (3-0-6); second and third terms. Prerequisites: AM 110 a, PM 115 a (may be taken concurrently). A study of the nature and physical theory of the deformation and fracture of crystalline solids under the influence of applied stress. Elasticity of crystals, plastic flow by slip and twinning, the concept of dislocations, properties of dislocations, dislocation interactions, dislocations in specific crystal lattices, interactions of dislocations with point defects and alloying elements, applications of dislocation theory to a variety of problems in the mechanical behavior of crystalline solids. Texts: *Dislocations in Crystals*, Read; and *Mechanical Properties of Metals*, McLean. Instructors: Wood and Vreeland.

**PM 217. X-Ray Metallography Laboratory II.** 9 units (0-6-3); any term. Prerequisite: PM 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.

**PM 225. Industrial Physical Metallurgy.** 9 units (0-6-3); any term. Prerequisites: PM 103, PM 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.

**PM 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.

**PM 300. Thesis Research.**

## 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-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, thermo-

dynamics, and black body radiation. Instructors: Leighton, Sutton, Strong, Vogt, and Graduate 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: Wilts, Neher, Neugebauer, Pine, and Graduate Assistants.

**Ph 77. Experimental Physics Laboratory.** 6-9 units (*subject to arrangement with instructor.*) *Either first or second term.* A one-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, van Putten, Hellwarth, Boehm.

#### ADVANCED SUBJECTS

**Ph 107 abc. Electricity and Magnetism.** 9 units (3-0-6); *first, second, and third terms.* Prerequisites: *Ph 2 abc, Ma 2 abc.* A course in classical electromagnetism that starts with the fundamental law of electromagnetic force and Maxwell's Equations. Topics include electromagnetic energy and momentum, electromagnetic induction and radiation, and solutions to various boundary-value problems involving static fields and traveling waves. The emphasis is upon the more general aspects of the subject, and upon physical principles. Graduate students majoring in physics or astronomy will be given only 6 units credit for this course. Instructor: Cowan.

**Ph 108 abc. Theoretical Mechanics.** 9 units (3-0-6); *first, second, and third terms.* Prerequisites: *Ph 1 abc, Ph 2 abc, and preferably Ph 107 abc.* An intermediate course in the application of mathematical methods to problems in mechanics. Topics include particle mechanics, Lagrange and Hamilton equations, damped vibrations, coupled vibratory systems, rigid body dynamics. Graduate students majoring in physics or astronomy will receive only 6 units credit for this course. Text: *Classical Mechanics*, Goldstein. Instructors: Davis, Van Putten.

**Ph 109. Analytical Mechanics.** 9 units (3-0-6); *first term.* Prerequisite: *Ph 2 abc.* A one-term course in the application of mathematical methods to problems in mechanics. Topics include particle mechanics, Lagrange and Hamilton equations, small vibrations and normal modes. Graduate students majoring in physics will be given only 6 units credit for this course. Instructor: Estabrook.

**Ph 112 abc. Atomic and Nuclear Physics.** 12 units (4-0-8); *first, second, and third terms.* Prerequisites: *Ph 107 abc and Ph 111 abc, or equivalent.* A problem and lecture course in the experimental and theoretical foundations of modern atomic and nuclear physics. Topics include the special theory of relativity with applications to kinematics and electrodynamics, and an introduction to quantum mechanics with applications to the harmonic oscillator, the free particle, the one-electron atom and selection rules. Also treated, on a less analytical basis, are the exclusion principle and atomic shell structure; optical spectroscopy; molecular binding and molecular spectra; quantum statistics; the band theory of solids; X-rays; radioactivity and nuclear structure; nuclear reactions; elementary particles; high energy physics. Text: *Principles of Modern Physics*, Leighton. Instructor: Barnes.

**Ph 114 ab. Introduction to Atomic and Nuclear Physics.** 9 units (3-0-6); second and third terms. Prerequisites: Ph 2 abc, Ph 125 a. Recommended: Ph 125 bc concurrently. The properties of atoms and nuclei important in understanding the macroscopic properties of matter are described and interpreted by quantum mechanical arguments supplemented by the vector model. Topics covered include: the spectra and structure of atoms with one and two valence electrons, electron spin, the exclusion principle and atomic shell structure, behavior of atoms in electric and magnetic fields, hyperfine structure, magnetic resonance, molecular binding, and diatomic spectra. The mass, size, shape, spin and electric magnetic moments of nuclei are discussed in terms of the phenomena by which these properties are measured. Nuclear binding energy is treated quantitatively by means of the semi-empirical mass formula and interpreted in terms of qualitative properties of the nuclear force. The mass formula forms the basis for a discussion of nuclear stability and nuclear reactions. Barrier penetrability is introduced to interpret alpha decay and nuclear reaction rates. Other topics treated briefly include beta decay, excited states and gamma emission, nuclear models, the two nucleon system. Graduate students majoring in physics will be given only 6 units credit for this course. Instructor: Whaling.

**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 1963-64.

**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 Schrodinger 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 credit for this course. Instructors: Christy and Frautschi.

**Ph 129 abc. Methods of Mathematical Physics.** 9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 107 abc and Ph 108 abc or the equivalents (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 131 abc. Electricity and Magnetism.** 9 units (3-0-6); first, second, and third terms. Prerequisite: An average grade of C in Ph 107 abc. A problem course in electricity, magnetism and electromagnetic waves for students who are doing or plan to do graduate work. The first two terms cover potential theory as applied to electrostatics, magnetostatics and current flow in extended mediums; eddy currents; and the laws of electromagnetic induction as applied to linear circuits. The third term covers electromagnetic waves and the motion of charged particles in electromagnetic fields. Text: *Static and Dynamic Electricity*, Smythe. Instructor: Smythe.

**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. Given in alternate years. Not offered in 1963-64.

**Ph 203 abc. Nuclear Physics.** 9 units (3-0-6); *first, second, and third terms.* *Prerequisite:* Ph 112 abc or equivalent. A problem and lecture course in nuclear physics. Subjects include fundamental properties and structure of nuclei, including the liquid drop, shell, and collective models, nuclear forces, modes of nuclear decay, nuclear reactions, interaction of particles and radiation with matter, and particle acceleration and detection. The third term is usually devoted to such specialized topics as nuclear processes in stars including energy generation and element synthesis. Instructor: Fowler.

**Ph 204 abc. Low Temperature Physics.** 9 units (3-0-6); *first, second, and third terms.* *Prerequisite:* Ph 112 abc. *Recommended:* Ph 205 abc, Ph 227 abc. First and second terms: 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. Third term: Advanced topics on specific aspects of low temperature physics to be covered by special reading assignments.

**Ph 205 abc. Principles of Quantum Mechanics.** 9 units (3-0-6); *first, second, and third terms.* *Prerequisites:* Ph 112 abc or equivalent; 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: Zachariassen.

**Ph 209 abc. Electromagnetism and Electron Theory.** 9 units (3-0-6); *first, second, and third terms.* *Prerequisite:* Ph 107 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: Jon Mathews.

**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 1963-64.

**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 1963-64. Instructor: Tollestrup.

**Ph 220 abc. Introduction to Solid State Physics.** 6 units (2-0-4); first, second and third terms. *Prerequisite: Ph 112 abc. Recommended: Ph 205 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. Not offered in 1963-64.

**Ph 221 ab. Solid State Physics.** 6 units (2-0-4); first and second terms. *Prerequisite: Ph 220 abc.* A continuation of Ph 220 abc. Offered in 1963-64. Instructor: Mössbauer.

**Ph 227 abc. Thermodynamics, Statistical Mechanics, and Kinetic Theory.** 9 units (3-0-6); first, second and third terms. *Prerequisites: Ph 108 abc, 205 ab (may be taken concurrently) 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 1963-64.

**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: Gell-Mann.

**Ph 231 abc. High Energy Physics.** 9 units (3-0-6); first, second and third terms. 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. Given in alternate years. Not offered in 1963-64.

**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 1963-64.

**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, Feynman, Frautschi, Gell-Mann, Mathews, Zachariasen.

**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 7, 1963

## DOCTOR OF PHILOSOPHY

Harlow Garth Ahlstrom (Aeronautics). *B.S., University of Washington, 1959; M.S., 1959.* Thesis: Experiments on the Upstream Wake in Magneto-Fluid Dynamics.

Shelton Setzer Alexander (Geophysics and Mathematics). *B.S., University of North Carolina, 1956; M.S., California Institute of Technology, 1959.* Thesis: Surface Wave Propagation in the Western United States: I. Crustal Structure in the Western United States from Multimode Surface Wave Dispersion. II. The effects of the Continental Margin in Southern California on Rayleigh Wave Propagation.

William Judson Anderson (Aeronautics and Mathematics). *B.S., Iowa State University, 1957; M.S., 1958.* Thesis: Studies in Panel Flutter: I. Flat and Slightly Curved Panels. II. Cylindrical Shells with Boundary Layer.

John Edwin Baldwin (Chemistry and Physics). *A.B., Dartmouth College, 1959.* Thesis: I. Mechanism of the Thermal Isomerization of 2-Norbornene-5,6-*endo*-dicarboxylic Anhydride. II. The Aldoketene Dimer Rearrangement.

Philip Oren Banks (Geochemistry). *S.B., Massachusetts Institute of Technology, 1958.* Thesis: Systematics of the Distribution of Uranium and Lead in Relation to the Petrology of the Mt. Rubidoux Granites, Riverside County, California.

Dennis Barrett (Biochemistry). *A.B., University of Pennsylvania, 1957.* Thesis: The Parallel Accumulation and Distribution of Two Purine-Oxidizing Enzymes During Frog Development.

Frank Bliss Booth (Chemistry and Physics). *B.S., University of California (Los Angeles), 1953; M.S., 1954.* Thesis: I. Electron Magnetic Resonance Studies on Irradiated Single Crystals of Sebacic Acid. II. Rate of Electron Exchange Between Di-p-Anisyl Nitrogen Oxide Molecules by Electron Paramagnetic Resonance.

William Charles Boyle (Civil Engineering). *C.E., University of Cincinnati, 1959; M.S., 1960.* Thesis: Studies on the Biochemistry of Disinfection by Mono-chloramine.

James Stanley Clovis (Chemistry and Economics). *B.S., Waynesburg College, 1959.* Thesis: The Mechanism of the Benzidine Rearrangement.

Thomas Alan Cole (Biochemistry). *B.A., Wabash College, 1958.* Thesis: Peptidyl Acylating Agents in the Pupae of *Drosophila melanogaster* and Their Possible Relationship to Protein Synthesis.

Jacques de Barbeyrac Saint-Maurice (Electrical Engineering). *Dipl.C.A.E., Ecole Nationale Supérieure de l'Aéronautique (Paris), 1959; M.S., California Institute of Technology, 1960.* Thesis: Minimal Time Deadbeat Regulation and Control of Linear, Stationary, Sampled-Data Systems.

Clarence Forbes Dewey, Jr. (Aeronautics). *B.E., Yale University, 1956; M.S., Stanford University, 1957.* Thesis: Measurements in Highly Dissipative Regions of Hypersonic Flows: I. Hot-Wire Measurements in Low Reynolds Number Hypersonic Flows. II. The Near Wake of a Blunt Body at Hypersonic Speeds.

Robert Ernest Diebold (Physics). *B.S., University of New Mexico, 1958; M.S., California Institute of Technology, 1960.* Thesis: Photoproduction of Neutral Pions from Protons at Center of Mass Angles of 60°, 90°, and 120° from .6 to 1.2 BeV.

John Jacob Domingo (Physics). *B.S., California Institute of Technology, 1955.* Thesis: A Study of the Effect of the 3.10-MeV State of F<sup>17</sup> on the O<sup>16</sup>-(p,gamma)F<sup>17</sup> Reaction.

Michael B. Duke (Geochemistry). *B.S., California Institute of Technology, 1957; M.S., Pennsylvania State University, 1958; M.S., California Institute of Technology, 1961.* Thesis: Petrology of the Basaltic Achondrite Meterorites.

Thornton Roberts Fisher (Physics). *B.S., Wesleyan University, 1958.* Thesis: I. A Study of the Na<sup>23</sup>(p,alpha)Ne<sup>20</sup> Reaction for Proton Bombarding Energies from 100 to 450 keV. II. A Measurement of the Half-lives of N<sup>12</sup> and B<sup>12</sup>.

Robert Paul Foss (Chemistry). *B.A., Northwestern University, 1958.* Thesis: The Mechanism of Triplet-Energy Transfer in Solution: the Quenching of Excited-State Benzophenone by Transition-Metal Chelates.

Michael Eugene Fourney (Aeronautics). *B.S.A.E., West Virginia University, 1958; M.S., California Institute of Technology, 1959.* Thesis: I. On the Application of a Laser to High Speed Photography. II. Torsional Magnetoelastic Waves in a Circular Cylinder.

Charles Julius Fritchie, Jr. (Chemistry). *B.S., Tulane University, 1958.* Thesis: The Molecular and Crystal Structures of a Dimer of a Cyclobutadiene Derivative; the Crystal Structure of Bis-(2-bromopyridine)-dodecahydrodeca-borane.

Harris Gold (Aeronautics). *B.M.E., Polytechnic Institute of Brooklyn, 1958; M.S.M.E., Columbia University, 1959.* Thesis: Stability of Laminar Wakes.

Louise Dillon Gray (Engineering Science). *B.S., University of California (Los Angeles), 1957; M.S., 1959.* Thesis: I. Theoretical Calculations of Equilibrium Infrared Gas Emissivities from Spectroscopic Data. II. Representative Radiative Energy Transfer Calculations for Transparent and Optically Dense Media.

David Eiben Groce (Physics and Electrical Engineering). *B.S., California Institute of Technology, 1958.* Thesis: Magnetic Analysis of Reactions Leading to Excited States in Li<sup>6</sup> and B<sup>11</sup>.

David Warren Hall (Chemistry). *B.S., University of Arizona, 1957.* Thesis: I. Electrophilic Substitution Reactions of Some Substituted Ferrocenes. II. The Effects of Heteroannular Substituents on the Rates of Solvolyses of Methyl-ferrocenylcarbiny1 Acetates; a Comparison with Substituent Effects in Other Reactions of Ferrocene.

Carole Lois Hamilton (Chemistry). *B.S., Colorado State University, 1958.* Thesis: I. An Investigation of Rearrangement in 2-Phenylethyl Organometallic Compounds. II. Skeletal Interconversion in Allylcarbiny1, Cyclopropylcarbiny1 and Cyclobutyl Grignard Reagents.

David Garrison Harkrider (Geophysics). *B.S., Rice University, 1953; M.A., 1957.* Thesis: I. Propagation of Acoustical Gravity Waves from an Explosive Source in the Atmosphere. II. Rayleigh and Love Waves from Sources in a Multilayered Elastic Halfspace.

Kenneth Edwin Harwell (Aeronautics). *B.S., University of Alabama, 1958; M.S., California Institute of Technology, 1960.* Thesis: Initial Ionization of Shock-Heated Argon, Krypton, and Xenon.

Thomas McCalfree Helliwell (Physics). *B.A., Pomona College, 1958.* Thesis: The Nodal Boundary Condition Method: Wave Functions and Transition Probabilities for Atoms with Two Valence Electrons.

Robert Hickling (Engineering Science). *M.A., University of St. Andrews, 1954.* Thesis I. Acoustic Radiation and Reflection from Spheres. II. Some Effects of Thermal Conduction and Compressibility in the Collapse of a Cavity in a Liquid.

Richard O'Neil Hundley (Physics). *B.S., California Institute of Technology, 1957; M.S., 1959.* Thesis: Direct Pair Production by Electrons.

Marcos Intaglietta (Applied Mechanics). *B.S., University of California, 1957; M.S., California Institute of Technology, 1958.* Thesis: Streaming Birefringence Study of the Interactions of Submicroscopic Particles.

Paul Christian Jennings (Civil Engineering). *B.S., Colorado State University, 1959; M.S., California Institute of Technology, 1960.* Thesis: Response of Simple Yielding Structures to Earthquake Excitation.

Kenneth Irwin Kellermann (Physics and Astronomy). *S.B., Massachusetts Institute of Technology, 1959.* Thesis: The Spectra of Galactic and Extragalactic Radio Sources.

James W. Kessel (Chemistry). *B.S., University of Michigan, 1958.* Thesis: I. The Isolation and Structure of Two Alkaloids from *Tabernaemontana rupicola*. II. The Structure of Necrosamine.

Joseph R. Kilner (Physics). *B.S., Case Institute of Technology, 1957.* Thesis: The Photoproduction of Positive Pions from Hydrogen at Energies of 1.1 to 1.4 GeV.

Donald Menford King (Chemistry). *B.S., State College of Washington, 1957.* Thesis. I. A Kinetic Study of the Reaction Between Thioacetamide and Hydrazine. II. The Iodometric Determination of Peroxydisulfate. III. Effect of Surface Oxidation and Platinization on the Behavior of Platinum Electrodes.

Wolfgang Gustav Knauss (Aeronautics). *B.S., California Institute of Technology, 1958; M.S., 1959.* Thesis: Rupture Phenomena in Viscoelastic Materials.

Donald Ervin Knuth (Mathematics). *B.S., Case Institute of Technology, 1960.* Thesis: Finite Semifields and Projective Planes.

William L. Ko (Aeronautics). *B.S., National Taiwan University, 1950; M.S., California Institute of Technology, 1959.* Thesis: Application of Finite Elastic Theory to the Behavior of Rubber-Like Materials.

Alvin L. Kwiram (Chemistry). *B.S.*, *Walla Walla College*, 1958. Thesis: I. A Chemical Application of Electron-Nuclear Double Resonance. II. Auxiliary Equipment.

George Melvin Lawrence (Physics). *B.S.*, *University of Utah*, 1959. Thesis: Experimental Absolute f-Values for Lines of Ni, Co, Au, and Ag.

Michael Jerry Levine (Physics). *B.S.*, *University of Illinois*, 1958. Thesis: Neutrino Processes of Significance in Stars.

Paul Hersh Levine (Physics). *S.B.*, *Massachusetts Institute of Technology*, 1956; *M.S.*, *California Institute of Technology*, 1957. Thesis: Phase Space Formulation of the Quantum Many-Body Problem.

John Kailin Link (Physics). *B.S.*, *Antioch College*, 1959. Thesis: Measurement of Absolute f-Values for Selected Metals with an Atomic Beam Method.

Robert Lee Luttermoser (Physics and Astronomy). *B.S.*, *University of Michigan*, 1948; *M.S.*, 1950. Thesis: Nuclear Interactions in a High Energy Multiplate Cloud Chamber.

Egon Marx-Oberländer (Physics). *E.E.*, *University of Chile*, 1959. Thesis: On Pion Nucleon Resonances.

Francis Clay McMichael (Civil Engineering and Geophysics). *B.S.*, *Lehigh University*, 1958; *M.S.*, *California Institute of Technology*, 1959. Thesis: Suspensions of Particles Generated by an Upward Flow.

Chiang Chung Mei (Engineering Science). *B.S.C.E.*, *National Taiwan University*, 1955; *M.S.*, *Stanford University*, 1958. Thesis: I. On the Initial Value Problems of Radiation and Scattering of Water Waves by Immersed Obstacles. II. Gravity Waves Due to a Point Disturbance in a Stratified Flow.

James Eardley Midgley (Physics). *B.S.E.*, *University of Michigan*, 1956. Thesis: Calculation by a Moment Technique of the Perturbation of the Geomagnetic Field by the Solar Wind.

Ralph Fraley Miles, Jr. (Physics). *B.S.*, *California Institute of Technology*, 1955; *M.S.*, 1960. Thesis: The Density of Cosmic-Ray Neutrons in the Atmosphere.

Norton Leonard Moise (Physics and Aeronautics). *B.S.*, *University of Illinois*, 1948; *M.A.*, *University of California (Los Angeles)*, 1954; *M.S.*, *California Institute of Technology*, 1959. Thesis: A Study of Atomic Transition Probabilities; the Correlation of Oscillator Strengths and Vapor Pressures.

Fernando B. Morinigo (Physics). *B.S.*, *University of Southern California*, 1957. Thesis: A Study of Excited Levels in  $\text{Be}^8$  via the Reaction  $\text{Li}^6(\text{He}^3, \text{p})\text{Be}^{8*}$ .

D. James F. Morré (Biochemistry and Plant Physiology). *B.S.*, *University of Missouri*, 1957; *M.S.*, *Purdue University*, 1958. Thesis: Biochemistry of Cell Extension.

Robert George Mortimer (Chemistry and Physics). *B.S.*, *Utah State University*, 1958; *M.S.*, 1959. Thesis: I. Irreversible Thermodynamics of Photochemistry. II. Approximations to Ensemble Averages.

Robert Canute Neuman, Jr. (Chemistry). *B.S.*, *University of California (Los Angeles)*, 1959. Thesis: I. A Nuclear Magnetic Resonance Study on Amidinium Ions in Solution. II. The Kinetics of the Thermal Decomposition of Azo-bis-isobutyramidines and Their Salts in Solution.

Robert Wilson Noyes (Physics). *B.A., Haverford College, 1957.* Thesis: Observations of Oscillatory Motions in the Solar Atmosphere.

Peter Donald MacDougall Parker (Physics). *B.A., Amherst College, 1958.* Thesis: Investigation of the Direct-Capture Reaction,  $\text{He}^3(\text{alpha},\text{gamma})\text{Be}^7$ .

Robert Allan Ridley Parker (Astronomy and Physics). *B.A., Amherst College, 1958.* Thesis: The Physical Conditions Pertaining to Some Possible Supernova Remnants.

John Davie Pearson (Physics). *B.Sc., Brown University, 1956.* Thesis: A Study of the Gamma Radiation Produced in the Alpha-Particle Bombardment of  $\text{O}^{16}$ .

James Macon Peterson (Chemistry and Physics). *B.S., Wake Forest College, 1958.* Thesis: I. Remarks on the Archibald Technique for Determining Molecular Weights in the Ultracentrifuge. II. The Hydrodynamic Alignment of Rod-like Molecules in Centrifugal Fields.

James Sibley Petty (Aeronautics). *B.S., California Institute of Technology, 1959; M.S., 1960.* Thesis: Linearized Transonic Flow About Symmetric Non-Lifting Airfoils.

Alfred Cyril Pinchak (Mechanical Engineering and Physics). *B.S.E.E., Case Institute of Technology, 1957; M.S.E., Purdue University, 1959.* Thesis: Experimental Investigation of Gas Phase and Surface Phenomena in a Seeded Plasma.

John William Porter, Jr. (Engineering Science). *B.A., Rice University, 1959; M.S., California Institute of Technology, 1960.* Thesis: I. Chemical Reactions During Flow in Rocket Nozzles. II. Gas Discharge Rates Through De Laval Nozzles and the Experimental Determination of Desorption Rates.

James Howard Renken (Physics). *B.S., Ohio State University, 1957; M.S., 1958.* Thesis: The Elastic Scattering of Deuterons by Beryllium.

Charles Dyer Russell (Chemistry). *S.B., Massachusetts Institute of Technology, 1957.* Thesis: Chronopotentiometry in Acetonitrile; Oxidation of Substituted Acetates and Substituted Ferrocenes at Platinum Electrodes.

Louis Vincent Schmidt (Aeronautics). *B.S., California Institute of Technology, 1946; M.S., 1948; Ae.E., 1950.* Thesis: Air Loads on a Circular Cylinder.

Philip Anthony Seeger (Physics). *B.A., Rice University, 1958.* Thesis: Electromagnetic Decay of the Second Excited State of  $\text{C}^{12}$ .

George Andrew Seielstad (Physics). *A.B., Dartmouth College, 1959.* Thesis: Measurements of the Linear Polarization of Radio Sources at Decimeter Wave Lengths.

Yun-Yuan Shi (Aeronautics). *B.S., National Taiwan University, 1955; M.S., Brown University, 1958.* Thesis: Low Reynolds Number Flow Past Finite Cylinders of Large Aspect Ratio.

Jon Hardy Shirley (Physics and Mathematics). *A.B., Middlebury College, 1957.* Thesis: Interaction of a Quantum System with a Strong Oscillating Field.

George Warren Simon (Physics). *A.B., Grinnell College, 1955; M.S., California Institute of Technology, 1961.* Thesis: Correlations Between Large-Scale Solar Photospheric and Chromospheric Motions, Ca II (k) Emission, and Magnetic Fields.

Himan Sternlicht (Chemistry and Physics). *B.S., Columbia University, 1958.* Thesis: I. The Electron Spin Resonance Line Shape of a Polycrystalline Radical. II. Paramagnetic Excitons in Molecular Crystals.

Robert Farrell Stewart (Chemistry). *B.A., Carleton College, 1958.* Thesis: Polarized Absorption Spectra of Purines and Pyrimidines.

Frederick William Studier (Biophysics and Chemistry). *B.S., Yale University, 1958.* Thesis: Studies on the DNA of Bacteriophage T<sub>4</sub>.

Donald Gary Swanson (Physics). *B.Th., Northwest Christian College, 1958; B.S., University of Oregon, 1958; M.S., California Institute of Technology, 1961.* Thesis: An Experimental Study of Compressional Hydromagnetic Waves.

Richard Michael Talman (Physics). *B.A., University of Western Ontario, 1956; M.A., 1957.* Thesis: Photoproduction of  $\pi^-$ 's from Protons in the Forward Direction in the Region of the Second and Third Resonances.

Robert Clem Titsworth (Electrical Engineering and Mathematics). *B.S., New Mexico College of Agriculture and Mechanic Arts, 1957; M.S., California Institute of Technology, 1958.* Thesis: Correlation Properties of Cyclic Sequences.

M. Nafi Toksöz (Geophysics and Electrical Engineering). *Geoph. Eng., Colorado School of Mines, 1958; M.S., California Institute of Technology, 1960.* Thesis: Velocities of Long Period Surface Waves and Microseisms and Their Use in Structural Studies: I. Mantle Love and Mantle Rayleigh Waves and the Structure of the Earth's Upper Mantle. II. Microseisms and Their Application to Seismic Exploration.

Nicholas John Turro, Jr. (Chemistry). *B.A., Wesleyan University, 1960.* Thesis: Energy Transfer in Organic Photochemistry. I. Photosensitized cis-trans Isomerization. II. Photosensitized Dimerization of Conjugated Dienes.

Harris E. Ulery (Chemistry). *B.A., Grinnell College, 1959.* Thesis: I. Acid Catalyzed Reactions of 1,5-Epoxyolefins. II. The Alkylative Cyclization of 1,5-Hexadiene. III. The Acid Catalyzed Cyclizations of cis,cis-and trans,trans,2,6-Octadiene. IV. The Infrared Spectra of Cyclobutane Compounds.

Janis Vasilevskis (Chemistry). *B.S., University of California, 1958.* Thesis: Studies of the Metal Ion Complexes of Purines and Pyrimidines by Electrophoresis and Other Methods.

George Charpentier Vlases (Aeronautics). *B.S., The Johns Hopkins University, 1958; M.S., California Institute of Technology, 1959.* Thesis: Experiments in a Cylindrical Magnetic Shock Tube.

Joseph L. Vogl (Physics). *A.B., Columbia College (New York), 1957; M.S., California Institute of Technology, 1959.* Thesis: Radiative Capture of Protons by C<sup>12</sup> and C<sup>13</sup> Below 700 KeV.

Yui-Loong Wang (Chemical Engineering). *B.S., Taiwan College of Engineering, 1956; California Institute of Technology, 1958.* Thesis: I. Thermal Decomposition of n-Butane. II. Flow in Entrance Section of Parallel Plates.

Ronald Watson (Mechanical Engineering). *B.S.(M.E.), Illinois Institute of Technology, 1952; M.S., California Institute of Technology, 1953.* Thesis: I. Experimental Spectroscopic Temperature Measurements in the Reflected Wave Region of a Shock Tube Using the OH<sup>2</sup>Σ<sub>u</sub><sup>+</sup>π Band System. II. Shock Tube

Measurements of the Absorption Oscillator Strength for the  $^2\Sigma^+ - ^2\pi$  Band System of OH.

Ned Conder Webb (Chemistry and Physics). *B.A., Vanderbilt University, 1959.* Thesis: Determinations of the Crystal Structures of Bis-indenylruthenium and of Two So-Called Gamma-Brass Type Compounds: I. Bis-indenylruthenium. II. " $\text{Ni}_3\text{Cd}_{21}$ ." III. " $\text{Ni}_3\text{Zn}_{21}$ ."

Robert Avrum Weisberg (Virology). *A.B., Harvard College, 1958.* Thesis: Studies on Mouse Embryo Cultures Infected with Polyoma Virus.

Douglas Warren Willett (Mathematics). *B.S., South Dakota School of Mines and Technology, 1959.* Thesis: Solutions of Nonlinear Integral Equations and Their Application to Singular Perturbation Problems.

Ying-Chu Lin Wu (Aeronautics). *B.E., National Taiwan University, 1955; M.S., Ohio State University, 1959.* Thesis: Flow Generated by Suddenly Heated Flat Plate.

Robert Eugene Zartman (Geology). *B.S., Pennsylvania State University, 1957; M.S., California Institute of Technology, 1959.* Thesis: A Geochronological Study of the Lone Grove Pluton from the Llano Uplift, Texas.

Jonas Stasys Zmuidzinas (Physics and Mathematics). *B.S., Indiana Technical College, 1958; M.S., California Institute of Technology, 1959.* Thesis: High-Energy Nucleon Compton Scattering

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## AERONAUTICAL ENGINEER

Harry Spencer Blackiston, Jr. *B.S.*, *Purdue University*, 1957; *M.S.*, 1959.

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Richard Earl Parks, Lt. U.S.N. *B.S.*, *United States Naval Academy*, 1954; *B.S.*, *United States Naval Postgraduate School*, 1962.

Viviane Claude Rupert. *Ing. d'Aéronautique*, *Ecole Nationale Supérieure de l'Aéronautique (Paris)*, 1961; *M.S.*, *California Institute of Technology*, 1962.

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Charles Fleming Stebbins, Lt., U.S.A.F. *B.S.*, *United States Air Force Academy*, 1961; *M.S.*, *California Institute of Technology*, 1962.

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## MECHANICAL ENGINEER

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Edmund Eugene Spaeth. *B.S., Stanford University, 1962.*

GEOLOGY

Michael Timberlake Field. *S.B., Massachusetts Institute of Technology, 1961.*

GEOPHYSICS

Héctor M. Alvarez. *Ing.Civ., University of Chile, 1958.*

John Edward Beitzel. *B.S., Michigan College of Mining and Technology, 1961.*

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MATHEMATICS

Robert Allister MacLeod. *B.Sc., University of Alberta, 1961.*

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John W. Davies. *B.A., State University of Iowa, 1961.*

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Henry Hunter Hill. *B.A., Rice University, 1960.*

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Calvin Elroy Moss. *B.S., University of Virginia, 1961.*

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Ahmad K. Abu-Shumays. *B.S., California Institute of Technology, 1962.*

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Steven Collins Crow. *B.S., California Institute of Technology, 1962.*

Everett Leon DeLano, Jr. *B.S., Northrop Institute of Technology, 1959.*

David Franklin Gates. *B.S., Maryville College, 1954.*

Robert Theodore Herzog. *B.S., California Institute of Technology, 1956.*

Jark Chong Lau. *Dipl., Royal Melbourne Technical College, 1957.*

Jen-shih Lee. *B.S., National Taiwan University, 1961.*

John Eldon Lewis. *B.S., University of California (Berkeley), 1962.*

Mervyn Daniel Olson. *B.S.Sc.*, *University of British Columbia*, 1962.  
 John Merrill Rosen. *B.S.*, *University of Minnesota*, 1956.  
 Charles Joseph Ruger. *B.A.E.*, *Polytechnic Institute of Brooklyn*, 1962.  
 Jerome Allan Smith. *B.S.E.*, *University of Michigan*, 1962.  
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#### APPLIED MECHANICS

Klaus Victor Bury. *B.A.Sc.*, *University of Toronto*, 1959; *B.A.*, *Sir George Williams University*, 1962.  
 David Chapman Cartwright. *B.S.*, *Hamline University*, 1962.  
 Jacques Godin. *B.Sc.A.*, *Universite de Montreal*, 1954.  
 Leo Horowitz. *B.S.*, *Drexel Institute*, 1962.  
 Donald Frederick Jensen. *B.S.*, *Virginia Polytechnic Institute*, 1962.  
 Logan Keith Kuiper. *B.A.*, *State University of Iowa*, 1962.  
 Donald Joseph Mokski. *B.S.*, *University of Buffalo*, 1954.  
 Frederick Reyes Norwood. *B.S.*, *University of California (Los Angeles)*, 1962.  
 Jay Smith III. *B.S.*, *Virginia Polytechnic Institute*, 1963.  
 Christopher Kwong Wah Tam. *Dipl.*, *Hong Kong Technical College*, 1959; *B.E.*, *McGill University*, 1962.

#### CIVIL ENGINEERING

Percy Max Augustus. *B.S.*, *University of Kentucky*, 1962.  
 Ralph Eric Bredehorst. *B.S.*, *California Institute of Technology*, 1961.  
 Hugo Breed Fischer. *B.S.*, *California Institute of Technology*, 1958.  
 Michael John Anthony Hannon. *B.E.*, *University College, Cork, Ireland*, 1960.  
 Hon-Yim Ko. *B.Sc.*, *University of Hong Kong*, 1962.  
 Jay C. Pyle. *B.S.*, *Agricultural and Mechanical College of Texas*, 1962.  
 Dwight Clare Schroeder. *B.S.*, *California Institute of Technology*, 1950.  
 Boris Simpser-Dubovoy. *C.E.*, *University of Mexico*, 1961.  
 Eliot Francis Tucker. *B.S.*, *Northeastern University*, 1962.

#### ELECTRICAL ENGINEERING

Carl Edward Baum. *B.S.*, *California Institute of Technology*, 1962.  
 David Bernard Benson. *B.S.*, *California Institute of Technology*, 1962.  
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 Robert William Bower. *B.A.*, *University of California (Berkeley)*, 1962.  
 Bruce Leroy Conroy. *S.B.*, *Massachusetts Institute of Technology*, 1962.  
 James Edward Cordes. *B.S.*, *California Institute of Technology*, 1962; *B.A.*, *Occidental College*, 1962.  
 Ted H. Davey. *B.S.*, *California Institute of Technology*, 1962.  
 Andrew Dienes. *B.E.*, *McGill University*, 1962.  
 Michael John Ferguson. *B.A.Sc.*, *University of Toronto*, 1962.  
 Lavelle Roger Gibson. *B.S.*, *University of Oklahoma*, 1962.  
 Malcolm Lee Heimer. *B.S.*, *Bucknell University*, 1962.

Arnold Richard Jones. *B.S., California Institute of Technology, 1961, 1962.*  
 Algis John Juodikis. *B.S., University of Illinois, 1961.*  
 Robert Kenneth Keenan. *B.S., University of California (Los Angeles), 1962.*  
 Richard Michael Leichus. *B.E., Stevens Institute of Technology, 1962.*  
 Anastasios Gerasimos Livitsanos. *B.E., Stevens Institute of Technology, 1962.*  
 Wayne A. Massey. *B.S., California Institute of Technology, 1961.*  
 John Wallace Matthews. *B.S., University of California (Los Angeles), 1962.*  
 Patrick Anthony McGovern. *B.E., University of Queensland, 1961; B.Sc., 1962.*  
 Lauren Vail Merritt. *B.S., California Institute of Technology, 1962.*  
 Fernando Mexia-Algar. *Ae.E., Aeronautical Engineering Technical University, Madrid, 1955.*  
 Paul Joel Nahin. *B.S., Stanford University, 1962.*  
 Robert Ronald Natale. *B.E.S., The Johns Hopkins University, 1962.*  
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 Raymond Félix Poggi. *Dipl., Faculte des Sciences de Marseille, 1962.*  
 George Robert Root, Jr. *B.S., California Institute of Technology, 1962.*  
 Robert James Schneider. *B.S., Washington University, 1961.*  
 Gaetan Joseph St-Cyr. *B.S., California Institute of Technology, 1962.*  
 Byron Fletcher Summers, Jr. *B.S., California Institute of Technology, 1961.*  
 Richard Franklin Webber. *B.S., California Institute of Technology, 1955.*  
 Clarence G. Winterheimer. *B.A., Evansville College, 1957; B.S., 1958.*  
 James Yoh. *B.S., California Institute of Technology, 1962.*

#### ENGINEERING SCIENCE

David Storer Burnett. *B.E.P., Cornell University, 1962.*  
 David G. Carta. *B.S., California Institute of Technology, 1962.*  
 James Edward Lancaster. *B.S., Seattle Pacific College, 1961.*  
 Joseph Po-keung Lau. *B.Sc., Purdue University, 1962.*  
 Laurence Bei-Yu Zung. *B.Sc., Purdue University, 1962.*

#### MATERIALS SCIENCE

Samuel Theodore Furr. *B.S., California Institute of Technology, 1962; B.A., Occidental College, 1962.*  
 Edmond Remy Iagolnitzer. *Dipl. d'Ingenieur, Ecole des Mines de Nancy, 1962.*  
 Miguel Enrique Levy. *B.S., California Institute of Technology, 1962.*  
 John Christian Russ. *B.S., California Institute of Technology, 1962.*  
 Chang-chyi Tsuei. *B.S., National Taiwan University, 1960.*

#### MECHANICAL ENGINEERING

Irwin Emanuel Alber. *B.S., University of California (Los Angeles), 1962.*  
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 Lon Edward Bell. *B.S., California Institute of Technology, 1962.*  
 Jacob Brentjes. *B.S., University of California (Berkeley), 1960.*  
 William Winston Evans. *B.Sc., University of Alberta, 1962.*  
 Pierre Facon. *M.E., Universite de Nancy, 1962.*  
 William Paul Gruber. *B.S., University of Washington, 1962.*

Dwight Harwood Harrison. *B.S., University of Kansas, 1955.*

William Lynderman Hendry. *B.S., University of California (Los Angeles), 1962.*

David Fielding James. *B.Sc., Queen's University, 1962.*

Keishi Kawamo. *B.E., Waseda University, 1959.*

C. Robert Klotz. *B.M.E., Fenn College, 1962.*

Alan Lippert. *B.M.E., Cornell University, 1961.*

Franklin Lester Marshall. *B.S., California Institute of Technology, 1962.*

Rex Bredesen Peters. *B.S., California Institute of Technology, 1956.*

Frank Ridolphi. *B.S., California Institute of Technology, 1962.*

Alvin Kenneth Yedlin. *B.M.E., Polytechnic Institute of Brooklyn, 1962.*

## BACHELOR OF SCIENCE

**Henry Don Isaac Abarbanel**, Beverly Hills, California. *Physics*.

**Daniel John Alderson**, Tujunga, California. *Astronomy*.

John Caffall Alleman, Monterey Park, California. *Mathematics*.

David John Allen, Pasadena, California. *Engineering*.

Ernest Howard Anderson, Everett, Washington. *Geology*.

Kurt Steven Anderson, Rockford, Illinois. *Astronomy*.

Jack Lee Arnold, Forest Grove, Oregon. *Engineering*.

Thomas Vincent Atkinson, Jr., Bellaire, Texas. *Chemistry*.

Raymond Dean Ayers, San Diego, California. *Physics*.

**David Lowell Barker**, Pasadena, California. *Chemistry*.

Michael F. Behrens, Arcadia, California. *Mathematics*.

Brian Charles Belanger, Duluth, Minnesota. *Engineering*.

**Edward Anton Bender**, Sacramento, California. *Mathematics*.

Donald Allen Blankenship, Seattle, Washington. *Physics*.

Richard Clark Blish II, West Covina, California. *Physics*.

**Joseph Thomas Bocklage**, Baltimore, Maryland. *Engineering*.

Thomas Theodore Bopp, Louisiana, Missouri. *Chemistry*.

**Edwin Ogilvie Buchman**, Pasadena, California. *Mathematics*.

**William Lionel Burke**, St. Petersburg, Florida. *Physics*.

**Robert Louis Causey**, South San Gabriel, California. *Mathematics*.

John Millard Caywood, Oroville, California. *Engineering*.

Gregory Thomas Chalfin, Pasadena, California. *Engineering*.

Gerald David Chandler, Hawthorne, California. *Engineering*.

**Bruce Wilcox Chesebro**, Los Angeles, California. *Chemistry*.

David Charles Clark, Woodland, California. *Mathematics*.

Ronald Keith Counsell, Kalispell, Montana. *Chemistry*.

**Dennis Irwin Couzin**, Skokie, Illinois. *Mathematics*.

Frank Rees Curtis, Hollywood, California. *Engineering*.

Herbert Starr Curtis, Boulder City, Nevada. *Geology*.

**Dikran Damlamayan**, Istanbul, Turkey. *Engineering*.

Richard Arthur D'Ari, Auburn, California. *Biology*.

**Jan William Dash**, Long Beach, California. *Engineering*.

Vladimir Dvornychenko, Los Angeles, California. *Physics*.

Patrick Kerwin Earley, North Hollywood, California. *Engineering*.

Sanfred Willard Elieson, Jr., Pasadena, California. *Engineering*.

**Terry Eugene Ernest**, San Pedro, California. *Chemical Engineering*.

Remigio Fernandez-Martin, Santiago De Cuba, Cuba. *Chemical Engineering*.

William Fisher Francis, Jr., Yazoo City, Mississippi. *Engineering*.

James Terence Geddis, San Diego, California. *Mathematics*.

**Lawrence Kenneth Gershwin**, Bayside, New York. *Physics*.

William Cannon Giauque, Monrovia, California. *Geology*.

Frederic Andrews Gibbs, Jr., Chicago, Illinois. *Biology*.

Jerrold Ralph Goodwin, Newport Beach, California. *Mathematics*.

*Students whose names appear in boldface type are being graduated with honor in accordance with a vote of the Faculty.*

**Richard William Griffith**, Los Angeles, California. *Engineering*.

Harold Roger Harrison, Arlington, Virginia. *Physics*.

Harold Jay Haskins, Lincoln, Nebraska. *Engineering*.

**Roger Calvert Hill**, Pasadena, California. *Physics*.

**Martin Robert Hoffman**, Glencoe, Illinois. *Mathematics*.

**John Michael Hosack**, La Mesa, California. *Mathematics*.

Sigmund John Hoverson, Seattle, Washington. *Physics*.

Alan Frank Huber, Mountain View, California. *Biology*.

Wayne Charles Huber, Hawthorne, California. *Engineering*.

Jackson Isamu Ito, Sacramento, California. *Engineering*.

Robert Lee Jernigan, Santa Fe, New Mexico. *Chemistry*.

Carlos S. Johnson, Jr., San Diego, California. *Mathematics*.

Harry Edward Keller III, Pasadena, California. *Chemistry*.

John Richard Kessler, Glencoe, Illinois. *Mathematics*.

**John Andrew Kiger, Jr.**, Pasadena, California. *Biology*.

**Allan R. King**, San Diego, California. *Engineering*.

John Louis Kleiderer, Indianapolis, Indiana. *Engineering*.

**Ronald Lee Koretz**, Los Angeles, California. *Biology*.

Michael Marvin Krieger, Los Angeles, California. *Mathematics*.

**Nishan Kay Krikorian**, Pasadena, California. *Mathematics*.

David James Large, Mount Vernon, Washington. *Engineering*.

Anthony Shui-Yee Lau, Kowloon, Hong Kong. *Physics*.

Don Howard Lee, Portland, Oregon. *Engineering*.

**Stephen Howard Leppla**, Palos Verdes Estates, California. *Biology*.

**John Seymour Letcher, Jr.**, Lexington, Virginia. *Physics*.

**John Hathaway Lindsey II**, Southport, Connecticut. *Mathematics*.

Stephen Ludwig Lowe, San Francisco, California. *Chemistry*.

Hayden Bryant Macurda, Pleasantville, New York. *Engineering*.

John Patrick Manning, Torrance, California. *Chemistry*.

Stephen Howard Mastin, Skokie, Illinois. *Chemistry*.

John Michael May, Malibu, California. *Mathematics*.

**Barry Malcolm McCoy**, Tucson, Arizona. *Physics*.

James Ernest McCoy, Dallas, Texas. *Physics*.

Cyrus Mead IV, Highland Park, Illinois. *Chemistry*.

Aram Z. Mekjian, Westbury, New York. *Physics*.

Wendell Willkie Mendell, Houston, Texas. *Physics*.

Charles Vincent Minichiello, Jr., Winthrop, Massachusetts. *Chemistry*.

Lee Marvin Molho, Glendale, California. *Engineering*.

Barry Kyler Moritz, Linden, New Jersey. *Physics*.

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Richard John O'Connell, Helena, Montana. *Physics*.

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David Frederick Ollis, Los Gatos, California. *Chemical Engineering*.

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**Michael David Perlman**, Chicago, Illinois. *Mathematics*.

Richard Emil Peterson, Lenexa, Kansas. *Physics*.  
**Allen Michael Pfeffer**, Portland, Connecticut. *Mathematics*.  
**Raymond Herman Plaut**, Los Angeles, California. *Engineering*.  
**Stephen William Prata**, Sacramento, California. *Astronomy*.  
Larry Rabinowitz, Los Angeles, California. *Mathematics*.  
John Rayner, Ridgewood, New Jersey. *Physics*.  
**Richard Stuart Robertson**, Bainbridge Island, Washington. *Mathematics*.  
Arthur Brouhard Robinson, Houston, Texas. *Chemistry*.  
**N. Paul Rosenthal**, Beverly Hills, California. *Chemistry*.  
**Bruce Lee Rothschild**, Los Angeles, California. *Mathematics*.  
**Larry Edward Ruff**, Sacramento, California. *Physics*.  
Joseph Edward Russo, Boston, Massachusetts. *Mathematics*.  
**Charles Albert Ryavec**, Santa Monica, California. *Mathematics*.  
William Frederick Saam, Butte, Montana. *Physics*.  
James Mamoru Sagawa, Phoenix, Arizona. *Engineering*.  
Stanley Walter Sajdera, Chicago, Illinois. *Biology*.  
Robert William Schmieder, Phoenix, Arizona. *Physics*.  
Robert Jay Schmulian, San Francisco, California. *Engineering*.  
Franklin Alfred Schultz, Corona del Mar, California. *Chemistry*.  
Richard Eugene Sears, Palo Alto, California. *Chemical Engineering*.  
Truman Leo Seely, *Forest Grove, Oregon*. *Chemical Engineering*.  
Albert Julius Semtner, Dallas, Texas. *Mathematics*.  
**James Franklin Shaw**, San Marino, California. *Engineering*.  
David S. Siegel, Chicago, Illinois. *Mathematics*.  
Jack Raymond Slager, Seattle, Washington. *Engineering*.  
**George Fredrick Soule**, Arcadia, California. *Engineering*.  
**Willard Gibbs Spiegelman**, Champaign, Illinois. *Mathematics*.  
**Howard Alan Stewart**, Chattanooga, Tennessee. *Physics*.  
**Kenneth Barry Stolarsky**, San Diego, California. *Mathematics*.  
David Ross Stoutemyer, Pacific Palisades, California. *Engineering*.  
**Karvel Kuhn Thornber**, Portland, Oregon. *Engineering*.  
**Ivar Harald Tombach**, Palos Verdes Estates, California. *Engineering*.  
Leslie Jens Tomley, Hayward, California. *Physics*.  
**Charles Robert Trimble**, Pitman, New Jersey. *Engineering*.  
Howard H. Wang, Seattle, Washington. *Biology*.  
**Randle William Ware**, Phoenix, Arizona. *Engineering*.  
Michael Kenneth Wells, Beverly Hills, California. *Engineering*.  
**Warren Humphreys White**, East Norwich, New York. *Mathematics*.  
**James Gerard Williams**, Los Angeles, California. *Astronomy*.  
David Franklin Windsor, Whittier, California. *Engineering*.  
Ying-Bun Woo, Hong Kong. *Engineering*.  
**Alan Cameron Wright**, Houston, Texas. *Chemistry*.  
**Steven Joseph Yellin**, Los Angeles, California. *Physics*.  
Joel William Young, Berea, Kentucky. *Engineering*.  
**Albert Yeou-Cherung Yu**, Hong Kong. *Engineering*.

CANDIDATES FOR COMMISSIONS  
UNITED STATES AIR FORCE  
RESERVE OFFICERS TRAINING CORPS

Joseph Thomas Bocklage\*

Stephen Ludwig Lowe

*\*Distinguished Air Force Reserve Officers Training Corps Graduate*

## 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 1962-63.

## CLASS OF 1964

|                             |                           |
|-----------------------------|---------------------------|
| Jesse Lee Beauchamp         | Robert James McEliece     |
| Richard Ray Burgess         | Richard Paul McGehee      |
| John Robert Burke           | William Stuart Meisel     |
| Herbert Hwa-Sen Chen        | Robert Ricardo Meyer      |
| Bob Ly-Shyng Ching          | Guthrie Miller            |
| David Lem Colton            | Roger Leon Minear         |
| Francis Anthony Dahlen, Jr. | Robert Alan Moline        |
| Steven Mark Farber          | Howard Ken Ono            |
| Samuel Robert Gordon        | George Norman Reeke, Jr.  |
| Mark Northrop Gurnee        | Dennis Kent Ross          |
| David Andrew Hammer         | David Henry Seib          |
| David Russell Hearn         | Richard Heath Stanton     |
| Alan Carleton Hindmarsh     | Arthur Turner             |
| David Holtz                 | Charles Irvin Vinsonhaler |
| Ronald Wayne Larsen         | Volker Michael Vogt       |
| Thomas Walker Latham        | Joseph Herman Weis        |
| Tommy Carl Lubensky         | Paul Frank Winkler, Jr.   |
| John Michael Julius Madey   | Alvin Bau Yuen Young      |
| Kenneth Fred Manly          | Ralph Howard Young        |
| Terry Steven Mast           |                           |

## CLASS OF 1965

|                           |                          |
|---------------------------|--------------------------|
| Ivars Ambats              | Mark Joel Gingold        |
| George Conrad Brackett    | Kenneth Kunen            |
| Norman Hyde Camien        | Michael Norman Misheloff |
| I-Lok Chang               | Kenneth Kiyoshi Murata   |
| Peter King Clark          | Lee Niedengard           |
| Roger Carl Davisson       | Jerry Earl Nelson        |
| Martin B. Einhorn         | David Thomas Price       |
| Richard Charles Essenberg | Ronald Sylvester Remmel  |
| Richard Skipp Frenk       | Edwin Paul Swatek III    |

## CLASS OF 1966

|                               |                       |
|-------------------------------|-----------------------|
| Michael Paul Anthony          | Dan Mc Cammon         |
| Jared Asher Austin            | Larry Robert Miller   |
| Richard Henry Bigelow         | William Franklin Orr  |
| Gary Lee Bornzin              | Earl Crawford Salo    |
| William Bruce Broste          | David Dawson Shochat  |
| Philip Lynn Coleman           | Richard Neil Silver   |
| Elmer William Colglazier, Jr. | Sean Carl Solomon     |
| Benjamin Dembart              | Richard Peter Stanley |
| Douglas Whitney Gage          | Timothy Lee Stephens  |
| Stuart Wilber Galley          | John Charles Trijonis |
| Jesse Grodnik                 | John R. Tucker        |
| Girard Eastman Haven          | John Peyton Walter    |
| Alden Douglas Holford         | Roy Blakeney Woolsey  |
| Frederick Insley Mayer        |                       |

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.

IVAR HARALD TOMBACH

DON BAXTER, INC. PRIZES

Awarded to the undergraduate students who during the year have carried out the best original researches in chemistry.

*First Prize:* ALAN C. WRIGHT

*Second Prize:* DAVID L. BARKER

*Honorable Mention:* JESSE L. BEAUCHAMP

ROBERT D. BRUNER

E. T. BELL MATHEMATICS PRIZE

Awarded annually to one or more juniors or seniors for outstanding original research in mathematics.

EDWARD A. BENDER

JOHN H. LINDSEY II

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:* STEVEN MORSE

*Second Prize:* ROGER C. DAVISSON

EASTMAN KODAK SCIENTIFIC AWARDS

Awarded to doctoral students on the basis of outstanding contributions and progress either in graduate studies and research or in teaching.

*Chemistry:* NICHOLAS J. TURRO, JR.

GEORGE M. WHITESIDES

*Physics:* KENNETH I. KELLERMANN

DAVID JOSEPH MACPHERSON PRIZE

Awarded annually to the graduating senior in engineering who best exemplifies excellence in scholarship.

KARVEL K. THORNBER

MARY A. EARLE MCKINNEY PRIZES

Established in 1946 by the late Samuel P. McKinney, M.D., as a memorial to his mother, to cultivate proficiency in writing.

*First Prize:* VOLKER M. VOGT

*Second Prize:* LARRY RABINOWITZ

*Third Prize:* PHILIP H. BOWLES

*Fourth Prize:* MICHAEL J. COSGROVE

DON SHEPARD AWARDS

Awarded annually to one or more outstanding residents of the Student Houses in order to pursue cultural opportunities which they might otherwise not be able to enjoy.

CARTER G. NAYLOR

GERALD H. THOMAS

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