Berkeley '95-'97

240. Digital Data Processing. (3) Three hours of lecture and two hours of laboratory per week. *Prerequisites: Consent of instructor.* Considerations for digital signal processing and data analysis. Fourier Transforms, convoluti tems, Z tranfon flection data, de to 3-D seismic

1995 - 1997

242. Numerical Mineral Engin one hour of disc sent of instruct niques to proble mineral enginee ical procedures lustrated by ap lems in physical and extractive metallurgy, ceramics, mineral processing, and engineering geoscience. (F) *Staff*

250. Petroleum Well Drilling and Completion. (3) Three hours of lecture per week. *Prerequisites: Graduate Standing.* Present methods for drilling and evaluating hydrocarbon wells. Examination of the physics and mechanics underlying the various processes which are involved in drilling, completion and testing. (SP) *Cooper*

251. Advances in Modeling of Fluid Flow in the Subsurface. (3) Three hours of lecture per week. *Prerequisites: Graduate standing in Engineering.* The fundamentals of multiphase, multicomponent and non-isothermal flow in the subsurface are explained and applied to practical problems in reservoir engineering. The course material will be useful in studies of massive, multicomponent organic spills in the shallow subsurface; oil recovery; and subsurface storage of nuclear waste. (F,SP)

260. Surface Properties of Materials. (3) Three hours of lecture per week. Thermodynamics of surfaces and phase boundaries, surface tension of solids and liquids, surface activity, adsorption, phase equilibria and contact angles, electrochemical double layers at interfaces, theory and applications. (F) *Staff*

261. Applied Colloidal Phenomena. (2) Two hours of lecture per week. The characterization of colloidal materials and the physical chemistry of colloid systems. Primary emphasis on the interaction of colloid particles, particularly in aqueous environments; floculation, coagulation, and dispersion phenomena, selective flocculation. (SP) *Staff*

262. Surface Chemistry of Flotation. (2) Two hours of lecture per week. Application of surface and crystal chemistry to the separation of minerals by flotation; selective absorption of surfactants; natural floatability; flotation of fine particulates, precipitates, oil droplets. *Staff*

265. Modeling of Particulate Rate Processes. (3) Three hours of lecture per week. *Prerequisites: Graduate standing in engineering.* Fundamental principles of process modeling; introduction to particulate systems in mineral, metallurgical, ceramic, and chemical industries; quantitative description of particulate systems; transport through reactors, development of population balance models and analysis of rate processes involving particulate size changes; solid-liquid and solid-solid separations, and fluid-solid reactions. (SP) *Sastry*

266. Mineral Process Simulation. (2) Two hours of lecture per week. *Prerequisites: 265.* Principles of process simulation, model validation and parameter estimation in mineral and metallurgical systems; process analysis by computer simulation; detailed description of size reduction, size enlargement, size separation and hydrometallurgical processes. (SP) *Sastry*

270. Advanced Hydrometallurgy. (3) Three hours of lecture per week. Principles of hydrometallurgical processing of minerals and ores. Emphasis on thermodynamics, kinetics, and mechanisms of hydrometallurgical reactions. Analysis of methods for the recovery of metals from leach liquors. (SP) *Doyle*

271. Electrochemical Techniques in Process Metallurgy. (2) Two hours of lecture per week. Analysis of electrochemical methods for the extraction, refining and processing of metals in aqueous and molten salt ns. Thermodynamic and kinetic principles gov- the development and operation of such pro- s. (SP) *Doyle*

letallurgical Transport and Rate Phenomena. hree hours of lecture per week. *Prerequisites: iate standing in engineering.* Heat, mass, and ntum transport and reaction kinetics in systems int to extractive metallurgy, mineral processing, iaterials processing. (F) *Evans*

Advanced Topics in Seismology. (3) Course ie repeated for credit. Three hours of lecture per *Prerequisites: Introductory course in seismology; 240.* Active areas of research in applied seismology. Subjects include: anisotropic and viscoelastic wave propagation, borehole seismology, crosswell seismology, including crosswell seismic tomography, vertical seismic profiling, reservoir monitoring including passive seismic methods. (SP) *Rector*

290D. Advanced Topics in Electrical and Electromagnetic Methods. (3) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: Math 50A-50B and an introductory course in geology.* Theory of electric and low frequency electromagnetic fields in inhomogeneous conductive media. Fundamental properties of fields above, on, and within layered media for plane wave, line, and dipole source fields. Time and frequency domain solutions with finite difference, finite element, and integral equation techniques. Inversion and imaging of electrical conductivity. Course will emphasize recent developments and new research directions. FORTRAN or C required. (F,SP) *Morrison*

298. Group Studies, Seminars, or Group Research. (1-8) Course may be repeated for credit. Must be taken on a *satisfactory/unsatisfactory* basis. *Prerequisites: Graduate standing in engineering.* Advanced study in various subjects through special seminars on topics to be selected each year, informal group studies of special problems, group participation in comprehensive design problems, or group research on complete problems for analysis and experimentation.

299. Individual Study or Research. (1-12) Course may be repeated for credit. Must be taken on a *satisfactory/unsatisfactory* basis. Individual investigation of advanced mineral engineering problems. (F,SP) *Staff*

601. Individual Study for Master's Students. (1-8) Course may be repeated for credit. Course does not satisfy unit or residence requirements for master's degree. Must be taken on a *satisfactory/unsatisfactory* basis. *Prerequisites: Graduate standing in engineering.* Individual study for the comprehensive or language requirements in consultation with the field adviser. (F,SP) *Staff*

602. Individual Study for Doctoral Students. (1-8) Course may be repeated for credit. Course does not satisfy unit or residence requirements for doctoral degree. Must be taken on a *satisfactory/unsatisfactory* basis. *Prerequisites: Graduate standing in engineering.* Individual study in consultation with the major field adviser, intended to provide an opportunity for qualified students to prepare themselves for the various examinations required of candidates for the Ph.D. (and other doctoral degrees). (F,SP) *Staff*

Mathematics

(College of Letters and Science)

Department Office: 970 Evans Hall, 642-6550

Professors:

Robert M. Anderson, Ph.D. Yale University. Mathematical economics, non-standard analysis
William B. Arveson, Ph.D. University of California at Los Angeles. Functional analysis, operator algebras
*William G. Bade, Ph.D. University of California at Los Angeles. Functional analysis
George M. Bergman, Ph.D. Harvard University. Rings, universal algebra, counterexamples
Elwyn R. Berlekamp, Ph.D. Massachusetts Institute of Technology. Algebraic coding theory
Richard E. Borcherds, Ph.D. Trinity College, Cambridge. Kac-Moody algebras
Andrew J. Casson, B.A. University of Cambridge. Topology
Paul R. Chernoff, Ph.D. Harvard University. Functional analysis
Alexandre J. Chorin, Ph.D. New York University. Applied mathematics, numerical methods
Robert F. Coleman, Ph.D. Princeton University. Algebraic geometry
James W. Demmel, Ph.D. University of California, Berkeley. Numerical analysis, applied control theory
L. Craig Evans, Ph.D. University of California at Los Angeles. Partial differential equations
David A. Freedman, Ph.D. Princeton University. Probability theory, statistics
F. Alberto Grünbaum, Ph.D. Rockefeller University. Applied mathematics, medical imaging
†Ole H. Hald, Ph.D. New York University. Numerical analysis
Leo A. Harrington, Ph.D. Massachusetts Institute of Technology. Recursion theory, model theory
Jenny C. Harrison, Ph.D. University of Warwick. Dynamical systems
Robert C. Hartshorne, Ph.D. Princeton University. Algebraic geometry
*Henry Helson, Ph.D. Harvard University. Harmonic analysis, function theory
*Morris W. Hirsch, Ph.D. University of Chicago. Dynamical systems, topology
Wu-Yi Hsiang, Ph.D. Princeton University. Transformation groups, differential geometry
Vaughan F.R. Jones, Ph.D. Docteur es Sciences, School of Mathematics, Geneva. Von Neumann algebras
William M. Kahan, Ph.D. University of Toronto. Error analysis, numerical computations
†Richard M. Karp, Ph.D. Harvard University. Algorithms and computational complexity.
Robion C. Kirby, Ph.D. University of Chicago. Topology of manifolds
Michael J. Klass, Ph.D. University of California at Los Angeles. Probability theory, combinatorics
*Shoshichi Kobayashi, Ph.D. University of Washington. Riemannian and complex manifolds
Maxim Kontsevich, Ph.D. University of Bonn. Mathematical physics
Tsit-Yuen Lam, Ph.D. Columbia University. Algebra
Hendrik W. Lenstra, Jr., Ph.D. University of Amsterdam. Number theory
Jerrold E. Marsden, Ph.D. Princeton University. Mathematical physics and engineering
Curtis T. McMullen, Ph.D. Harvard University. Complex analysis, topology, dynamics
C. Keith Miller, Ph.D. Rice University. Partial differential equations
Calvin C. Moore, Ph.D. Harvard University. Representations of topological groups
John C. Neu, Ph.D. California Institute of Technology. Applied mathematics
Arthur E. Ogus, Ph.D. Harvard University. Algebraic geometry
*Beresford N. Parlett, Ph.D. Stanford University. Numerical analysis, scientific computation
*Murray H. Protter, Ph.D. Brown University. Partial differential equations
Charles C. Pugh, Ph.D. Johns Hopkins University. Dynamics
Marina Ratner, Ph.D. Moscow State University. Ergodic theory
Nicolai Reshetikhin, Ph.D. Steklov Institute. Mathematical physics, low-dimensional topology
John L. Rhodes, Ph.D. Massachusetts Institute of Technology. Algebra, finite semigroups, automata
Kenneth A. Ribet, Ph.D. Harvard University. Algebraic geometry, number theory
Marc A. Rieffel, Ph.D. Columbia University. Operator algebras, group representations
Donald E. Sarason, Ph.D. University of Michigan. Functional analysis, function theory
James A. Sethian, Ph.D. University of California, Berkeley. Applied mathematics, numerical methods
Jack H. Silver, Ph.D. University of California, Berkeley. Mathematical logic, set theory
*Stephen Smale, Ph.D. University of Michigan. Dr. Sc. University of Warwick. Algorithms, numerical analysis
*John R. Stallings, Jr., Ph.D. Princeton University. Topology, group theory
Bernd Sturmfels, Ph.D. University of Washington (Seattle). Combinatiorics, computational algebra, algebraic geometry
William P. Thurston, Ph.D. University of California, Berkeley. Topology and geometry
Dan-Virgil Voiculescu, Ph.D. University of Bucharest. Operator algebras
Paul A. Vojta, Ph.D. Harvard University. Number theory

John B. Wagoner, Ph.D. Princeton University. Differential topology, algebraic *K*-theory
Alan D. Weinstein, Ph.D. University of California, Berkeley. Symplectic geometry, mathematical physics
*Joseph A. Wolf, Ph.D. University of Chicago. Lie groups, harmonic analysis
Thomas H. Wolff, Ph.D. University of California, Berkeley. Harmonic analysis
Mariusz Wodzicki, Ph.D. Steklov Mathematical Institute. Global analysis, geometry, K-theory
W. Hugh Woodin, Ph.D. University of California, Berkeley. Set theory, large cardinals
Hung-Hsi Wu, Ph.D. Massachusetts Institute of Technology. Riemannian geometry, complex manifolds
John W. Addison, Jr. *(Emeritus)*, Ph.D. University of Wisconsin. Logic, descriptive set theory
David H. Blackwell *(Emeritus)*, Ph.D. University of Illinois, Urbana, Bayesian inference, game theory
Hans J. Bremermann *(Emeritus)*, Ph.D. University of Münster. Mathematical biology
Paul L. Chambré *(Emeritus)*, Ph.D. University of California, Berkeley. Applied mathematics
Shiing-Shen Chern *(Emeritus)*, D.Sc., LL.D. University of Hamburg. D.Sc. University of Chicago. LL.D. Chinese University of Hong Kong. Differential and integral geometry
Heinz O. Cordes *(Emeritus)*, Ph.D. University of Göttingen. Classical analysis
Gerard Debreu *(Emeritus)*, D.Sc. University of Paris. Mathematical economics
Stephen P.L. Diliberto *(Emeritus)*, Ph.D. Princeton University. Celestial mechanics, applied mathematics
Lester E. Dubins *(Emeritus)*, Ph.D. University of Chicago. Probability, gambling theory, geometry
Jacob Feldman *(Emeritus)*, Ph.D. University of Chicago. Ergodic theory, operator algebras
Alfred L. Foster *(Emeritus)*, Ph.D. Princeton University. Universal algebra
David Gale *(Emeritus)*, Ph.D. Princeton University. Mathematical economics
Leon A. Henkin *(Emeritus)*, Ph.D. Princeton University. Logic, foundations, mathematics education
Gerhard P. Hochschild *(Emeritus)*, Ph.D. Princeton University. Lie groups, algebraic groups
Irving Kaplansky *(Emeritus)*, Ph.D. Harvard University. Algebra
Tosio Kato *(Emeritus)*, D.Sc. University of Tokyo. Mathematical physics
John L. Kelley *(Emeritus)*, Ph.D. University of Virginia. Functional analysis
Lucien M. Le Cam *(Emeritus)*, Ph.D. University of California, Berkeley. Theoretical statistics, cancer research
R. Sherman Lehman *(Emeritus)*, Ph.D. Stanford University. Number theory, numerical analysis
Ralph N. McKenzie *(Emeritus)*, Ph.D. University of Colorado. Algebra, logic, lattice theory
Andrew P. Ogg, *(Emeritus)* Ph.D. Harvard University. Number theory, elliptic curves
Edmund J. Pinney *(Emeritus)*, Ph.D. California Institute of Technology. Applied mathematics, differential equations
Raphael M. Robinson *(Emeritus)*, Ph.D. University of California, Berkeley. One complex variable, foundations
Maxwell A. Rosenlicht *(Emeritus)*, Ph.D. Harvard University. Algebraic geometry, differential algebra
Rainer K. Sachs *(Emeritus)*, Ph.D. Syracuse University. Relativity, biophysics
Ichiro Satake *(Emeritus)*, Ph.D. University of Tokyo. Symmetric spaces, automorphic functions
Isadore M. Singer *(Emeritus)*, Ph.D. University of Chicago, Dr. Sc. Tulane University. Geometry, partial differential equations
Robert M. Solovay *(Emeritus)*, Ph.D. University of Chicago. Metamathematics of set theory
Edwin H. Spanier *(Emeritus)*, Ph.D. University of Michigan. Topology, theory of languages
Abraham H. Taub *(Emeritus)*, Ph.D. Princeton University. Mathematical physics, relativity, computation
Angus E. Taylor *(Emeritus)*, Ph.D. California Institute of Technology. History of mathematics
P. Emery Thomas *(Emeritus)*, Ph.D. Princeton University. Topology, number theory
Robert L. Vaught *(Emeritus)*, Ph.D. University of California, Berkeley. Foundations of mathematics

Assistant Professors:

Alexandre Givental, Ph.D. Moscow State University. Geometry, singularity theory, mathematical physics
Fraydoun Rezakhanlou, Ph.D. New York University. Probability theory, partial differential equations
Vera Serganova, Ph.D. Leningrad University. Representation theory, lie algebras
John Strain, Ph.D. University of California, Berkeley. Numerical analysis, computational physics

---

Adjunct Professor:

Paul Concus, Ph.D. Harvard University. Fluid dynamics, numerical analysis

Affiliated Professor:

Alan H. Schoenfeld *(Education)*, Ph.D. Stanford University. Psychology of problem solving

Visiting Faculty:

Galia Dafni, Ph.D. Princeton University. Classical analysis
Justin Roberts, Ph.D. Cambridge University. Geometry

The Major Programs

The department offers undergraduate students a choice of two programs leading to the A.B. degree: the major in mathematics and the major in applied mathematics. Each major program in mathematics gives students the opportunity to obtain a strong, well-rounded mathematical background suitable for postgraduate study as well as for professional careers in science, industry, or education. The courses required for the major emphasize theoretical material. Students with an interest in the applications of mathematics may find the major program in applied mathematics particularly responsive to their needs. The requirements for both majors are summarized below. More detailed information is given in the Undergraduate Announcement, available from the undergraduate assistant in 965 Evans Hall.

General Major Requirements. Both major programs require a lower division base of Mathematics 1A-1B and 53 and 54. Courses 16A-16B are not an acceptable alternative. Math 1A-1B must be completed with average grades of C or better; Math 53 and 54 must be completed with minimum grades of C in each. Transfer students should contact the undergraduate assistant in 965 Evans Hall about requirements for admission to the major. The minimum upper division major requirements are as follows:

Major in Mathematics. (a) Courses 104, 110, 113 and 185; (b) One course from each of two of the following three subject areas: I. Computing (128A); II. Geometry (140, 142); III. Logic and foundations (125A, 135); (c) At least eight upper division courses in all.

With the approval of the major adviser, students may count not more than two mathematically theoretical courses in computer science, statistics, physics, astronomy, mathematical economics, or other sciences toward requirements for the major in mathematics.

Major in Applied Mathematics. (a) 104, 110, 113, 128A, and 185; (b) Three additional upper division courses, approved by a major adviser, which form a coherent cluster in some applied area such as actuarial science, biophysics, classical mechanics, computer science, decision theory, economics, fluid mechanics, geophysics, mathematical biology, numerical analysis, operations research, probability theory, quantum mechanics, systems theory. Many other clusters are also possible.

Honors Program. In addition to completing the requirements for the major in mathematics or major in applied mathematics, students in the honors program must (a) earn a grade-point average of at least 3.5 in upper division and graduate courses in the major and at least 3.3 in all courses taken at the University; (b) complete course 196 in which they will write a senior honors thesis, or pass two graduate mathematics courses with a grade of at least A-; (c) receive the recommendation of their major adviser. Students interested in the honors program should consult with their major adviser at least two semesters before graduation.

The Minor Program

Students in the College of Letters and Science may complete one or more minors of their choice, normally in a field both academically and administratively distinct from their major. The minor program in the Department of Mathematics consists of the following course work:

Prerequisites: Mathematics 1A-1B and 53 and 54 (or their equivalents). These courses must be taken for a letter grade and must be passed with *average* grades of C or better. The department *strongly* recommends that students attempt the minor only if Mathematics 53 and 54 have *each* been passed with a *minimum* grade of C.

Minor Requirements: Mathematics 104, 110, 113, and 185, plus one additional upper division mathematics course. These five courses must each be taken for a letter grade, and a minimum grade-point average of 2.0 is required for upper division courses applied to the minor program. At least three of the five courses must be completed at Berkeley.

Upon completion of the required courses, students shall complete a Confirmation of Minor Program petition (available from 970 Evans Hall) and present the petition, together with a transcript (official or unofficial) to the undergraduate assistant, 965 Evans Hall, who will approve completion of the minor program.

Students may petition for the minor program at any time after the requirements have been completed until they graduate.

For more information about this program, please contact the undergraduate assistant in 965 Evans Hall.

Preparation for Graduate Study

Students preparing for graduate work in mathematics are strongly advised to acquire a reading knowledge of two foreign languages, from among French, German, and Russian. Course H117, designed to challenge students' ability to do creative thinking, is useful for students preparing for graduate work. Undergraduate students also often take one or more of the following introductory graduate courses: 202A-202B, 214, 225A-225B, 228A-228B, 250A-250B.

Graduate Programs

The department offers the M.A. degree in mathematics and Ph.D. degrees both in mathematics and applied mathematics. Detailed information concerning admission, graduate student instructorships and fellowships, and degree requirements is given in the *Graduate Announcement of the Department of Mathematics*, which is available upon request from the graduate assistant, Department of Mathematics.

Courses and Seminars

Courses and seminars are listed below. More detailed and up-to-the-minute information on semester offerings, instructors, textbooks, course and seminar content, teaching and grading methods, and schedules are posted outside 910 Evans Hall before the beginning of each semester.

Lower Division Courses

Math 1A-1B is the calculus sequence intended for students planning majors in mathematics, engineering, or the sciences. The sequence is also acceptable as a substitute for Math 16A-16B. It is designed to prepare students for further courses in mathematics.

Math 16A-16B is a terminal calculus sequence intended for students planning majors in the life or social sciences.

Math 32 is intended for students who wish to take Math 1A or 16A but have not met the prerequisites.

1A. Calculus. (4) Students will receive no credit for 1A after 2 or 16B; 2 units after 16A. Two hours of lecture and two hours of discussion per week; optional third hour of lecture or workshop. *Prerequisites: Three and a half years of high school math, including trigonometry and analytic geometry, plus a satisfactory grade in one of the following: CEEB MAT test, an AP test, the UC/CSU math diagnostic test, or 32. Consult the Mathematics Department for details. Students with AP credit should consider choosing a course more advanced than 1A.* This sequence is intended for majors in engineering and the physical sciences. An introduction to differential and integral calculus of functions of one variable, with applications, transcendental functions, and techniques of integration. (F,SP)

*Professor in the Graduate School
†Recipient of Distinguished Teaching Award

Berkeley '95-'97

1AL. Calculus Computer Laboratory. (1) Two hours of microcomputer laboratory per week. Must be taken on a *passed/not passed* basis. *Prerequisites: Concurrent enrollment in 1A.* Optional microcomputer supplement to accompany 1A. Graphing and analysis of functions and curves, including algebraic, trigonometric, and exponential functions. Maximum and minimum problems, root finding, and the graphing of derivatives. (F)

1B. Calculus. (4) Students will receive no credit for 1B after taking 3; 2 units after 16B. Three hours of lecture and two hours of discussion per week. *Prerequisites: 1A.* Continuation of 1A. Techniques of integration; applications of integration. Infinite sequences and series. First order ordinary differential equations; exact equations. Second order ordinary differential equations; oscillation and damping; series solutions of ordinary differential equations. (F,SP)

1BL. Calculus Computer Laboratory. (1) Two hours of microcomputer laboratory per week. Must be taken on a *passed/not passed* basis. *Prerequisites: Concurrent enrollment in 1B.* Optional microcomputer supplement to accompany 1B. Computer solutions of first-order differential equations, growth and decay and simple harmonic motion. Numerical integration (including Simpson's and the trapezoidal rules) with error analysis; error analysis of infinite series. Graphing of surfaces by the method of sections. (SP)

15. Concepts of Mathematics for Elementary School Teachers. (3) Three hours of lecture per week. *Prerequisites: Upper division standing and consent of instructor.* Development and structure of the real number system and its subsystems. Elementary concepts of set theory, numeration, factoring and divisibility, nonmetric geometry, measurement. (SP)

16A. Analytic Geometry and Calculus. (3) Students will receive no credit for 16A after taking 1A. Two hours of lecture and one hour of discussion per week; optional third hour of lecture or workshop. *Prerequisites: Three years of high school math, including trigonometry, plus a satisfactory grade in one of the following: CEEB MAT test, an AP test, the UC/CSU math diagnostic exam or 32. Consult the Mathematics department for details.* This sequence is intended for majors in the life and social sciences. Inequalities, absolute value, graphs of simple functions, the derivative, maxima and minima, rates of change and differentials, increasing and decreasing functions, basic properties of log and exp, introduction to integration. (F,SP)

16B. Analytic Geometry and Calculus. (3) Students will receive no credit for 16B after 3 or 1B, 2 units after 1A. Two hours of lecture and one hour of discussion per week; optional third hour of lecture or workshop. *Prerequisites: 16A.* Continuation of 16A. Introduction to integration, properties of sin and cos, fundamental theorem of calculus, properties of the integral, integration by substitution and by parts, volumes of solids of revolution and arc lengths. (F,SP)

24. Freshman Seminars. (1) Course may be repeated for credit as topic varies. One hour of seminar per week. Sections 1-2 to be graded on a letter-grade basis. Sections 3-4 to be graded on a *passed/not passed* basis. The Berkeley Seminar Program has been designed to provide new students with the opportunity to explore an intellectual topic with a faculty member in a small-seminar setting. Berkeley Seminars are offered in all campus departments, and topics vary from department to department and semester to semester. (F,SP)

32. Precalculus. (4) Students will receive no credit for 32 after taking 1A-1B or 16A-16B, and 2 units after taking P. *Prerequisites: Three years of high school mathematics, plus satisfactory score on one of the following: CEEB MAT test, math SAT, or UC/CSU diagnostic examination.* Exponential and logarithmic functions; trigonometry. Complex numbers, binomial theorem, conics, analytic geometry. Designed for students who wish to prepare for calculus. (F,SP)

39. Freshman/Sophomore Seminar. (2-4) Course may be repeated for credit as topic varies. Seminar format. *Prerequisites: Priority given to freshmen and sophomores.* Freshman and sophomore seminars offer lower division students the opportunity to explore an intellectual topic with a faculty member and a group of peers in a small-seminar setting. These seminars are offered in all campus departments; topics vary from department to department and from semester to semester. (F,SP) *Staff*

49. Supplementary Work in Lower Division Mathematics. (1-3) Course may be repeated for credit. Meetings to be arranged. *Prerequisites: Some units in a lower division Mathematics class.* Students with partial credit in lower division mathematics courses may, with consent of instructor, complete the credit under this heading. (F,SP)

53. Multivariable Calculus. (4) Students will receive 1 unit for 53 after taking 50B and 3 units after taking Math 50A. Three hours of lecture and two hours of discussion per week. Parametric equations and polar coordinates. Vectors R2 and R3. Partial derivatives. Multiple integrals. Vector calculus. (F,SP)

H53. Honors Multivariable Calculus. (4) Students will receive 1 unit for H53 after taking 50B and 3 units after taking 50A. Three hours of lecture and two hours of discussion per week. Honors version of 53. Parametric equations and polar coordinates. Vectors in R2 and R3. Partial derivatives. Multiple integrals. Vector calculus. (F,SP) *Staff*

53L. Multivariable Calculus Computer Laboratory. (1) Two hours of microcomputer laboratory per week. *Prerequisites: Concurrent enrollment in 53.* Optional microcomputer supplement to 53. (F,SP) *Staff*

54. Linear Algebra and Differential Equations. (4) Students will receive 1 unit for 54 after taking 50A and 3 units after taking Math 50B. Three hours of lecture and two hours of discussion per week. *Prerequisites: 1B.* Basic linear algebra: matrix arithmetic and determinants. Vectors R2 and R3; vector spaces; inner product as spaces. Eigenvalues and eigenvectors; linear transformations. Homogeneous ordinary differential equations; first order differential equations with constant coefficients. Fourier series and partial differential equations. (F,SP)

H54. Honors Linear Algebra and Differential Equations. (4) Students will receive 1 unit for H54 after taking 50A and 3 units after taking 50B. Three hours of lecture and two hours of discussion per week. Honors version of 54. Basic linear algebra: matrix arithmetic and determinants. Vectors in R2 and R3; vector spaces; inner product spaces. Eigenvalues and eigenvectors; linear transformations. Homogeneous ordinary differential equations; first order differential equations with constant coefficients. Fourier series and partial differential equations. (F,SP) *Staff*

54L. Linear Algebra Computer Laboratory. (1) Two hours of microcomputer laboratory per week. *Prerequisites: Concurrent enrollment in 54.* Optional microcomputer supplement to 54. (F,SP) *Staff*

55. Discrete Mathematics. (4) Two hours of lecture and two hours of discussion per week. *Prerequisites: Mathematical maturity appropriate to a sophomore math class.* Logic, mathematical induction, finite series, sets, relations, and functions, introduction to trees, combinatorics, algebraic structures, discrete probability and statistics. Emphasis on topics of interest to students of computer science. (F,SP)

67. Techniques in Mathematical Problem Solving. (3) Three hours of lecture/workshop per week. *Prerequisites: One semester of calculus or consent of instructor.* An introduction to problem-solving techniques in mathematics, including analogy, induction, "without loss of generality" arguments, working backwards, specialization and generalization, contradiction, decomposing and recombining. A large percentage of in-class time will be devoted to solving problems from a broad range of mathematical domains, including geometry, number theory, probability, logic, and set theory. (F)

74. Transition to Upper Division Mathematics. (3) Three hours of lecture per week. *Prerequisites: 53 and 54.* The course will focus on reading and understanding mathematical proofs. It will emphasize precise thinking and the presentation of mathematical results, both orally and in written form. The course is intended for students who are considering majoring in mathematics, but wish additional training. (F)

H90. Honors Undergraduate Seminar in Mathematical Problem Solving. (1) Course may be repeated for credit. Two hours of seminar per week. *Prerequisites: Consent of instructor; undergraduate standing.* This seminar is designed especially, but not exclusively, to prepare students for the annual national Putnam Mathematical Competition in December. Students will develop problem solving skills and experience by attempting the solution of challenging mathematical problems that require insight more than knowledge. (F)

96. College Algebra. (2) Students will receive no credit for 96 after taking P, PS, or 32. Four hours of workshop per week. Must be taken on a *passed/not passed* basis. Review of algebra; designed for students who do not meet the prerequisites for 32. Offered through the Student Learning Center. (F,SP) *Staff*

98. Supervised Group Study. (1-4) Must be taken on a *passed/not passed* basis. Directed Group Study, topics vary with instructor. (F,SP)

Upper Division Courses

103. Introduction to Mathematical Economics. (3) Three hours of lecture per week. *Prerequisites: 53 and 54. Formerly Economics 104.* Selected topics illustrating the application of mathematics to economic theory. This course is intended for upper division students in Mathematics, Statistics, the Physical Sciences, and Engineering, and for economics majors with adequate mathematical preparation. No economics background is required. Also listed as Economics 103 and Interdepartmental Studies 103.

104. Introduction to Analysis. (4) Three hours of lecture per week. *Prerequisites: 53 and 54.* The real number system. Sequences, limits, and continuous functions in **R** and $\mathbf{R}^n$. The concept of a metric space. Uniform convergence, interchange of limit operations. Infinite series. Mean value theorem and applications. The Riemann integral. (F,SP)

H104. Introduction to Analysis. (4) Three hours of lecture per week. *Prerequisites: 53 and 54.* Honors section corresponding to 104. Recommended for students who enjoy mathematics and are good at it. Greater emphasis on theory and challenging problems.

105. Second Course in Analysis. (4) Three hours of lecture per week. *Prerequisites: 104.* Differential calculus in $\mathbf{R}^n$: the derivative as a linear map; the chain rule; inverse and implicit function theorems. Lebesgue integration on the line; comparison of Lebesgue and Riemann integrals. Convergence theorems. Fourier series, L^2 theory. Fubini's theorem, change of variable. (SP)

110. Linear Algebra. (4) No credit allowed after completion of Math 112 or 113B. Three hours of lecture per week. *Prerequisites: 53 and 54.* Matrices, vector spaces, linear transformations, inner products, determinants. Eigenvectors. QF factorization. Quadratic forms and Rayleigh's principle. Jordan canonical form, applications. Linear functionals. (F,SP)

H110. Linear Algebra. (4) No credit allowed after completion of Math 112 or 113B. Three hours of lecture per week. *Prerequisites: 53 and 54.* Honors section corresponding to course 110 for exceptional students with strong mathematical inclination and motivation. Emphasis is on rigor, depth, and hard problems. (SP)

113. Introduction to Abstract Algebra. (4) Three hours of lecture per week. *Prerequisites: 53 and 54.* Sets and relations. The integers, congruences and the Fundamental Theorem of Arithmetic. Groups and their factor groups. Commutative rings, ideals and quotient fields. The theory of polynomials: Euclidean algorithm and unique factorizations. The Fundamental Theorem of Algebra. Fields and field extensions. (F,SP)

H113. Introduction to Abstract Algebra. (4) Three hours of lecture per week. *Prerequisites: Same as Math 113.* Honors section corresponding to 113. Recommended for students who enjoy mathematics and are good at it. Greater emphasis on theory and challenging problems. (F)

114. Second Course in Abstract Algebra. (4) Three hours of lecture per week. *Prerequisites: 113.* Further topics on groups, rings and fields not covered in Math 113. Possible topics include: the Sylow Theorems and their applications to group theory; classical groups; abelian groups and modules over a principal ideal domain; algebraic field extensions; splitting fields and Galois theory; construction and classification of finite fields. (SP)

115. Introduction to Number Theory. (4) Three hours of lecture per week. *Prerequisites: 53 and 54.* Divisibility, congruences, numerical functions, theory of primes. Topics selected: Diophantine analysis, continued fractions, partitions, quadratic fields, asymptotic distributions, additive problems. (SP)

H117. Honors Mathematical Problem Solving. (4) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: Consent of instructor.* Recommended for exceptional students with strong mathematical background and interest. Problems calling for original thought and various mathematical approaches. May include advanced topics developed through problems and open research problems.

119. Introduction to Applied Mathematics. (4) Three hours of lecture per week. *Prerequisites: 53 and 54.* A sample of ideas important in the mathematical sciences. Topics: duality in constrained optimization, structure of equilibrium equations (both discrete and continuous), initial value problems, conservation laws, uses of (fast) Fourier transform, calculus of variations, use of complex analysis, chaos. (F)

121A-121B. Mathematical Tools for the Physical Sciences. (4;4) Three hours of lecture per week. *Prerequisites: 53 and 54.* Functions of a complex variable, Fourier series, finite-dimensional linear systems. Infinite-dimensional linear systems, orthogonal expansions, special functions, partial differential equations arising in mathematical physics. Intended for students in the physical sciences who are not planning to take more advanced mathematics courses. (F,SP)

123. Ordinary Differential Equations. (4) Three hours of lecture per week. *Prerequisites: 104.* Existence and uniqueness of solutions, linear systems, regular singular points. Other topics selected from analytic systems, autonomous systems, Sturm-Liouville Theory. (F)

125A-125B. Mathematical Logic. (4;4) Three hours of lecture per week. *Prerequisites: 113 or consent of instructor.* Sentential and quantificational logic. Formal grammar, semantical interpretation, formal deduction, and their interrelation. Applications to formalized mathematical theories. Selected topics from model theory or proof theory. (F,SP)

126. Introduction to Partial Differential Equations. (4) Three hours of lecture per week. *Prerequisites: 104.* Classification of second order equations, boundary value problems for elliptic and parabolic equations, initial value problems for hyperbolic equations, existence and uniqueness theorems in simple cases, maximum principles, *a priori* bounds, the Fourier transform. (SP)

128A. Numerical Analysis. (5) Three hours lecture, one hour discussion and three hours of computer laboratory per week. *Prerequisites: 53 and 54.* Programming for numerical calculations, round-off error, approximation and interpolation, numerical quadrature, and solution of ordinary differential equations. Practice on the computer. (F,SP)

128B. Numerical Analysis. (5) Three hours of lecture, one hour of discussion and three hours of computer laboratory per week. *Prerequisites: 110 and 128A.* Iterative solution of systems of nonlinear equations, evaluation of eigenvalues and eigenvectors of matrices, applications to simple partial differential equations. Practice on the computer. (SP)

130. The Classical Geometries. (4) Three hours of lecture per week. *Prerequisites: 113 and 110.* Topics chosen from the following list: axioms for affine and projective planes, planes over a division ring, duality, the coordinatization theorem, n-dimensional projective geometry over a field, collineations and correlations, classification of hyperquadrics, the projective group and its sub-groups, non-Euclidean geometry, inversive geometry.

135. Introduction to the Theory of Sets. (4) Three hours of lecture per week. *Prerequisites: 113 and 104.* Set-theoretical paradoxes and means of avoiding them. Sets, relations, functions, order and well-order. Proof by transfinite induction and definitions by transfinite recursion. Cardinal and ordinal numbers and their arithmetic. Construction of the real numbers. Axiom of choice and its consequences. (F,SP)

140. Metric Differential Geometry. (4) Three hours of lecture per week. *Prerequisites: 104 or 121B.* Frenet formulas, isoperimetric inequality, local theory of surfaces in Euclidean space, first and second fundamental forms. Gaussian and mean curvature, isometries, geodesics, parallelism, the Gauss-Bonnet-Von Dyck Theorem. (SP)

142. Elementary Algebraic Topology. (4) Three hours of lecture per week. *Prerequisites: 104 and 113.* The topology of one and two dimensional spaces: manifolds and triangulation, classification of surfaces, Euler characteristic, fundamental groups, plus further topics at the discretion of the instructor. (F)

160. History of Mathematics. (4) Three hours of lecture per week. *Prerequisites: 53, 54, and 113.* History of algebra, geometry, analytic geometry, and calculus from ancient times through the seventeenth century and selected topics from more recent mathematical history. (SP)

170. Linear Programming, Games, Models of Exchange. (4) Three hours of lecture per week. *Prerequisites: 53 and 54.* Topics include linear programming, matrix games, models of production and exchange. Treats properties of the models and methods for calculating their behavior.

185. Introduction to Complex Analysis. (4) Three hours of lecture per week. *Prerequisites: 104.* Analytic functions of a complex variable. Cauchy's integral theorem, power series, Laurent series, singularities of analytic functions, the residue theorem with application to definite integrals. Some additional topics such as conformal mapping. (F,SP)

H185. Introduction to Complex Analysis. (4) Three hours of lecture per week. *Prerequisites: 104.* Honors section corresponding to Math 185 for exceptional students with strong mathematical inclination and motivation. Emphasis is on rigor, depth, and hard problems. (SP)

187. Senior Level Analysis. (4) Three hours of lecture per week. *Prerequisites: 104, 113, and 185.* Course gives a comprehensive view of analysis. Emphasis is on the interrelations among topics taken from differential equations, harmonic analysis and group representation, elementary functional analysis and special functions.

189. Mathematical Methods in Classical and Quantum Mechanics. (4) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: 104, 110, 2 semesters lower division Physics.* Topics in mechanics presented from a mathematical viewpoint: e.g., hamiltonian mechanics and symplectic geometry, differential equations for fluids, spectral theory in quantum mechanics, probability theory and statistical mechanics. See department bulletins for specific topics each semester course is offered. (SP)

191. Experimental Courses in Mathematics. (1-4) Course may be repeated for credit. Hours to be arranged. *Prerequisites: Consent of instructor.* The topics to be covered and the method of instruction to be used will be announced at the beginning of each semester that such courses are offered. See departmental bulletins.

195. Special Topics in Mathematics. (4) Course may be repeated for credit. Hours to be arranged. *Prerequisites: Consent of instructor.* Lectures on special topics, which will be announced at the beginning of each semester that the course is offered.

196. Honors Thesis. (4) Course may be repeated for credit. Hours to be arranged. *Prerequisites: Admission to the Honors Program; an overall GPA of 3.0 and a GPA of 3.30 in the major.* Independent study of an advanced topic leading to an honors thesis. (F,SP)

199. Supervised Independent Study and Research. (1-4) Hours to be arranged. Must be taken on a *passed/not passed* basis. *Prerequisites: The standard college regulations for all 199 courses.* (F,SP)

Graduate Courses

202A. Introduction to Topology and Analysis. (4) Three hours of lecture per week. *Prerequisites: 104 and 110.* General topological spaces. Metric spaces. Compactness and connectedness. Theorems of Tychonoff, Urysohn, Tietze. Baire category theorem. Function spaces. Arzela-Ascoli and Stone-Weierstrass theorems. Introduction to linear topological spaces. Banach and Hilbert spaces. Banach-Steinhaus, closed graph theorems. Convexity. Hahn-Banach theorem. Weak and weak-* topologies. Banach-Alaoglu theorem. Krein-Milman theorem. Additional topics selected by the instructor. (F,SP)

202B. Introduction to Topology and Analysis. (4) Three hours of lecture per week. *Prerequisites: 202A.* Measure theory and Lebesgue integration. Convergence theorems. L^p spaces. Product spaces, Fubini type theorems. Signed measures. Hahn and Jordan decomposition. Radon-Nikodym theorem. Integration on the line and in R^n. Differentiation of the integral. Fourier transform. Duality, the dual of L^p. Measures in locally compact spaces, the dual of $C(X)$. Additional topics chosen may include compact operators, spectral theory of compact operators. Application to integral equations. (F,SP)

204A-204B. Ordinary and Partial Differential Equations. (4;4) Three hours of lecture per week. *Prerequisites: 105 and 185 or consent of instructor.* Fundamental existence theorem for ordinary differential equations. Properties of linear systems with constant and periodic coefficients. Sturm-Liouville theory; Poincare-Bendixson Theorem. Cauchy-Kowalewski theory for systems of partial differential equations. Initial and boundary value problems for elliptic, parabolic, and hyperbolic second order equations. Nonlinear equations and systems. Sequence begins Fall.

205. Theory of Functions of a Complex Variable. (4) Three hours of lecture per week. *Prerequisites: 185.* Normal families. Riemann Mapping Theorem. Picard's theorem and related theorems. Multiple-valued analytic functions and Riemann surfaces. Further topics selected by the instructor may include: harmonic functions, elliptic and algebraic functions, boundary behavior of analytic functions and H^p spaces, the Riemann zeta functions, prime number theorem.

206. Banach Algebras and Spectral Theory. (4) Three hours of lecture per week. *Prerequisites: 202A-202B.* Banach algebras. Spectrum of a Banach algebra element. Gelfand theory of commutative Banach algebras. Analytic functional calculus. Hilbert space operators. C^*-algebras of operators. Commutative C^*-algebras. Spectral theorem for bounded self-adjoint and normal operators (both forms: the spectral integral and the "multiplication operator" formulation). Riesz theory of compact operators. Hilbert-Schmidt operators. Fredholm operators. The Fredholm index. Selected additional topics. (F)

207. Unbounded Operators. (4) Three hours of lecture per week. *Prerequisites: 206.* Unbounded self-adjoint operators. Stone's Theorem, Friedrichs extensions. Examples and applications, including differential operators. Perturbation theory. Further topics may include: unbounded operators in quantum mechanics, Stone-Von Neumann Theorem. Operator semigroups and evolution equations, some non-linear operators. Weyl theory of defect indices for ordinary differential operators.

*Professor in the Graduate School
†Recipient of Distinguished Teaching Award

Berkeley '95-'97

209. Operator Algebras. (4) Three hours of lecture per week. *Prerequisites: 206.* Elementary C*-algebra theory. Connections with group representations. Basic von Neumann algebra theory. Density theorems, normal states, traces. Further topics may include: basic K-theory of C*-algebras, applications to physics such as the Stone-von Neumann theorem, automorphism groups, C*-dynamical systems.

211. Mathematical Theory of Fluid Mechanics. (4) Three hours of lecture per week. Development of the fundamental equations describing the behavior of fluid continuum followed by the treatment of special topics selected to exhibit different physical situations, analytical techniques, and approximate methods of solutions.

212. Several Complex Variables. (4) Three hours of lecture per week. *Prerequisites: 185 and 202A-202B or their equivalents.* Power series developments, domains of holomorphy, Hartogs' phenomenon, pseudo convexity and plurisubharmonicity. The remainder of the course may treat either sheaf cohomology and Stein manifolds, or the theory of analytic subvarieties and spaces.

214. Differentiable Manifolds. (4) Three hours of lecture per week. *Prerequisites: 202A.* Smooth manifolds and maps, tangent and normal bundles. Sard's theorem and transversality, Whitney embedding theorem. Morse functions, differential forms, Stokes' theorem, Frobenius theorem. Basic degree theory. Flows, Lie derivative, Lie groups and algebras. Additional topics selected by instructor. (F,SP)

215A-215B. Algebraic Topology. (4;4) Three hours of lecture per week. *Prerequisites: 113 and point-set topology (e.g. 202A).* Fundamental group and covering spaces, simplicial and singular homology theory with applications, cohomology theory, duality theorem. Homotopy theory, fibrations, relations between homotopy and homology, obstruction theory, and topics from spectral sequences, cohomology operations, and characteristic classes. Sequence begins fall.

219. Ordinary Differential Equations and Flows. (4) Three hours of lecture per week. *Prerequisites: 214.* Ordinary differential equations. Diffeomorphisms and flows on manifolds. Stable manifolds, generic properties, structural stability. Special topics selected by the instructor. (F)

221. Advanced Matrix Computations. (4) Three hours of lecture per week. *Prerequisites: 128A-128B, or equivalent experience with matrix computation.* Direct solution of linear systems, including large sparse systems: error bounds, iteration methods, least square approximation, eigenvalues and eigenvectors of matrices, nonlinear equations, and minimization of functions. (F)

222A-222B. Partial Differential Equations. (4;4) Three hours of lecture per week. *Prerequisites: 105 or 202B; 185.* The theory of initial value and boundary value problems for hyperbolic, parabolic, and elliptic partial differential equations, with emphasis on nonlinear equations. More general types of equations and systems of equations. Sequence begins fall.

224A-224B. Mathematical Methods for the Physical Sciences. (4;4) Three hours of lecture per week. *Prerequisites: 110; 104 and 185, or 121A-121B.* Introduction to the theory of distributions. Fourier and Laplace transforms. Partial differential equations. Green's function. Operator theory, with applications to one-parameter unitary groups, eigenfunction expansions, perturbation theory. Sequence begins fall.

225A-225B. Metamathematics. (4;4) Three hours of lecture per week. *Prerequisites: 125B and 135.* Metamathematics of predicate logic. Completeness and compactness theorems. Interpolation theorem, definability, theory of models. Metamathematics of number theory, recursive functions, applications to truth and provability. Undecidable theories. Sequence begins fall.

226A. Abstract Machines and Languages. (4) Three hours of lecture per week. *Prerequisites: 135; 114 or 113 and 110.* Finite state automata, regular sets, Turing machines, recursive functions, decision problems. Context-free languages, pushdown automata, ambiguity, special families of languages, power series in non-commuting variables.

226B. Semigroups and Machines. (4) Three hours of lecture per week. *Prerequisites: 226A or consent of instructor.* Semigroups, wreath products, prime decomposition theorem, application to finite state machines, algebraic theory of complexity.

227A-227B. Theory of Recursive Functions. (4;4) Three hours of lecture per week. *Prerequisites: 225B.* Recursive and recursively enumerable sets of natural numbers; characterizations, significance, and classification. Relativization, degrees of unsolvability. The recursion theorem. Constructive ordinals, the hyperarithmetical and analytical hierarchies. Recursive objects of higher type. Sequence begins fall.

228A-228B. Numerical Solution of Differential Equations. (4;4) Three hours of lecture per week. *Prerequisites: 128A.* Ordinary differential equations: Runge-Kutta and predictor-corrector methods; stability theory, Richardson extrapolation, stiff equations, boundary value problems. Partial differential equations: stability, accuracy and convergence, Von Neumann and CFL conditions, finite difference solutions of hyperbolic and parabolic equations. Finite differences and finite element solution of elliptic equations.

229. Theory of Models. (4) Three hours of lecture per week. *Prerequisites: 225B.* Syntactical characterization of classes closed under algebraic operations. Ultraproducts and ultralimits, saturated models. Methods for establishing decidability and completeness. Model theory of various languages richer than first-order.

235A-235B. Theory of Sets. (4;4) Three hours of lecture per week. *Prerequisites: 125A and 135.* Axiomatic foundations. Operations on sets and relations. Images and set functions. Ordering, well-ordering, and well-founded relations; general principles of induction and recursion. Ranks of sets, ordinals and their arithmetic. Set-theoretical equivalence, similarity of relations; definitions by abstraction. Arithmetic of cardinals. Axiom of choice, equivalent forms, and consequences. Sequence begins fall.

236. Metamathematics of Set Theory. (4) Three hours of lecture per week. *Prerequisites: 225B and 235A.* Various set theories: comparison of strength, transitive, and natural models, finite axiomatizability. Independence and consistency of axiom of choice, continuum hypothesis, etc. The measure problem and axioms of strong infinity.

240. Riemannian Geometry. (4) Three hours of lecture per week. *Prerequisites: 214.* Riemannian metric and Levi-Civita connection, geodesics and completeness, curvature, first and second variations of arc length. Additional topics such as the theorems of Myers, Synge, and Cartan-Hadamard, the second fundamental form, convexity and rigidity of hypersurfaces in Euclidean space, homogeneous manifolds, the Gauss-Bonnet theorem, and characteristic classes. (SP)

241. Complex Manifolds. (4) Three hours of lecture per week. *Prerequisites: 214 and 215A.* Riemann surfaces, divisors and line bundles on Riemann surfaces, sheaves and the Dolbeault theorem on Riemann surfaces, the classical Riemann-Roch theorem, theorem of Abel-Jacobi. Complex manifolds, Kahler metrics. Summary of Hodge theory, groups of line bundles, additional topics such as Kodaira's vanishing theorem, Lefschetz hyperplane theorem. (SP)

245A-245B. General Theory of Algebraic Structures. (4;4) Three hours of lecture per week. *Prerequisites: 113 and 135.* Structures defined by operations and/or relations, and their homomorphisms. Classes of structures determined by identities. Constructions such as free objects, objects presented by generators and relations, ultraproducts, direct limits. Applications of general results to groups, rings, lattices, etc. Course may emphasize study of congruence- and subalgebra-lattices, or category-theory and adjoint functors, or other aspects.

250A. Groups, Rings, and Fields. (4) Three hours of lecture per week. *Prerequisites: 114 or consent of instructor.* Group theory, including the Jordan-Holder theorem and the Sylow theorems. Basic theory of rings and their ideals. Unique factorization domains and principal ideal domains. Modules. Chain conditions. Fields, including fundamental theorem of Galois theory, theory of finite fields, and transcendence degree. (F)

250B. Multilinear Algebra and Further Topics. (4) Three hours of lecture per week. *Prerequisites: 250A.* Tensor algebras and exterior algebras, with application to linear transformations. Commutative ideal theory, localization. Elementary specialization and valuation theory. Related topics in algebra. (SP)

251. Ring Theory. (4) Three hours of lecture per week. *Prerequisites: 250A.* Topics such as: Noetherian rings, rings with descending chain condition, theory of the radical, homological methods.

252. Representation Theory. (4) Three hours of lecture per week. *Prerequisites: 250A.* Structure of finite dimensional algebras, applications to representations of finite groups, the classical linear groups. (F)

253. Homological Algebra. (4) Three hours of lecture per week. *Prerequisites: 250A.* Modules over a ring, homomorphisms and tensor products of modules, functors and derived functors, homological dimension of rings and modules.

254A-254B. Number Theory. (4;4) Three hours of lecture per week. *Prerequisites: 250A.* Valuations, units, and ideals in number fields, ramification theory, quadratic and cyclotomic fields, topics from class field theory, zeta-functions and L-series, distribution of primes, modular forms, quadratic forms, diophantine equations, P-adic analysis, and transcendental numbers. Sequence begins fall.

255B-255C. Foundations of Geometry. (4;4) Three hours of lecture per week. *Prerequisites: 125B and 130.* Historical introduction. Primitive terms and axioms of Euclidean geometry. Principal consequences of axioms; introduction to Cartesian coordinates. Completeness, categoricity, decidability; independence of axioms. Alternative systems of primitive terms and axioms. Non-Euclidean geometries-parallel development to Euclidean geometry.

256A-256B. Algebraic Geometry. (4;4) Three hours of lecture per week. *Prerequisites: 250A.* Affine and projective algebraic varieties. Theory of schemes and morphisms of schemes. Smoothness and differentials in algebraic geometry. Coherent sheaves and their cohomology. Riemann-Roch theorem and selected applications. Sequence begins fall.

257. Group Theory. (4) Three hours of lecture per week. *Prerequisites: 250A.* Topics such as: generators and relations, infinite discrete groups, groups of Lie type, permutation groups, character theory, solvable groups, simple groups, transfer and cohomological methods.

258. Classical Harmonic Analysis. (4) Three hours of lecture per week. *Prerequisites: 206 or a basic knowledge of real, complex, and linear analysis.* Basic properties of Fourier series, convergence and summability, conjugate functions, Hardy spaces, boundary behavior of analytic and harmonic functions. Additional topics at the discretion of the instructor.

259. Transformation Groups. (4) Three hours of lecture per week. *Prerequisites: 215A and 214.* Topological groups, Haar measure, general theory of topological transformation groups, the existence of slices and applications, the Smith theory of periodic transformations.

260. Abstract Harmonic Analysis. (4) Three hours of lecture per week. *Prerequisites: 206.* Topological groups, Haar measure, Pontryagin duality, and structure theory of locally compact abelian groups, Peter-Weyl theorem for compact groups. Further topics may include finer study of harmonic analysis on commutative groups, or else head in the direction of group representations for noncommutative locally compact groups.

261A-261B. Lie Groups. (4;4) Three hours of lecture per week. *Prerequisites: 214.* Lie groups and Lie algebras, fundamental theorems of Lie, general structure theory; compact, nilpotent, solvable, semi-simple Lie groups; classification theory and representation theory of semi-simple Lie algebras and Lie groups, further topics such as symmetric spaces, Lie transformation groups, etc., if time permits. In view of its simplicity and its wide range of applications, it is preferable to cover compact Lie groups and their representations in 261A. Sequence begins Fall.

265. Differential Topology. (4) Three hours of lecture per week. *Prerequisites: 214 plus 215A or some familiarity with algebraic topology.* Approximations, degrees of maps, vector bundles, tubular neighborhoods. Introduction to Morse theory, handlebodies, cobordism, surgery. Additional topics selected by instructor from: characteristic classes, classification of manifolds, immersions, embeddings, singularities of maps.

271. Topics in Foundations. (4) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: Consent of instructor.* Advanced topics chosen by the instructor. The content of this course changes, as in the case of seminars.

273. Topics in Numerical Analysis. Three hours of lecture per week. *Prerequisites: Consent of instructor.* Advanced topics chosen by the instructor. The content of this course changes, as in the case of seminars. (F,SP)

274. Topics in Algebra. (4) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: Consent of instructor.* Advanced topics chosen by the instructor. The content of this course changes, as in the case of seminars.

275. Topics in Applied Mathematics. (4) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: Consent of instructor.* Advanced topics chosen by the instructor. The content of this course changes, as in the case of seminars.

276. Topics in Topology. (4) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: Consent of instructor.* Advanced topics chosen by the instructor. The content of this course changes, as in the case of seminars.

277. Topics in Differential Geometry. (4) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: Consent of instructor.* Advanced topics chosen by the instructor. The content of this course changes, as in the case of seminars.

278. Topics in Analysis. (4) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: Consent of instructor.* Advanced topics chosen by the instructor. The content of this course changes, as in the case of seminars.

279. Topics in Partial Differential Equations. (4) Course may be repeated for credit. Three hours of lecture per week. *Prerequisites: Consent of instructor.* Advanced topics chosen by the instructor. The content of this course changes, as in the case of seminars.

280A-280B. Mathematical Theory of Relativity. (4;4) Three hours of lecture per week. *Prerequisites: 140 or consent of instructor.* Special theory of relativity, reformulation of classical physical theories in relativistic form, principle of equivalence, Einstein's theory of gravitation, astrophysical and cosmological problems. Additional topics chosen by the instructor.

290. Seminars. (1-6) Course may be repeated for credit. Hours to be arranged. Topics in foundations of mathematics, theory of numbers, numerical calculations, analysis, geometry, topology, algebra, and their applications, by means of lectures and informal conferences; work based largely on original memoirs. (F,SP)

295. Individual Research. (1-12) Course may be repeated for credit. Hours to be arranged. Sections 1-30 to be graded on a letter-grade basis. Sections 31-60 to be graded on a *satisfactory/unsatisfactory* basis. Intended for candidates for the Ph.D. degree. (F,SP)

299. Reading Course for Graduate Students. (1-6) Course may be repeated for credit. Hours to be arranged. Sections 1-30 to be graded on a letter-grade basis. Sections 31-60 to be graded on a *satisfactory/unsatisfactory* basis. Investigation of special problems under the direction of members of the department. (F,SP)

600. Individual Study for Master's Students. (1-6) Course may be repeated for credit. Course does not satisfy unit or residence requirements for master's degree. Hours to be arranged. Must be taken on a *satisfactory/unsatisfactory* basis. *Prerequisites: For candidates for master's degree.* Individual study for the comprehensive or language requirements in consultation with the field adviser. (F,SP)

Professional Courses

300. Teaching Workshop. (3) Two hours of lecture per week, plus class visits. Must be taken on a *satisfactory/unsatisfactory* basis. Mandatory for all graduate student instructors teaching for the first time in the department. The course consists of practice teaching, alternatives to standard classroom methods, guided group and self-analysis of videotapes, reciprocal classroom visitations, and an individual project. (F,SP)

301. Undergraduate Mathematics Instruction. (1-2) Course may be repeated once for credit. Three hours of seminar and four hours of tutorial per week. Must be taken on a *passed/not passed* basis. *Prerequisites: Permission of SLC instructor, as well as sophomore standing and at least a B average in two semesters of calculus. Apply at Student Learning Center.* May be taken for one unit by special permission of instructor. Tutoring at the Student Learning Center or for the Professional Development Program. (F,SP)

Other Departments and Groups with Related Programs

Biostatistics

Electrical Engineering and Computer Sciences

Industrial Engineering and Operations Research

Logic and the Methodology of Science

Science and Mathematics Education

Statistics

Mechanical Engineering

(College of Engineering)

Department Office: 6189 Etcheverry Hall, 642-1338
Chair: David B. Bogy, Ph.D.

Professors:

Alice M. Agogino, Ph.D. Stanford University. Decision and expert systems
David M. Auslander, Sc.D. Massachusetts Institute of Technology. Dynamic systems, automatic controls
†Stanley A. Berger, Ph.D. Brown University. Fluid mechanics
David B. Bogy, Ph.D. *(William S. Floyd, Jr., Professor of Engineering)* Brown University. Elasticity, plasticity, computer mechanics
Van P. Carey *(Vice Chair)*, Ph.D. State University of New York-Buffalo. Transport in multiphase systems, thermophysics of phase-change processes
James Casey, Ph.D. University of California, Berkeley. Continuum mechanics
Phillip Colella, Ph.D. University of California, Berkeley. Computational fluid dynamics, scientific computing, fluid dynamics
Hari Dharan, Ph.D. University of California, Berkeley. Composite materials
Robert W. Dibble, Ph.D. University of Wisconsin. Combustion, gas dynamics
David A. Dornfeld, Ph.D. *(Director, Engineering Systems Research Center)* University of Wisconsin. Manufacturing processes, robotics
Carlos Fernandez-Pello, Ph.D. University of California at San Diego. Combustion, heavy and condensed fuels
Ralph Greif, Ph.D. Harvard University. Thermal radiation, phase change
Karl J. Hedrick *(Vice Chair)*, Ph.D. Stanford University. Control systems, transportation systems
Roberto Horowitz, Ph.D. University of California, Berkeley. Automatic control systems design, robotics
George C. Johnson, Ph.D. Stanford University. Ultrasonic stress evaluation
Philip Marcus, Ph.D. Princeton University. Computational fluid dynamics
†Clayton D. Mote, Jr., Ph.D. *(Vice Chancellor and FANUC Professor of Mechanical Systems)* University of California, Berkeley. Dynamics, biomechanics
Patrick J. Pagni, Ph.D. Massachusetts Institute of Technology. Combustion phenomena
Albert P. Pisano, Ph.D. Columbia University. Computer-aided design, design optimization
Boris Rubinsky, Ph.D. Massachusetts Institute of Technology. Heat, mass transfer, cryopreservation
*Robert F. Sawyer, Ph.D. *(Class of '35 Professor of Energy)* Princeton University. Combustion, fossil and synthetic fuels
Chang-Lin Tien, Ph.D. *(Chancellor and A. Martin Berlin Professor of Mechanical Engineering)* Princeton University. Heat and mass transfer
Masayoshi Tomizuka, Ph.D. Massachusetts Institute of Technology. Automatic control systems, robotics and manufacturing, systems
Kent S. Udell, Ph.D. University of Utah. Heat transfer, geothermal energy
Paul K. Wright, Ph.D. University of Birmingham. Manufacturing processes, automation
Cyril P. Atkinson, M.S. M.E. *(Emeritus)*
Gilles M. Corcos, Ph.D. *(Emeritus)*
Israel I. Cornet, Ph.D. *(Emeritus)*
Don M. Cunningham, M.S. *(Emeritus)*
E. Paul DeGarmo, M.S. *(Emeritus)*
Iain Finnie, D.Sc., Sc.D. *(The Fife Professor Emeritus)*
Joseph Frisch, M.S. *(Emeritus)*
Werner Goldsmith, Ph.D. *(Emeritus)*
Frank E. Hauser, Ph.D. *(Emeritus)*
Maurice Holt, Ph.D. *(Emeritus)*
Chieh S. Hsu, Ph.D. *(Emeritus)*
Franklin C. Hurlbut, Ph.D. *(Emeritus)*
Shiro Kobayashi, Ph.D. *(FANUC Professor of Mechanical Systems Emeritus)*
Alan D.K. Laird, Ph.D. *(Emeritus)*
Edmund V. Laitone, Ph.D. *(Emeritus)*
George Leitmann, Ph.D. *(Roscoe and Elizabeth Hughes Professor of Mechanical Engineering Emeritus)*
George J. Maslach, B.S. *(Emeritus)*
Antoni K. Oppenheim, Ph.D, D.Sc. *(Emeritus)*
Milton R. Pickus, Ph.D. *(Emeritus)*
Charles W. Radcliffe, M.S., M.E. *(Emeritus)*
Reinhardt M. Rosenberg, M.S., Ph.D. (hon.) *(Emeritus)*
Samuel A. Schaaf, Ph.D. *(Emeritus)*
Frederick S. Sherman, Ph.D. *(Emeritus)*
Wilbur H. Somerton, Pet.E. *(Emeritus)*
Walter W. Soroka, Sc.D. *(Emeritus)*
†Robert F. Steidel, Jr., D.Eng. *(Emeritus)*
Yasundo Takahashi, Ph.D. *(Emeritus)*
Lawrence Talbot, Ph.D. *(Emeritus)*
Herman Thal-Larsen, M.S. *(Emeritus)*
Erich G. Thomsen, Ph.D. *(Emeritus)*
George J. Trezek, Ph.D. *(Emeritus)*
D. Roger Willis, Ph.D. *(Emeritus)*

Associate Professors:

Juh-Yuan Chen, Ph.D. Cornell University. Turbine combustion, chemical kinetics, numerical simulation
Costas Grigoropoulos, Ph.D. Columbia University. Heat transfer, laser materials processing
Homayoon Kazerooni, D.Sc. Massachusetts Institute of Technology. Mechatronics, robotics
Kyriakos Komvopoulos, Ph.D. Massachusetts Institute of Technology. Tribology, contact mechanics, mechanical behavior of materials
†Dennis K. Lieu, D. Eng. University of California, Berkeley. High speed electromechanic devices
Fai Ma, Ph.D. California Institute of Technology. Mechanical vibrations, analysis and simulation of random systems
Stephen Morris, Ph.D. Johns Hopkins University. Geophysical fluid dynamics
†Andrew Packard, Ph.D. University of California, Berkeley. Automatic control systems, mechanical systems
Kameshwar Poolla, Ph.D. University of Florida at Gainesville. Dynamic systems, automatic controls
Omar Savas, Ph.D. California Institute of Technology. Aerodynamics, boundary layers, combustion, rotating flows, turbulence

Assistant Professors:

Tony Keaveny, Ph.D. Cornell University. Biomechanics, mechanical behavior of bone tissue
Dorian Liepmann, Ph.D. University of California, San Diego. Classical fluid dynamics, bio-fluid mechanics
Oliver M. O'Reilly, Ph.D. Cornell University. Nonlinear dynamics with applications to continuum mechanics
Panayiotis Papadopoulos, Ph.D. University of California at Berkeley. Computational mechanics, solid mechanics
Lisa A. Pruitt, Ph.D. Brown University. Material science and engineering, polymeric matrix composites
Paul Sheng, Ph.D. Massachusetts Institute of Technology. Manufacturing, laser machining

---

Professors:

Harry B. Skinner, Ph.D., M.D.
Kurt S. Spiegler, Ph.D. *(In Residence) (Emeritus)*
Lawrence Stark, M.D. *(Emeritus)*

Adjunct Professor:

Gary T. Chapman, Ph.D.

Mechanical Engineering includes the science and art of the formulation, design, development, and control of systems and components involving thermodynamics, mechanics, fluid mechanics, mechanisms, and the conversion of energy into useful work. The mechanical engineer needs a thorough preparation in mathematics, physics, chemistry,

*Professor in the Graduate School
†Recipient of Distinguished Teaching Award