Courses

Courses numbered below 100 are taken primarily by undergraduate students. Those numbered from 100 to 199 are taken by both undergraduates and graduates, and those numbered 200 and above are taken primarily by graduate students.

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, in laboratory, and estimated to be spent in 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).

At the end of the seventh week of each term, a list of courses to be offered the following term is published by the Registrar's Office. On the day of registration (see Academic Calendar), an updated and revised course schedule is published announcing the courses, class hours, and room assignments for the term. Students may not schedule two courses taught at the same time.

Abbreviations

Ae	Aeronautics
An	Anthropology
ACM	Applied and Computational Mathematics
AM	Applied Mechanics
APh	Applied Physics
Art	Art History
Ay	Astrophysics
BMB	Biochemistry and Molecular Biophysics
BE	Bioengineering
Bi	Biology
BEM	Business Economics and Management
ChE	Chemical Engineering
Ch	Chemistry
CE	Civil Engineering
CNS	Computation and Neural Systems
CS	Computer Science
CDS	Control and Dynamical Systems
Ec	Economics
EE	Electrical Engineering
E	Engineering
En	English
ESL	English As a Second Language
ESE	Environmental Science and Engineering
F	Film
Ge	Geological and Planetary Sciences
H	History
HPS	History and Philosophy of Science
Hum	Humanities
ISP	Independent Studies Program
IST	Information Science and Technology
L	Languages
Law	Law
MS	Materials Science
Ma	Mathematics
ME	Mechanical Engineering
Mu	Music
PA	Performance and Activities
Pl	Philosophy
PE	Physical Education
Ph	Physics
PS	Political Science
Psy	Psychology
SS	Social Science

AERONAUTICS

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Ae 100. Research in Aeronautics. *Units to be arranged in accordance with work accomplished.* Open to suitably qualified undergraduates and first-year graduate students under the direction of the staff. Credit is based on the satisfactory completion of a substantive research report, which must be approved by the Ae 100 adviser and by the option representative.

Ae/APh/CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 17 or ME 18, and ME 19 or equivalent, ACM 95/100 or equivalent (may be taken concurrently).* Fundamentals of fluid mechanics. Microscopic and macroscopic properties of liquids and gases; the continuum hypothesis; review of thermodynamics; general equations of motion; kinematics; stresses; constitutive relations; vorticity, circulation; Bernoulli's equation; potential flow; thin-airfoil theory; surface gravity waves; buoyancy-driven flows; rotating flows; viscous creeping flow; viscous boundary layers; introduction to stability and turbulence; quasi one-dimensional compressible flow; shock waves; unsteady compressible flow; acoustics. Instructors: Gharib, Pullin.

Ae/AM/CE/ME 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6); first, second, third terms. Prerequisite: ME 35 abc or equivalent.* Static and dynamic stress analysis. Two- and three-dimensional theory of stressed elastic solids. Analysis of structural elements with applications in a variety of fields. Variational theorems and approximate solutions, finite elements. A variety of special topics will be discussed in the third term such as, but not limited to, elastic stability, wave propagation, and introductory fracture mechanics. Instructor: Ravichandran.

Ae 103 abc. Propulsion, Dynamics, and Control of Aircraft and Spacecraft. *9 units (3-0-6); first, second, third terms. Prerequisites: ACM 95/100 abc or equivalent (may be taken concurrently); basic fluid mechanics; CDS 110 a or equivalent for third term only.* First term: elementary airfoil and wing theory, basic compressible flow, and performance evaluations (range, climb, turning). Second term: combustion and propulsion, with an emphasis on gas turbines, but also including propellers, ram/scramjets, PDEs, and rockets. Third term: aerodynamic stability derivatives, control surfaces, small amplitude dynamical motions, and application of classical and modern control theory to feedback control of rigid aircraft. Not offered 2006–07.

Ae/APh 104 abc. Experimental Methods. *9 units (3-0-6) first term; (1-3-5) second, third terms. Prerequisites: ACM 95/100 abc or equivalent (may be taken concurrently), Ae/APh/CE/ME 101 abc or equivalent (may be taken concurrently).* Lectures on experiment design and implementation. Measurement methods, transducer fundamentals, instrumentation, optical systems, signal processing, noise theory, analog and digital electronic fundamentals, with data acquisition and processing systems. Experiments (second and third terms) in solid and fluid mechanics with emphasis on current research methods. Instructor: McKeon.

Ae 105 abc. Aerospace Engineering. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 17 or ME 18 and ME 19 or equivalent. Ae 101 and 102 may be taken concurrently.* (a) Fundamentals of aerospace engineering and mechanics, launch vehicles and systems, rocket and space propulsion fundamentals, orbital mechanics and astrodynamics, trajectory and orbit design and maintenance, launch ascent and planetary reentry aerodynamics. (b) Spacecraft mechanical, structural, and thermal design; power in space; space environment and survivability; spacecraft and payload design; communications. (c) Space mission analysis and design, space logistics and reliability, mission and life-cycle cost analysis, and space systems integration. Student team projects focusing on a mission design study during third term. Instructors: Dimotakis, Watkins, staff.

CE/Ae/AM 108 abc. Computational Mechanics. *9 units (3-0-6).* For course description, see Civil Engineering.

Ae 115 ab. Spacecraft Navigation. *9 units (3-0-6); second, third terms. Prerequisite: CDS 110 a.* This course will survey all aspects of modern spacecraft navigation, including astrodynamics, tracking systems for both low-Earth and deep-space applications (including the Global Positioning System and the Deep Space Network observables), and the statistical orbit determination problem (in both the batch and sequential Kalman filter implementations). The course will describe some of the scientific applications directly derived from precision orbital knowledge, such as planetary gravity field and topography modeling. Numerous examples drawn from actual missions as navigated at JPL will be discussed. Not offered 2006–07.

Ae/ME 120 ab. Combustion Fundamentals. *9 units (3-0-6); second, third terms. Prerequisite: ME 119 a or equivalent.* The course will cover thermodynamics of pure substances and mixtures, equations of state, chemical equilibrium, chemical kinetics, combustion chemistry, transport phenomena, and the governing equations for multicomponent gas mixtures. Topics will be chosen from non-premixed and premixed flames, the fluid mechanics of laminar flames, flame mechanisms of combustion-generated pollutants, and numerical simulations of multicomponent reacting flows. Instructor: Shepherd.

Ae 121 abc. Space Propulsion. *9 units (3-0-6); each term. Open to all graduate students and to seniors with instructor's permission.* Modern aspects of rocket, electrical, and nuclear propulsion systems and the principles of their application to lifting, ballistic, and spaceflight trajectories. Combustion and burning characteristics of solid and liquid propellants, liquid-propellant fuel systems, and combustion instability. Fundamentals of electric propulsion including ion thrusters, MHD, Hall effect, and arcjets. Introduction to spacecraft station keeping, stability, and control. Instructor: Polk.

Ae/CDS 125 abc. Space Missions and Systems Engineering. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc, Ph 2 ab, Ma 2 ab.* This course presents the fundamentals of modern systems engineering, spacecraft design methods, and space trajectories and mission engineering. The theory and application of the following topics are addressed: systems engineering principles and methods, space trajectories and mission design, spacecraft attitude determination and control systems, rocket propulsion systems, avionics, spacecraft mechanical design, spacecraft thermal design, telecommunications theory and link analysis. Ae/CDS 125 a, b: spacecraft and mission design lectures and problems selected by the instructor. Ae/CDS 125 b, c: a collaborative, computer-assisted spacecraft and mission design project in which students assume the roles of cognizant engineers. Not offered 2006–07.

Ae 150 abc. Aerospace Engineering Seminar. *1 unit (1-0-0); first, second, third terms.* Speakers from campus and outside research and manufacturing organizations discuss current problems and advances in aerospace engineering. Graded pass/fail. Instructor: Pullin.

Ae/Ge/ME 160 ab. Continuum Mechanics of Fluids and Solids. *9 units (3-0-6); first, second terms.* Elements of Cartesian tensors. Configurations and motions of a body. Kinematics—study of deformations, rotations and stretches, polar decomposition. Lagrangian and Eulerian strain velocity and spin tensor fields. Irrotational motions, rigid motions. Kinetics—balance laws. Linear and angular momentum, force, traction stress. Cauchy's theorem, properties of Cauchy's stress. Equations of motion, equilibrium equations. Power theorem, nominal (Piola-Kirchoff) stress. Thermodynamics of bodies. Internal energy, heat flux, heat supply. Laws of thermodynamics, notions of entropy, absolute temperature. Entropy inequality (Clausius-Duhem). Examples of special classes of constitutive laws for materials without memory. Objective rates, corotational, convected rates. Principles of materials frame indifference. Examples: the isotropic Navier-Stokes fluid, the isotropic thermoelastic solid. Basics of finite differences, finite elements, and boundary integral methods, and their applications to continuum mechanics problems illustrating a variety of classes of constitutive laws. Instructor: Lapusta.

Ae 200. Advanced Research in Aeronautics. *Units to be arranged.* Ae.E. or Ph.D. thesis level research under the direction of the staff. A written research report must be submitted during finals week each term.

Ae 201 ab. Advanced Fluid Mechanics. *9 units (3-0-6); first, second terms. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent; AM 125 abc or ACM 101 abc (may be taken concurrently).* Foundations of the mechanics of real fluids. Basic concepts will be emphasized. Subjects covered will include a selection from the following topics: physical properties of real gases; the equations of motion of viscous and inviscid fluids; the dynamical significance of vorticity; vortex dynamics; exact solutions; motion at high Reynolds numbers; hydrodynamic stability; boundary layers; flow past bodies; compressible flow; subsonic, transonic, and supersonic flow; shock waves. Not offered 2006–07.

Ae 204 ab. Technical Fluid Mechanics. *9 units (3-0-6); first, second terms. Prerequisite: Ae/APh/CE/ME 101 abc or equivalent.* External and internal flow problems encountered in engineering, for which only empirical methods exist. Turbulent shear flow, separation, transition, three-dimensional and nonsteady effects. Basis of engineering practice in the design of devices such as mixers, ejectors, diffusers, and control valves. Studies of flow-induced oscillations, wind effects on structures, vehicle aerodynamics. Not offered 2006–07.

Ae 208 abc. GALCIT Colloquium. *1 unit (1-0-0); first, second, third terms.* A seminar course in fluid, solid, space, and bio mechanics. Weekly lectures on current developments are presented by staff members, graduate students, and visiting scientists and engineers. Graded pass/fail. Instructors: Gharib, Ravichandran.

Note: The following courses, with numbers greater than 209, are one-, two-, or three-term courses offered to interested students. Depending on conditions, some of the courses may be taught as tutorials or reading courses, while others may be conducted more formally.

Ae/AM/MS/ME 213. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6); second term. Prerequisites: Ae/AM/CE/ME 102 abc (concurrently) or equivalent and instructor's permission.* Analytical and experimental techniques in the study of fracture in metallic and nonmetallic solids. Mechanics of brittle and ductile fracture; connections between the continuum descriptions of fracture and micromechanisms. Discussion of elastic-plastic fracture analysis and fracture criteria. Special topics include fracture by cleavage, void growth, rate sensitivity, crack deflection and toughening mechanisms, as well as fracture of nontraditional materials. Fatigue crack growth and life prediction techniques will also be discussed. In addition, "dynamic" stress wave dominated, failure initiation growth and arrest phenomena will be covered. This will include traditional dynamic fracture considerations as well as discussions of failure by adiabatic shear localization. Instructor: Rittel.

Ae/AM/CE/ME 214 abc. Computational Solid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: AM 125 abc or equivalent; ACM 100 abc or equivalent; CE/AM/Ae 108 abc or equivalent or instructor's permission; Ae/AM/CE/ME 102 abc or equivalent; Ae/Ge/ME 160 ab desirable or taken concurrently.* Introduction to the use of numerical methods in the solution of solid mechanics and materials problems. First term: geometrical representation of solids. Automatic meshing. Approximation theory. Interpolation error estimation. Optimal and adaptive meshing. Second term: variational principles in linear elasticity. Finite element analysis. Error estimation. Convergence. Singularities. Adaptive strategies. Constrained problems. Mixed methods. Stability and convergence. Variational problems in nonlinear elasticity. Consistent linearization. The Newton-Rahpson method. Bifurcation analysis. Adaptive strategies in nonlinear elasticity. Constrained finite deformation problems. Contact and friction. Third term: time integration. Algorithm analysis. Accuracy, stability, and convergence. Operator splitting and product formulas. Coupled problems. Impact and friction. Subcycling. Space-time methods. Inelastic solids. Constitutive updates. Stability and convergence. Consistent linearization. Applications to finite deformation viscoplasticity, viscoelasticity, and Lagrangian modeling of fluid flows. Not offered 2006–07.

Ae/AM/ME 215. Dynamic Behavior of Materials. *9 units (3-0-6); first term. Prerequisites: ACM 100 abc or AM 125 abc; Ae/AM/CE/ME 102 abc.* Fundamentals of theory of wave propagation; plane waves, wave guides, dispersion relations; dynamic plasticity, adiabatic shear banding; dynamic fracture; shock waves, equation of state. Instructor: Rittel.

Ae 220 ab.Theory of Structures. *9 units (3-0-6); first, second terms.* Geometry of spatial curves; finite 3-D rotations; finite deformations of curved rods; dynamics of rods; strings and cables; theory of plastic rods; statistical mechanics of chains; applications including frames and cable structures, polymers, open-cell foams, DNA mechanics, cell mechanics; small strain and von Karman theory of plates; applications to thin films, layered structures, functionally graded thin films, delamination, plastic collapse; surface geometry; finite deformations of shells; dynamics of plates and shells; membranes; theory of plastic plates and shells; fracture of plates and shells; elastic and plastic stability; wrinkling and relaxation; applications including solar sails, space structures, closed-cell foams, biological membranes; numerical methods for structural analysis; discrete geometry; finite elements for rods, plates and shells; time-integration methods; thermal analysis. Instructor: Ortiz.

Ae/AM/ME 223. Plasticity. *9 units (3-0-6); third term. Prerequisite: Ae/AM/CE/ME 102 abc or instructor's permission.* Theory of dislocations in crystalline media. Characteristics of dislocations and their influence on the mechanical behavior in various crystal structures. Application of dislocation theory to single and polycrystal plasticity. Theory of the inelastic behavior of materials with negligible time effects. Experimental background for metals and fundamental postulates for plastic stress-strain relations. Variational principles for incremental elastic-plastic problems, uniqueness. Upper and lower bound theorems of limit analysis and shakedown. Slip line theory and applications. Additional topics may include soils, creep and rate-sensitive effects in metals, the thermodynamics of plastic deformation, and experimental methods in plasticity. Instructor: Rittel.

Ae/AM/ME 225. Special Topics in Solid Mechanics. *Units to be arranged.* Subject matter will change from term to term depending upon staff and student interest but may include such topics as structural dynamics; aeroelasticity; thermal stress; mechanics of inelastic and composite materials; and nonlinear problems. Not offered 2006–07.

Ae/ACM 232 abc. Computational Fluid Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent; ACM 100 abc or AM 125 abc, or equivalent; ACM 104, ACM 105, or equivalent.* Introduction to the use of numerical methods in the solution of fluid mechanics problems. First term: review of basic numerical techniques: interpolation, integration, application for systems of ordinary differential equations, stability and accuracy. Treatment of partial differential equations in one space variable. Nonlinear convective-diffusive and convective-dispersive phenomena. Treatment of discontinuous solutions. Second term: survey of finite difference, finite element, and spectral approximations for the solution of the incompressible Navier-Stokes equations in two and three dimensions. Numerical study of problems of hydrodynamic stability, transition, and turbulence. Third term: methods for the numerical solution of the compressible Euler and Navier-Stokes equations in one, two, and three dimensions. Finite-difference and finite-volume methods. Methods based on solution of the Riemann problem. Flux-splitting. Shock-capturing methods and related stability problems. Implicit artificial viscosity for the Euler equations. Total variation diminishing approximations. Part c not offered 2006–07. Instructor: Colonius.

Ae 233. Hydrodynamic Stability. *9 units (3-0-6); third term. Prerequisite: Ae/APh/CE/ME 101 abc or equivalent.* Laminar-stability theory as a guide to laminar-turbulent transition. Rayleigh equation, instability criteria, and response to small inviscid disturbances. Discussion of Kelvin-Helmholtz, Rayleigh-Taylor, Richtmeyer-Meshkov, and other instabilities. The Orr-Sommerfeld equation, the dual role of viscosity, and boundary-layer stability. Effects of pressure gradient, suction, and heat transfer in liquids and gases. Global and convective instabilities. Active control in the transition regime. Weakly nonlinear stability theory. Not offered 2006–07.

Ae 234. Hypersonic Aerodynamics. *9 units (3-0-6); first term. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent, AM 125 abc, or instructor's permission.* An advanced course dealing with aerodynamic problems of flight at hypersonic speeds. Topics are selected from hypersonic small-disturbance theory, blunt-body theory, boundary layers and shock waves in real gases, heat and mass transfer, testing facilities and experiment. Instructor: Staff.

Ae 235. Rarefied Gasdynamics. *9 units (3-0-6); third term.* Molecular description of matter; distribution functions; discrete-velocity gases. Kinetic theory: free-path theory, internal degrees of freedom. Boltzmann equation: BBGKY hierarchy and closure, H theorem, Euler equations, Chapman-Enskog procedure. Collisionless and transitional flows. Direct simulation Monte Carlo methods. Applications. Not offered 2006–07.

Ae 236. Separated Flows. *9 units (3-0-6); third term.* Topics include a review of boundary-layer theory, Kirchhoff model of separation, triple-deck theory, Sychev model, effect of turbulence on separation, location of separation points in various practical applications, classes of three-dimensionality, separation in three-dimensional steady flow, topological structure of steady three-dimensional separation, open separation, local solutions, and shock-wave boundary-layer interaction. Not offered 2006–07.

Ae 237 ab. Nonsteady Gasdynamics. *9 units (3-0-6); second, third terms.* (a) Dynamics of shock waves, expansion waves, and related discontinuities in gases. Adiabatic phase-transformation waves. Interaction of waves in one- and two-dimensional flows. Boundary layers and shock structure. Applications and shock tube techniques. (b) Shock and detonation waves in solids and liquids. Equations of state for hydrodynamic computations in solids, liquids, and explosive reaction products. CJ and ZND models of detonation in solids and liquids. Propagation of shock waves and initiation of reaction in explosives. Interactions of detonation waves with water and metals. Part a not offered 2006–07. Instructor: Bakker.

Ae 238. Sources of Vorticity. *9 units (3-0-6); second term.* Torque exerted on element of fluid by stress distribution. Conditions at a solid boundary. The baroclinic torque, compressibility, stratification. Effects of viscoelasticity and turbulence. Accelerated reference frames, and body forces. Unorthodox boundary conditions. Vorticity production due to discretization errors in numerical computations. Not offered 2006–07.

Ae 239 ab. Turbulence. *9 units (3-0-6); second, third terms. Prerequisites: Ae/APh/CE/ME 101 abc; AM 125 abc or ACM 101 abc; Ae 201 ab (may be taken concurrently).* Homogeneous isotropic turbulence and structure of fine scales. Reynolds-averaged equations and the problem of closure. Physical and spectral models. Subgridscale modeling. Structure of scalar fields, fractals, and irregular level sets. Turbulent mixing. Not offered 2006–07.

Ae 240. Special Topics in Fluid Mechanics. *Units to be arranged; first term.* Subject matter changes depending upon staff and student interest. Not offered 2006–07.

Ae 241. Special Topics in Experimental Fluid and Solid Mechanics. *9 units (3-0-6). Prerequisites: Ae/APh 104 or equivalent or instructor's permission.* Selected topics, to be announced, subject matter depending on current interests. Not offered 2006–07.

Ae/BE 242. Biological Flows: Propulsion. *9 units (3-0-6); second term. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent or ChE 103 a.* Physical principles of unsteady fluid momentum transport: equations of motion, dimensional analysis, conservation laws. Unsteady vortex dynamics: vorticity generation and dynamics, vortex dipoles/rings, wake structure in unsteady flows. Life in moving fluids: unsteady drag, added-mass effects, virtual buoyancy, bounding and schooling, wake capture. Thrust generation by flapping, undulating, rowing, jetting. Low Reynolds number propulsion. Bio-inspired design of propulsion devices. Instructor: Dabiri.

BE/Ae 243. Biological Flows: Transport and Circulatory Systems. *9 units (3-0-6).* For course description, see Bioengineering.

Ae/Ge/ME 266 ab. Dynamic Fracture and Frictional Faulting. *9 units (3-0-6); first, second terms. Prerequisites: Ae/AM/CE/ME 102 abc or Ae/Ge/ME 160 ab or instructor's permission.* Introduction to elastodynamics and waves in solids. Dynamic fracture theory, energy concepts, cohesive zone models. Friction laws, nucleation of frictional instabilities, dynamic rupture of frictional interfaces. Radiation from moving cracks. Thermal effects during dynamic fracture and faulting. Crack branching and faulting along nonplanar interfaces. Related dynamic phenomena, such as adiabatic shear localization. Applications to engineering phenomena and physics and mechanics of earthquakes. Not offered 2006–07.

ANTHROPOLOGY

An 22. Introduction to Sociocultural Anthropology. *9 units (3-0-6); first term.* Introduction to anthropological theory. Exploration of the diversity of human culture. Examination of the relationship between ecology, technology, and subsistence, patterns of marriage and residence, gender and sexual division of labor, reproduction, kinship, and descent. Links between economic complexity, population, social stratification, political organization, law, religion, ritual, and warfare are traced. Ethnic diversity and interethnic relations are surveyed. The course is oriented toward understanding the causes of cross-cultural variation and the evolution of culture. Not offered 2006–07.

An 23. Human Evolution. *9 units (3-0-6); third term.* Introduction to human evolution, which is essential for understanding our species. Natural selection, sexual selection, genetics, systematics, behavioral ecology, and life history theory are covered. The order Primates is surveyed. Primary emphasis is on the hominid fossil and archeological record. Behavior, cognition, and culture of nonhuman primates and humans, as well as physical variation in present-day humans, is examined. Instructor: Kaufman.

An 101. Selected Topics in Anthropology. *9 units (3-0-6); offered by announcement.* Instructor: Staff.

APPLIED AND COMPUTATIONAL MATHEMATICS

ACM 95/100 abc. Introductory Methods of Applied Mathematics. *12 units (4-0-8); first, second, third terms. Prerequisites: Ma 1 abc, Ma 2 ab, or equivalents.* Introduction to functions of a complex variable; linear ordinary differential equations; special functions; eigenfunction expansions; integral transforms; linear partial differential equations and boundary value problems. Instructors: Meiron, Pierce.

ACM 101 abc. Methods of Applied Mathematics I. *9 units (3-0-6); first, second, third terms. Prerequisite: ACM 95/100 abc.* Analytical methods for the formulation and solution of initial and boundary value problems for ordinary and partial differential equations. Techniques include the use of complex variables, generalized eigenfunction expansions, transform methods and applied spectral theory, linear operators, nonlinear methods, asymptotic and approximate methods, Weiner-Hopf, and integral equations. Instructor: Bruno.

ACM 104. Linear Algebra. *9 units (3-0-6); second term. Prerequisite: ACM 100 abc or instructor's permission.* Vector spaces, bases, Gram-Schmidt, linear maps and matrices, linear functionals, the transposed matrix and duality, kernel, image and rank, invertibility, triangularization, determinants and multilinear forms, powers of matrices and difference equations, the exponential of a matrix and ODEs, eigenvalues, Gershgorin's disc theorem, eigenspaces, SVD, polar decomposition. Nilpotent-semisimple decomposition and the Jordan normal form. Symmetric hermitian and positive definite matrices, diagonalizability, unitary matrices, bilinear forms. Hilbert spaces, projections, Riesz theorem, Fourier series, spectrum, self-adjoint operators. Instructor: Chung.

ACM 105. Applied Real and Functional Analysis. *9 units (3-0-6); first term. Prerequisite: ACM 100 abc or instructor's permission.* The Lebesgue integral on the line, general measure and integration theory, convergence theorems, Fubini, Tonelli, the Lebesgue integral in n dimensions and the transformation theorem, L_p spaces, convolution, Fourier transform and Sobolev spaces with application to PDEs, the convolution theorem, Friedrich's mollifiers, dense subspaces and approximation, normed vector spaces, completeness, Banach spaces, linear operators, the Baire, Banach-Steinhaus, open mapping and closed graph theorems with applications to differential and integral equations, dual spaces, weak convergence and weak solvability theory of boundary value problems, spectral theory of compact operators. Instructor: Chung.

ACM 106 abc. Introductory Methods of Computational Mathematics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ma 2 ab, ACM 95/100 abc or equivalent.* The sequence covers the introductory methods in both theory and implementation of numerical linear algebra, approximation theory, ordinary differential equations, and partial differential equations. The course covers methods such as direct and iterative solution of large linear systems; eigenvalue and vector computations; function minimization; nonlinear algebraic solvers; preconditioning; time-frequency transforms (Fourier, wavelet, etc.); root finding; data fitting; interpolation and approximation of functions; numerical quadrature; numerical integration of systems of ODEs (initial and boundary value problems); finite difference, element, and volume methods for PDEs; level set methods. Programming is a significant part of the course. Instructors: Candes, Fok.

ACM 113. Introduction to Optimization. *9 units (3-0-6); first term. Prerequisites: ACM 95/100 abc, ACM 104 or equivalent, or instructor's permission.* Unconstrained optimization: optimality conditions, line search and trust region methods, properties of steepest descent, conjugate gradient, Newton and quasi-Newton methods. Linear programming: optimality conditions, the simplex method, primal-dual interior-point methods. Nonlinear programming: Lagrange multipliers, optimality conditions, logarithmic barrier methods, quadratic penalty methods, augmented Lagrangian methods. Integer programming: cutting plane methods, branch and bound methods, complexity theory, NP complete problems. Not offered 2006–07.

ACM/CS 114 ab. Parallel Algorithms for Scientific Applications. *9 units (3-0-6); second, third terms. Prerequisites: ACM 106 or equivalent.* Introduction to parallel program design for numerically intensive scientific applications. First term: parallel programming methods; distributed-memory model with message passing using the message passing interface; shared-memory model with threads using open MP; object-based models using a problem-solving environment with parallel objects. Parallel numerical algorithms: numerical methods for linear algebraic systems, such as LU decomposition, QR method, Lanczos and Arnoldi methods, pseudospectra, CG solvers. Second term: parallel implementations of numerical methods for PDEs, including finite-difference, finite-element, and shock-capturing schemes; particle-based simulations of complex systems. Implementation of adaptive mesh refinement. Grid-based computing, load balancing strategies. Not offered 2006–07.

ACM/EE 116. Introduction to Stochastic Processes and Modeling. *9 units (3-0-6); first term. Prerequisite: Ma 2 ab or instructor's permission.* Introduction to fundamental ideas and techniques of stochastic analysis and modeling. Random variables, expectation and conditional expectation, joint distributions, covariance, moment generating function, central limit theorem, weak and strong laws of large numbers, discrete time stochastic processes, stationarity, power spectral densities and the Wiener-Khinchine theorem, Gaussian processes, Poisson processes, Brownian motion. The course develops applications in selected areas such as signal processing (Wiener filter), information theory, genetics, queuing and waiting line theory, and finance. Instructor: Owhadi.

ACM/ESE 118. Methods in Applied Statistics and Data Analysis. *9 units (3-0-6); second term. Prerequisite: Ma 2 or another introductory course in probability and statistics.* Introduction to fundamental ideas and techniques of statistical modeling, with an emphasis on conceptual understanding and on the analysis of real data sets. Multiple regression: estimation, inference, model selection, model checking. Regularization of ill-posed and rank-deficient regression problems. Cross-validation. Principal component analysis. Discriminant analysis. Resampling methods and the bootstrap. Instructor: Schneider.

ACM 126 ab. Wavelets and Modern Signal Processing. *9 units (3-0-6); second, third terms. Prerequisites: ACM 104, ACM 105 or undergraduate equivalent, or instructor's permission.* The aim is to cover the interactions existing between applied mathematics, namely applied and computational harmonic analysis, approximation theory, etc., and statistics and signal processing. The Fourier transform: the continuous Fourier transform, the discrete Fourier transform, FFT, time-frequency analysis, short-time Fourier transform. The wavelet transform: the continuous wavelet transform, discrete wavelet transforms, and orthogonal bases of wavelets. Statistical estimation. Denoising by linear filtering. Inverse problems. Approximation theory: linear/nonlinear approximation and applications to data compression. Wavelets and algorithms: fast wavelet transforms, wavelet packets, cosine packets, best orthogonal bases matching pursuit, basis pursuit. Data compression. Nonlinear estimation. Topics in stochastic processes. Topics in numerical analysis, e.g., multigrids and fast solvers. Not offered 2006–07.

Ma/ACM 142 abc. Ordinary and Partial Differential Equations. *9 units (3-0-6).* For course description, see Mathematics.

Ma/ACM 144 ab. Probability. *9 units (3-0-6).* For course description, see Mathematics.

ACM 151 ab. Asymptotic and Perturbation Methods. *9 units (3-0-6); first, second terms. Prerequisite: ACM 101 abc or equivalent, may be taken concurrently with instructor's permission.* Approximation methods for formulating and solving applied problems, with examples taken from various fields of science. Applications to various linear and nonlinear ordinary and partial differential equations. Singular and multiscale perturbation techniques, boundary-layer theory, coordinate straining, a method of averaging. Bifurcation theory, amplitude equations, and nonlinear stability. Not offered 2006–07.

ACM 190. Reading and Independent Study. *Units by arrangement.* Graded pass/fail only.

ACM 201 ab. Partial Differential Equations. *12 units (4-0-8); first, second terms. Prerequisite: ACM 101 abc or instructor's permission.* Fully nonlinear first-order PDEs, shocks, eikonal equations. Classification of second-order linear equations: elliptic, parabolic, hyperbolic. Well-posed problems. Laplace and Poisson equations; Gauss's theorem, Green's function. Existence and uniqueness theorems (Sobolev spaces methods, Perron's method). Applications to irrotational flow, elasticity, electrostatics, etc. Heat equation, existence and uniqueness theorems, Green's function, special solutions. Wave equation and vibrations. Huygens' principle. Spherical means. Retarded potentials. Water waves and various approximations, dispersion relations. Symmetric hyperbolic systems and waves. Maxwell equations, Helmholtz equation, Schrödinger equation. Radiation conditions. Gas dynamics. Riemann invariants. Shocks, Riemann problem. Local existence theory for general symmetric hyperbolic systems. Global existence and uniqueness for the inviscid Burgers' equation. Integral equations, single- and double-layer potentials. Fredholm theory. Navier-Stokes equations. Stokes flow, Reynolds number. Potential flow; connection with complex variables. Blasius formulae. Boundary layers. Subsonic, supersonic, and transonic flow. Instructor: Meiron.

ACM 210 ab. Numerical Methods for PDEs. *9 units (3-0-6); second, third terms. Prerequisite: ACM 106 or instructor's permission.* Finite difference and finite volume methods for hyperbolic problems. Stability and error analysis of nonoscillatory numerical schemes: i) linear convection: Lax equivalence theorem, consistency, stability, convergence, truncation error, CFL condition, Fourier stability analysis, von Neumann condition, maximum principle, amplitude and phase errors, group velocity, modified equation analysis, Fourier and eigenvalue stability of systems, spectra and pseudospectra of nonnormal matrices, Kreiss matrix theorem, boundary condition analysis, group velocity and GKS normal mode analysis; ii) conservation laws: weak solutions, entropy conditions, Riemann problems, shocks, contacts, rarefactions, discrete conservation, Lax-Wendroff theorem, Godunov's method, Roe's linearization, TVD schemes, high-resolution schemes, flux and slope limiters, systems and multiple dimensions, characteristic boundary conditions; iii) adjoint equations: sensitivity analysis, boundary conditions, optimal shape design, error analysis. Interface problems, level set methods for multiphase flows, boundary integral methods, fast summation algorithms, stability issues. Spectral methods: Fourier spectral methods on infinite and periodic domains. Chebyshev spectral methods on finite domains. Spectral element methods and h-p refinement. Multiscale finite element methods for elliptic problems with multiscale coefficients. Instructor: Hou.

ACM 216. Markov Chains, Discrete Stochastic Processes and Applications. *9 units (3-0-6); second term. Prerequisite: ACM/EE 116 or equivalent.* Stable laws, Markov chains, classification of states, ergodicity, von Neumann ergodic theorem, mixing rate, stationary/equilibrium distributions and convergence of Markov chains, Markov chain Monte Carlo and its applications to scientific computing, Metropolis Hastings algorithm, coupling from the past, martingale theory and discrete time martingales, rare events, law of large deviations, Chernoff bounds. Instructor: Candes.

ACM 217. Advanced Topics in Stochastic Analysis. *9 units (3-0-6); third term. Prerequisite: ACM 216 or equivalent.* The topic of this course changes from year to year and is expected to cover areas such as stochastic differential equations, stochastic control, statistical estimation and adaptive filtering, empirical processes and large deviation techniques, concentration inequalities and their applications. Examples of selected topics for stochastic differential equations include continuous time Brownian motion, Ito's calculus, Girsanov theorem, stopping times, and applications of these ideas to mathematical finance and stochastic control. Instructors: van Handel, Bouten.

Ae/ACM 232 abc. Computational Fluid Dynamics. *9 units (3-0-6).* For course description, see Aeronautics.

ACM 256. Special Topics in Applied Mathematics: Large Deviations Techniques and Applications. *9 units (3-0-6); third term. Prerequisites: ACM 101 or equivalent.* Large deviations is a very active field of probability theory dealing with rare events, more precisely the asymptotic computation of small probabilities on an exponential scale. Its applications range from statistics, computing, statistical physics, and mathematical finance to DNA analysis, communication, and control. Instructor: Owhadi.

ACM 290 abc. Applied and Computational Mathematics Colloquium. *1 unit (1-0-0); first, second, third terms.* A seminar course in applied and computational mathematics. Weekly lectures on current developments are presented by staff members, graduate students, and visiting scientists and engineers. Graded pass/fail only.

ACM 300. Research in Applied and Computational Mathematics. *Units by arrangement.*

APPLIED MECHANICS

Ae/AM/CE/ME 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6).* For course description, see Aeronautics.

CE/Ae/AM 108 abc. Computational Mechanics. *9 units (3-0-6).* For course description, see Civil Engineering.

AM 125 abc. Engineering Mathematical Principles. *9 units (3-0-6); first, second, third terms. Prerequisite: ACM 95/100 abc.* Topics include linear spaces, operators and matrices, integral equations, variational principles, ordinary and partial differential equations, stability, perturbation theory. Applications to problems in engineering and science are stressed. Instructor: Beck.

AM 151 abc. Dynamics and Vibrations. *9 units (3-0-6); first, second, third terms. Prerequisite: ACM 95/100 abc or instructor's permission.* Variational principles and Lagrange's equations. Response of mechanical systems to periodic, transient, and random excitation. Free and forced response of discrete and continuous systems. Approximate analysis methods. Introduction to nonlinear oscillation theory and stability. Instructor: Staff.

AM/ME 165 ab. Elasticity. *9 units (3-0-6); second, third terms. Prerequisites: Ae/Ge/ME 160 a and registered in Ae/Ge/ME 160 b.* Fundamental concepts and equations of elasticity. Linearized theory of elastostatics and elastodynamics: basic theorems and special solutions. Finite theory of elasticity: constitutive theory, semi-inverse methods. Variational methods. Applications to problems of current interest. Not offered 2006–07.

AM 175 abc. Advanced Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: AM 125 abc and AM 151 abc or equivalents.* Topics include linear and nonlinear vibrations of discrete and continuous systems, stability and control of dynamical systems, and stochastic processes with applications to random vibrations. Not offered 2006–07.

AM 176 abc. Nonlinear Dynamical Systems and Chaos. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 125 abc or instructor's permission.* Basic ideas from dynamical systems theory. One-dimensional maps, circle maps, rotation numbers, kneading theory, strange attractors, structural stability, hyperbolicity, symbolic dynamics, invariant manifolds, Poincaré maps, the Smale horseshoe. Techniques of local bifurcation theory are developed with emphasis on center manifolds and normal forms, global bifurcations, chaos, homoclinic and heteroclinic motions. Applications will be taken from a variety of areas, including fluid mechanics, structural mechanics, control theory, circuit theory, orbital mechanics, condensed-matter physics, and classical field theory. Not offered 2006–07, but see CDS 140.

AM 200. Special Problems in Advanced Mechanics. *Hours and units by arrangement.* By arrangement with members of the staff, properly qualified graduate students are directed in independent studies in mechanics.

Ae/AM/MS/ME 213. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/CE/ME 214 abc. Computational Solid Mechanics. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/ME 215. Dynamic Behavior of Materials. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/ME 223. Plasticity. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/ME 225. Special Topics in Solid Mechanics. *Units to be arranged.* For course description, see Aeronautics.

AM 250. Research in Applied Mechanics. *Hours and units by arrangement.* Research in the field of applied mechanics. By arrangement with members of the staff, properly qualified graduate students are directed in research.

APPLIED PHYSICS

Ch/APh 2. Introduction to Energy Sciences. *9 units (4-0-5).* For course description, see Chemistry.

APh/EE 9 ab. Solid-State Electronics for Integrated Circuits. *6 units (2-2-2); first, second terms; six units credit for the freshman laboratory requirement. Prerequisite: successful completion of APh/EE 9 a is a prerequisite for enrollment in APh/EE 9 b.* Introduction to solid-state electronics, including physical modeling and device fabrication. Topics: semiconductor crystal growth and device fabrication technology, carrier modeling, doping, generation and recombination, pn junction diodes, MOS capacitor and MOS transistor operation, and deviations from ideal behavior. Laboratory includes computer-aided layout, and fabrication and testing of light-emitting diodes, transistors, and inverters. Students learn photolithography, and use of vacuum systems, furnaces, and device-testing equipment. Instructor: Scherer.

APh 17 abc. Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Introduction to the use of thermodynamics and statistical mechanics in physics and engineering. Entropy, temperature, and the principal laws of thermodynamics. Canonical equations of state. Applications to cycles, engines, phase and chemical equilibria. Probability and stochastic processes. Kinetic theory of perfect gases. Statistical mechanics. Applications to gases, gas degeneration, equilibrium radiation, and simple solids. Instructor: Vahala.

APh 23. Demonstration Lectures in Optics. *6 units (2-0-4); second term. Prerequisite: Ph 1 abc.* Nine lectures cover fundamentals of optics with emphasis on modern optical applications, intended to exhibit basic optical phenomena including interference, dispersion, birefringence, diffraction, and laser oscillation, and the applications of these phenomena in optical systems employing two-beam and multiple-beam interferometry, Fourier-transform image processing, holography, electro-optic modulation, and optical detection and heterodyning. System examples to be selected from optical communications, radar, and adaptive optical systems. Instructor: Painter.

APh 24. Introductory Modern Optics Laboratory. *6 units (0-4-2); third term. Prerequisite: APh 23.* Laboratory experiments to acquaint students with the contemporary aspects of modern optical research and technology. Experiments encompass many of the topics and concepts covered in APh 23. Instructor: Painter.

APh 77 bc. Laboratory in Applied Physics. *9 units (0-9-0); second, third terms.* Selected experiments chosen to familiarize students with laboratory equipment, procedures, and characteristic phenomena in plasmas, fluid turbulence, fiber optics, X-ray diffraction, microwaves, high-temperature superconductivity, black-body radiation, holography, and computer interfacing of experiments. Instructor: Staff.

APh 78 abc. Senior Thesis, Experimental. *9 units (0-9-0); first, second, third terms. Prerequisite: instructor's permission.* Supervised experimental research experience, open only to senior-class applied physics majors. Requirements will be set by individual faculty members, but will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Applied Physics Undergraduate Committee. Students desiring additional units should register in APh 100. Not offered on a pass/fail basis. Instructors: Atwater and applied physics faculty.

APh 79 abc. Senior Thesis, Theoretical. *9 units (0-9-0); first, second, third terms. Prerequisite: instructor's permission.* Supervised theoretical research experience, open only to senior-class applied physics majors. Requirements will be set by individual faculty members, but will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Applied Physics Undergraduate Committee. Not offered on a pass/fail basis. This course cannot be used to satisfy the laboratory requirement in APh. Instructors: Atwater and applied physics faculty.

APh 100. Advanced Work in Applied Physics. *Units in accordance with work accomplished.* Special problems relating to applied physics, arranged to meet the needs of students wishing to do advanced work. Primarily for undergraduates. Students should consult with their advisers before registering. Graded pass/fail.

Ae/APh/CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/APh 104 abc. Experimental Methods. *9 units (3-0-6 first term; 1-3-5 second, third terms).* For course description, see Aeronautics.

APh 105 abc. States of Matter. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 17 abc or equivalent.* A survey emphasizing unifying concepts, such as order parameters, scaling laws, quasi-particle excitations, and correlation functions. Topics: long-range ordered states such as crystals, superfluids, and ferromagnets; phase transitions; critical phenomena; ideal classical and degenerate gases; theory of liquids; band theory of solids; fluctuations; noise. Instructors: Johnson, staff.

APh 109. Introduction to the Micro/Nanofabrication Lab. *9 units (0-6-3); first, second, third terms.* Introduction to techniques of micro- and nanofabrication, including solid-state, optical, and microfluidic devices. Students will be trained to use fabrication and characterization equipment available in the applied physics micro- and nanofabrication lab. Topics include Schottky diodes, MOS capacitors, light-emitting diodes, microlenses, microfluidic valves and pumps, atomic force microscopy, scanning electron microscopy, and electron-beam writing. Instructor: Ghaffari.

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

APh 114 abc. Solid-State Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 125 ab or Ph 125 abc or equivalent.* Introductory lecture and problem course dealing with experimental and theoretical problems in solid-state physics. Topics include crystal structure, symmetries in solids, lattice vibrations, electronic states in solids, transport phenomena, semiconductors, superconductivity, magnetism, ferroelectricity, defects, and optical phenomena in solids. Instructors: Bockrath, Atwater.

APh 125 abc. Quantum Mechanics of Matter. *9 units (3-0-6); first, second, third terms.* Quantum mechanics and applications to problems in solids, liquids, and gases. Topics: central force problems; hydrogen atom; multielectron atoms; approximation methods: time-independent and time-dependent perturbation theory, variational method, WKB approximation; eigenstates of molecules; theories for chemical bonding; optical transitions in matter; scattering: Born approximation, partial wave expansions, electron and photon scattering in matter; the electromagnetic field; quantum theory of crystalline solids. Not offered 2006–07.

APh/EE 130. Electromagnetic Theory. *9 units (3-0-6); first term.* This course reviews EM theory and optical concepts that are frequently encountered. EM theory: tensor matrix, kDB space, Poynting theorem. Dispersion and absorption. Reflection at an interface. Nonlinear optics. Polarization: Jones matrix and Stokes vectors. Ray tracing: ABCD matrix, optical aberrations. Noise. Diffraction. Interferometry: system design, homodyne, heterodyne, spectral domain analysis. Instructors: Yang, Yariv.

APh/EE 131. Optical Wave Propagation. *9 units (3-0-6); second term.* This course focuses on optical wave propagation and related applications. Topics to be covered include Huygens' principle, Fourier optics, Gaussian waves, imaging, gratings, spectroscopy, interferometry, Fabry-Perot cavities, coherence, holography, femtosecond optics, dispersion, Kramers-Kronig relation, Mie scattering theory, photonic band gaps, and near-field imaging. Instructors: Psaltis, Yang.

APh/EE 132. Optoelectronic Materials and Devices. *9 units (3-0-6); third term.* Interaction of light and matter, spontaneous and stimulated emission, laser rate equations, mode-locking, Q-switching, semiconductor lasers. Optical detectors and amplifiers; noise characterization of optoelectronic devices. Propagation of light in crystals, electro-optic effects and their use in modulation of light; introduction to nonlinear optics. Optical properties of nanostructures. Instructor: Atwater.

APh 150. Topics in Applied Physics. *Units to be arranged; first, second terms.* Content will vary from year to year, but at a level suitable for advanced undergraduate or beginning graduate students. Topics are chosen according to the interests of students and staff. Visiting faculty may present portions of this course. Not offered 2006–07.

APh 156 abc. Plasma Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* An introduction to the principles of plasma physics. A multitiered theoretical infrastructure will be developed consisting of the Hamilton-Lagrangian theory of charged particle motion in combined electric and magnetic fields, the Vlasov kinetic theory of plasma as a gas of interacting charged particles, the two-fluid model of plasma as interacting electron and ion fluids, and the magnetohydrodynamic model of plasma as an electrically conducting fluid subject to combined magnetic and hydrodynamic forces. This infrastructure will be used to examine waves, transport processes, equilibrium, stability, and topological self-organization. Examples relevant to plasmas in both laboratory (fusion, industrial) and space (magnetosphere, solar) will be discussed. Instructor: Bellan.

APh/BE 161. Physical Biology of the Cell. *9 units (3-0-6); second term.* Physical models applied to the analysis of biological structures ranging from individual proteins and DNA to entire cells. Topics include the force response of proteins and DNA, models of molecular motors, DNA packing in viruses and eukaryotes, mechanics of membranes, and membrane proteins and cell motility. Instructor: Phillips.

APh/BE 162. Physical Biology Laboratory. *9 units (0-6-3); second term. Prerequisite: concurrent enrollment in APh/BE 161.* This laboratory course accompanies APh/BE 161 and is built around experiments that amplify material covered in that course. Particular topics include background on techniques from molecular biology, mechanics of lipid bilayer vesicles, DNA packing in viruses, fluorescence microscopy of cells, experiments on cell motility, and the construction of genetic networks. Instructor: Phillips.

APh/BE 165. Advanced Bioengineering Laboratory. *9 units (0-6-3); third term. Prerequisite: BE 201 or equivalent.* Laboratory experiments at the interface of molecular biology and biophysics. Topics will vary from year to year and will be selected from the following list: use of atomic force microscopy to image and to manipulate proteins and DNA, use of fluorescent probes for single-molecule observation, physics of fluids in small devices, use of microfluidic devices for cell sorting and for stretching DNA, and application of optical tweezers to measure forces on single molecules. Not offered 2006–07.

EE/APh 180. Solid-State Devices. *9 units (3-0-6).* For course description, see Electrical Engineering.

APh/EE 183 abc. Fundamentals of Electronic Devices. *9 units (3-0-6); first, second, third terms.* Introduction to the fundamentals of modern electronic and optoelectronic devices. Topics include pn junctions, bipolar transistors, field-effect transistors, magnetic devices, light-emitting diodes, lasers, detectors, solar cells, chemical sensors, and MEMS. Emphasis will be placed on nanostructures and nanofabrication techniques. Where appropriate, integration and systems-level issues will be included. Not offered 2006–07.

APh 190 abc. Quantum Electronics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125 or equivalent.* Generation, manipulations, propagation, and applications of coherent radiation. The basic theory of the interaction of electromagnetic radiation with resonant atomic transitions. Laser oscillation, important laser media, Gaussian beam modes, the electro-optic effect, nonlinear-optics theory, second harmonic generation, parametric oscillation, stimulated Brillouin and Raman scattering. Other topics include light modulation, diffraction of light by sound, integrated optics, phase conjugate optics, and quantum noise theory. Instructor: Yariv.

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

Ph/APh 223 abc. Advanced Condensed-Matter Physics. *9 units (3-0-6).* For course description, see Physics.

APh 250. Advanced Topics in Applied Physics. *Units and term to be arranged.* Content will vary from year to year; topics are chosen according to interests of students and staff. Visiting faculty may present portions of this course. Instructor: Staff.

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

ART HISTORY

Art 11. Selected Topics in Art History. *9 units (3-0-6); offered by announcement.* Instructor: Staff.

Art 23. Major Figures in Art. *9 units (3-0-6); first term.* A course devoted to the study of a single artist of world importance, the name of the artist to be announced prior to registration. This study, grounded in the artist's life and, where possible, his/her writings, will analyze and interpret his/her major works in chronological sequence in their artistic and historic contexts, and attempt, by close aesthetic examination, to account for their greatness—and, sometimes, their failure. Not offered 2006–07.

Art 46. The Age of the Great Cathedrals. *9 units (3-0-6); third term.* A study of the arts of Western Europe from the disintegration of the Roman Empire circa A.D. 476, to the 14th century. The diverse historical forces at work during this long period produced a correspondingly varied art. Emphasis will be on the later Middle Ages, circa 1200–1350, a period marked by a synthesizing of inherited traditions into a comprehensive whole. Major monuments of architecture, such as the cathedrals of Notre Dame, Chartres, Reims, Cologne, Strasbourg, and Westminster, as well as sculpture, illuminated manuscripts, mosaics, panel painting, and stained glass will be examined within the aesthetic and social framework of countries as culturally diverse as France, Italy, Germany, Spain, and Britain. Not offered 2006–07.

Art 49. From Van Eyck to Rembrandt: Northern European Art, 1400–1650. *9 units (3-0-6); third term.* A survey of artistic developments in Northern Europe and Spain from the late Middle Ages through the Renaissance and baroque periods. The course will focus upon the complexity of northern art, from its origins in the still forceful medieval culture of 15th-century Flanders, to its confrontation with Italian Renaissance humanism in the 16th century. The effects of this cultural synthesis and the eventual development of distinct national schools of painting in the 17th century are examined through the works of the period's dominant artists, including Van Eyck, Dürer, Holbein, Velázquez, Rubens, Hals, and Rembrandt. Not offered 2006–07.

Art 50. Baroque Art. *9 units (3-0-6); first term.* A survey of the arts of painting, sculpture, and architecture from the late 16th century to the late 18th century. A confident and optimistic age, the baroque fostered the rise of national schools that produced artistic giants like Bernini, Caravaggio, Rubens, Rembrandt, Velázquez, Claude, Poussin, Tiepolo, and Guardi. The masterpieces of these and other artists reflect the wide variety of baroque art and will be studied within the context of certain commonly held ideals and of the differing economic, political, and religious systems that characterized the period. Not offered 2006–07.

Art 51. European Art of the 18th Century: From the Rococo to the Rise of Romanticism. *9 units (3-0-6); first term.* The course will encompass 18th-century European painting, sculpture, architecture, and the decorative arts. During this period a variety of styles and subjects proliferated in the arts, as seen in the richly diverse works of artists such as Watteau, Boucher, Chardin, Fragonard, Tiepolo, Canaletto, Hogarth, Gainsborough, Blake, David, Piranesi, and Goya, which reflect a new multiplicity in ways of apprehending the world. Instructor: Bennett.

Art 52. British Art. *9 units (3-0-6).* A survey course on British painting, sculpture, and architecture in the 17th, 18th, and 19th centuries. By examining the works of well-known British artists such as Hogarth, Blake, Gainsborough, Reynolds, Constable, and Turner, the class will focus on the multiplicity of styles and themes that developed in the visual arts in Britain from 1740 to 1840 and are part of the wider artistic phenomenon known as romanticism. This introduction to the British visual arts will be enriched by several class meetings in the Huntington Art Gallery. Instructor: Bennett.

Art 55. Art of the 19th Century. *9 units (3-0-6); second term.* A survey of 19th-century art with an emphasis on French painting created between 1780 and 1880. The lectures will focus on issues such as the new image of the artist, the tension between public and private statements in the arts, the rise of landscape painting, the development of the avant-garde, and paintings of modern life during this period. Not offered 2006–07.

Art 66. Ancient Art: From the Pyramids to the Colosseum. *9 units (3-0-6); second term.* A survey of the art of the earliest civilization of the ancient near east and Mediterranean from the Bronze Age to A.D. 300. The major monuments—architectural, sculptural, and pictorial—of Mesopotamia, Egypt, the Aegean, Greece, and Rome will be examined as solutions to problems of form and function presented by communal political, economic, and religious life. Emphasis will be placed on the creation of Greco-Roman art, the foundation of the Western artistic tradition. Instructor: Woods.

Art 67. Italian Renaissance Art. *9 units (3-0-6); first term.* A basic study of the greatest achievements of Italian painting, sculpture, and architecture in the 15th and 16th centuries. Masterpieces by a succession of artists such as Giotto, Masaccio, Brunelleschi, Donatello, Alberti, the Bellini, Leonardo da Vinci, Michelangelo, Raphael, Titian, Veronese, and others will be examined for their formal beauty and power, and studied as manifestations of individual genius in the context of their time and place: Italy, fragmented politically, yet at the peak of its cultural dominance. Not offered 2006–07.

Art 68. Modern Art. *9 units (3-0-6); third term.* An in-depth survey of international painting and sculpture of the first half of the 20th century. Crucial movements, among them fauvism, German expressionism, cubism, dadaism, surrealism, and American abstraction and realism between the two world wars, will be studied, and masterworks by a number of major artists of this period (e.g., Picasso, Matisse, Nolde, Duchamp, Magritte, Hopper) will be closely examined. Not offered 2006–07.

Art 69. The Arts of Dynastic China. *9 units (3-0-6); second term.* A survey of the development of Chinese art in which the major achievements in architecture, sculpture, painting, calligraphy, and ceramics will be studied in their cultural contexts from prehistory through the Manchu domination of the Qing Dynasty (1644–1911). Emphasis will be placed on the aesthetic appreciation of Chinese art as molded by the philosophies, religions, and history of China. Instructor: Wolfgram. Not offered 2006–07.

Art 70. Traditions of Japanese Art. *9 units (3-0-6).* An introduction to the great traditions of Japanese art from prehistory through the Meiji Restoration (1868–1912). Students will examine major achievements of sculpture, painting, temple architecture, and ceramics as representations of each artistic tradition, whether native or adapted from foreign sources. Fundamental problems of style and form will be discussed, but aesthetic analysis will always take place within the conditions created by the culture. Instructor: Wolfgram.

Art 71. Arts of Buddhism. *9 units (3-0-6); offered by announcement.* An examination of the impact of Buddhism on the arts and cultures of India, Southeast Asia, China, Korea, and Japan from its earliest imagery in the 4th century B.C.E. India through various doctrinal transformations to the Zen revival of 18th-century Japan. Select monuments of Buddhist art, including architecture, painting, sculpture, and ritual objects, will serve as focal points for discussions on their aesthetic principles and for explorations into the religious, social, and cultural contexts that underlie their creation. Not offered 2006–07.

ASTROPHYSICS

Ay 1. The Evolving Universe. *9 units (3-3-3); third term. This course is intended primarily for freshmen not expecting to take more advanced astronomy courses and will satisfy the menu requirement of the Caltech core curriculum.* Introduction to modern astronomy that will illustrate the accomplishments, techniques, and scientific methodology of contemporary astronomy. The course will be organized around a set of basic questions, showing how our answers have changed in response to fresh observational discoveries. Topics to be discussed will include telescopes, stars, planets, the search for life elsewhere in the universe, supernovae, pulsars, black holes, galaxies and their active nuclei, and the Big Bang. There will be a series of laboratory exercises intended to highlight the path from data acquisition to scientific interpretation. Students will also be required to produce a term paper on an astronomical topic of their choice and make a short oral presentation. In addition, a field trip to Palomar Observatory will be organized. Not offered on a pass/fail basis. Instructor: Steidel.

Ge/Ay 11 c. Planetary Sciences. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ay 20. Basic Astronomy and the Galaxy. *9 units (3-0-6); first term. Prerequisites: Ma 1 abc, Ph 1 abc, or for freshmen with a strong high-school background in math and physics.* Astronomical terminology. Stellar masses, distances, and motions. Star clusters and their galactic distributions. Stellar spectra, magnitudes, and colors. Structure and dynamics of the galaxy. Instructor: Blain.

Ay 21. Galaxies and Cosmology. *9 units (3-0-6); second term.* Cosmological models and parameters, extragalactic distance scale, cosmological tests; constituents of the universe, dark matter, and dark energy; thermal history of the universe, cosmic nucleosynthesis, recombination, and cosmic microwave background; formation and evolution of structure in the universe; galaxy clusters, large-scale structure and its evolution; galaxies, their properties and fundamental correlations; formation and evolution of galaxies, deep surveys; star formation history of the universe; quasars and other active galactic nuclei, and their evolution; structure and evolution of the intergalactic medium; diffuse extragalactic backgrounds; the first stars, galaxies, and the reionization era. Instructor: Djorgovski.

Ay 30. Current Trends in Astronomy. *3 units (2-0-1); second term.* Weekly seminar open to declared Ay majors at the discretion of the instructor; nonmajors who have taken astronomy courses may be admitted. This seminar is held in faculty homes in the evening and is designed to encourage student communication skills as they are introduced to faculty members and their research. Graded pass/fail. Instructor: W. Sargent.

Ay 31. Writing in Astronomy. *3 units; third term.* This course is intended to provide practical experience in the types of writing expected of professional astronomers. Example styles include research proposals, topical reviews, professional journal manuscripts, and articles for popular magazines such as *Astronomy or Sky and Telescope.* Each student will adopt one of these formats in consultation with the course instructor and write an original piece. An outline and several drafts reviewed by both a faculty mentor familiar with the topic and the course instructor are required. This course is open only to those who have taken upper-level astronomy courses. *Fulfills the Institute scientific writing requirement.* Instructor: Hillenbrand.

Ay 40. Inventing Reality: The Human Search for Truth. *9 units (3-0-6); third term.* In this course, students will trace the history of cosmological thought by reading directly from the original writings of such thinkers as Aristotle, Newton, Einstein, and Hubble, en route to an understanding of how current observations are being used to determine the origin, evolution, and fate of the universe. While the primary focus will be cosmology, related topics in classical physics, quantum mechanics, and philosophy will also be considered. Not offered 2006–07.

Ay 43. Reading in Astronomy and Astrophysics. *Units in accordance with work accomplished.* Student must have a definite reading plan and obtain instructor's permission before registering. Graded pass/fail.

Ay 78 abc. Senior Thesis. *9 units. Prerequisite: To register for this course, the student must obtain approval of the astronomy option representative and the prospective thesis adviser.* Open only to senior astronomy majors. This research must be supervised by a faculty member, student's thesis adviser. The written thesis must be completed and approved by the adviser before the end of the third term. Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with the astronomy option representative. A grade will not be assigned in Ay 78 until the end of the third term. P grades will be given the first two terms, and then changed at the end of the course to the appropriate letter grade.

Ay 101. Physics of Stars. *11 units (3-2-6); first term. Prerequisite: Ay 20.* Physics of stellar atmospheres. Properties of stars, stellar spectra, radiative transfer, line formation. Stellar structure, stellar evolution, evolution of binaries. Nucleosynthesis in stars. Stellar oscillations. Instructor: Hillenbrand.

Ay 102. Physics of the Interstellar Medium. *9 units (3-0-6); second term. Prerequisite: Ay 20.* An introduction to observations of the interstellar medium and relevant physical processes. The structure and hydrodynamic evolution of ionized hydrogen regions associated with massive stars and supernovae, thermal balance in neutral and ionized phases, star formation and global models for the interstellar medium. Instructors: A. Sargent, Scoville.

Ay 105. Optical Astronomy Instrumentation Lab. *9 units (1-6-2); third term. Prerequisite: Ay 20.* An opportunity for astronomy and physics undergraduates (juniors and seniors) to gain firsthand experience with the basic instrumentation tools of modern optical and infrared astronomy. The 10 weekly lab experiments are expected to include radiometry measurements, geometrical optics, optical aberrations and ray tracing, spectroscopy, fiber optics, CCD electronics, CCD characterization, photon counting detectors, vacuum and cryogenic technology, and stepper motors and encoders. Instructors: Blain, Steidel.

Ay 121. Radiative Processes. *9 units (3-0-6); first term. Prerequisites: Ay 101 (undergraduates); Ph 125 or equivalent.* The interaction of radiation with matter: radiative transfer, emission, and absorption. Compton processes, synchrotron radiation, collisional excitation, spectroscopy of atoms and molecules. Instructor: Readhead.

Ay 122. Astronomical Measurements and Instrumentation. *9 units (3-0-6); first term. Prerequisite: Ph 106 or equivalent.* Measurement and signal analysis techniques throughout the electromagnetic spectrum. Telescopes and interferometers; detectors and receivers; photometry and radiometry; imaging devices and image processing; spectrometers; space telescopes. Instructors: Djorgovski, Readhead.

Ay 123. Structure and Evolution of Stars. *9 units (3-0-6); first term. Prerequisites: Ay 101 (undergraduates); Ph 125 or equivalent.* Thermodynamics, equation of state, convection, opacity, radiative transfer, stellar atmospheres, nuclear reactions, and stellar models. Evolution of low- and high-mass stars, supernovae, and binary stars. Instructors: Cohen, Sari.

Ay 124. Structure and Dynamics of Galaxies. *9 units (3-0-6); second term. Prerequisites: Ay 21 (undergraduates); Ph 106 or equivalent.* Stellar dynamics and properties of galaxies; kinematics and dynamics of our galaxy; spiral structure; stellar composition, masses, and rotation of external galaxies; star clusters; galactic evolution; binaries, groups, and clusters of galaxies. Instructor: W. Sargent.

Ay 125. High-Energy Astrophysics. *9 units (3-0-6); third term. Prerequisites: Ay 21 (undergraduates); Ph 106 or equivalent.* High-energy astrophysics and the final stages of stellar evolution; supernovae, binary stars, accretion disks, pulsars; extragalactic radio sources; active galactic nuclei; black holes. Instructor: Kulkarni.

Ay 126. Interstellar Medium. *9 units (3-0-6); second term. Prerequisite: Ay 102 (undergraduates).* Physical processes in the interstellar medium. Ionization, thermal and dynamic balance of interstellar medium, molecular clouds, hydrodynamics, magnetic fields, H II regions, supernova remnants, star formation, global structure of interstellar medium. Instructors: A. Sargent, Scoville.

Ay 127. Cosmology and Galaxy Formation. *9 units (3-0-6); third term. Prerequisites: Ay 21 (undergraduates); Ph 106 or equivalent.* Cosmology; extragalactic distance determinations; relativistic cosmological models; galaxy formation and clustering; thermal history of the universe, microwave background; nucleosynthesis; cosmological tests. Instructor: Phinney.

Ge/Ay 132. Atomic and Molecular Processes in Astronomy and Planetary Sciences. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ge/Ay 133. The Formation and Evolution of Planetary Systems. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ge/Ay 137. Planetary Physics. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ay 141 abc. Research Conference in Astronomy. *3 units (1-0-2); first, second, third terms.* Oral reports by astronomy students on current research. These provide an opportunity for practice in the organization and presentation of reports. A minimum of two presentations will be expected from each student each year. This course fulfills the option oral communication requirement and is required of all astronomy graduate students who have passed their preliminary exams. It is also recommended for astronomy seniors. Graded pass/fail. Instructors: Kulkarni, Sari, Hillenbrand, Kamionkowski, A. Sargent, Djorgovski.

Ay 142. Research in Astronomy and Astrophysics. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of research outlined. Approval by the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy. Graded pass/fail.

Ay 143. Reading and Independent Study. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of reading and independent study outlined. Approval by the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy. Graded pass/fail.

Ay 211. Extragalactic Astronomy. *9 units (3-0-6); third term. Prerequisites: Ay 123, Ay 124, and Ay 127.* This is an advanced course in extragalactic astronomy and aims to cover the following topics: cosmological background, origin of the galactic halo, stellar nucleosynthesis, primordial element abundances, QSO absorption lines, nature of the Ly alpha forest, physics and evolution of AGNs, gravitational lensing and dark matter, origin of elliptical galaxies, environmental processes in galaxy evolution, supernovae as cosmological probes, searches for high redshift galaxies, the galaxy luminosity function, assembly history of the Milky Way and M31. Not offered 2006–07.

Ay 215. Seminar in Theoretical Astrophysics. *9 units (3-0-6); third term.* Course for graduate students and seniors in astronomy and planetary science. Students will be required to lead some discussions. Topic will be selected based on student interest. Not offered 2006–07.

BIOCHEMISTRY AND MOLECULAR BIOPHYSICS

BMB/Bi/Ch 170. Principles of Three-Dimensional Protein Structure. *9 units (3-3-3); first term. Prerequisite: Bi/Ch 110.* The forces determining the folding of proteins into their unique tertiary structures. Protein structures will be classified by organization of the structural elements and structural motifs, and their influence on function will be explored. Topics will include enzyme and antibody structure and function, virus structures, protein–nucleic acid interactions, methods of macromolecular structure determination, and protein structure analysis. A computer graphics system will be used for the display and analysis of macromolecular structure. Instructors: Bjorkman, Rees.

BMB/Bi/Ch 174. Biophysical Chemistry. *9 units (3-0-6); second term. Prerequisite: BMB/Bi/Ch 170.* Principles of biophysical chemistry and structural biological techniques such as protein folding, structure prediction, NMR spectroscopy, various forms of protein imaging, and design. Instructors: Jensen, Mayo.

Bi/BMB 251 abc. Current Research in Cellular and Molecular Biology. *1 unit (1-0-0).* For course description, see Biology.

BMB 278. Fundamentals of Molecular Genetics. *9 units (3-0-6); third term. Prerequisite: BMB 176.* Principles and mechanisms of DNA repair and replication, transcription and splicing, and protein synthesis. Instructors: Campbell, Parker.

BMB 299. Graduate Research. *Units to be arranged; first, second, third terms.* Students may register for research units after consultation with their adviser.

BIOENGINEERING

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BE/Bi 5. Introduction to Biomechanics. *9 units (3-0-6); first term.* Introduction to the basic concepts of applying engineering principles of solid and fluid mechanics to the study of biological systems. The course emphasizes the organismal, rather than the molecular, level of complexity. It draws on a wide array of biological phenomena from plants and animals, and is not intended as a technical introduction to medically related biomechanics. Topics may include fundamental properties of solids and fluids, viscoelasticity, drag, biological pumps, locomotion, and muscle mechanics. Instructor: Dickinson.

BE 100 abc. Bioengineering Seminar. *1 unit; first, second, third terms.* Offered to graduate students in bioengineering. Seminar series and training discussions with visiting speakers. Instructor: Dickinson.

BE 141. Biomaterials: Science and Engineering. *9 units (3-0-6); first term. Prerequisites: Ph 2 ab or Ph 12 abc, Ch 1 ab, Ch 3 a, or instructor's permission. MS 115 ab recommended.* Lectures and experiments demonstrating the bulk and surface properties of materials; review of the major classes of materials—metals, ceramics, polymers—with a view to their relevance to the biomedical field. Special materials and processes of relevance will also be discussed, e.g., hydrogels, fabrics, thin films, bioresorbable and bioerodible materials, cardiac jelly, etc. Proteins, cells, tissues and their interactions with materials; key concepts in reactions between host materials and implants, including inflammation, coagulation, and tumorigenesis. Testing and degradation of biomaterials, material applications in medicine and dentistry, especially orthopedic, cardiovascular, ophthalmologic, oral and maxillofacial implants, and artificial organs. Instructor: Staff.

BE 150. Analysis, Design, and Selection of Biomolecules. *9 units (2-0-7); third term.* The course emphasizes computational approaches to analyzing and designing functional proteins and nucleic acids, describing opportunities for combining rational techniques with experimental selection methods. Analysis topics will include molecular modeling, molecular mechanics, molecular dynamics, and structure prediction and folding. Design topics will include positive and negative design paradigms, sequence selection methods, optimization of equilibrium and kinetic properties, and design of catalysts, sensors, motors, and circuits. Selection topics will include library design and selection cycle strategies. The computational approaches employed will include continuous optimization, discrete optimization, dynamic programming, and deterministic and stochastic solution methods for ordinary differential equations. Instructors: Pierce, Mayo.

APh/BE 161. Physical Biology of the Cell. *9 units (3-0-6).* For course description, see Applied Physics.

APh/BE 162. Physical Biology Laboratory. *9 units (0-6-3).* For course description, see Applied Physics.

ChE/BE 163. Introduction to Engineering Biological Molecules and Systems. *9 units (3-0-6).* For course description, see Chemical Engineering.

APh/BE 165. Advanced Bioengineering Laboratory. *9 units (0-6-3).* For course description, see Applied Physics.

EE/BE 166. Optical Methods for Biomedical Imaging and Diagnosis. *9 units (3-1-5).* For course description, see Electrical Engineering.

BE 167. Topics in Bioengineering. *1 unit; first term.*Introduction to the current research in bioengineering and related fields, focusing specifically on projects carried out by Caltech faculty. The course is intended for first-year graduate students in the BE option, but is open to all related options. The course will provide the students with background within the lecturer's specific discipline. Instructor: Dickinson.

ChE/BE 169. Biomolecular Cell Engineering. *9 units (3-0-6).* For course description, see Chemical Engineering.

CNS/Bi/BE/Ph 178. Evolution and Biocomplexity. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

CNS/EE/BE 182. Introduction to Neuromorphic and Bioinspired Mixed-Signal VLSI. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

BE 201 abc. Physiology for Bioengineering. *12 units (3-5-4); first, second, third terms.*

a. Cell physiology of eukaryotic cells, with an emphasis on the correlation of structure and function at the molecular, organelle, and cellular levels. Survey of physiological organization as cooperative assemblies of epithelial sheets, tissues, and organs.

b. Provides a foundation in physiology for bioengineering students. Systematic approach to examination of the functions of major systems, and the regulatory mechanisms controlling normal function. Detailed examination of specific systems pertinent to major areas of bioengineering research, including membranes, channels and transport, the muscular system, the nervous system, the sensory system and its integration, and the cardiac system.

c. Continues the approach of part b with a detailed examination of the circulatory, renal, respiratory, digestive, and hormonal/neurohormonal systems. Instructor: Staff.

BE 240. Special Topics in Bioengineering. *Units and term to be arranged.* Topics relevant to the general educational goals of the bioengineering option. Graded pass/fail.

Ae/BE 242. Biological Flows: Propulsion. *9 units (3-0-6).* For course description, see Aeronautics.

BE/Ae 243. Biological Flows: Transport and Circulatory Systems. *9 units (3-0-6); third term. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent or ChE 103 a.* Internal flows: steady and pulsatile blood flow in compliant vessels, internal flows in organisms. Fluid dynamics of the human circulatory system: heart, veins, and arteries (microcirculation). Mass and momentum transport across membranes and endothelial layers. Fluid mechanics of the respiratory system. Renal circulation and circulatory system. Biological pumps. Instructor: Gharib.

BE 248. Magnetic Resonance Imaging. *5 units (3-1-1); third term. Prerequisites: Undergraduate-level physics, biology, and/or engineering courses recommended.* Physics, engineering, and computational aspects of MRI. Theory, engineering, and practice of MRI for biological and medical applications are covered in detail. Provides technical background necessary for a full understanding of the concepts underpinning the specific uses of MRI for functional brain imaging. Complements SS/CNS 251. Instructor: Tyszka.

BE 250. Research in Bioengineering. *Units and term to be arranged.* By arrangement with members of the staff, properly qualified graduate students are directed in bioengineering research.

BIOLOGY

Bi 1. The Biology and Biophysics of Viruses. *9 units (4-0-5); third term.* This course introduces nonbiologists to recent advances in our understanding of how HIV and other viruses infect and cause damage to their hosts. Because understanding and treating HIV infection involves a basic knowledge of cell and molecular biology, virology, and immunology, the course will cover fundamental concepts in these areas from a quantitative, molecular, chemical, and biophysical perspective. Instructors: Bjorkman, Phillips.

Bi 2. Current Research in Biology. *6 units (2-0-4); first term. Intended for students considering the biology option; open to freshmen.* Current research in biology will be discussed, on the basis of reading assigned in advance of the discussions, with members of the divisional faculty. Graded pass/fail. Instructor: Elowitz.

BE/Bi 5. Introduction to Biomechanics. *9 units (3-0-6); first term.* For course description, see Bioengineering.

Bi 8. Introduction to Molecular Biology; Organization and Expression of Genetic Information. *9 units (3-0-6); second term.* This course and its sequel, Bi 9, cover biology at the cellular level. After introducing basic concepts necessary for understanding biological systems at the molecular level, Bi 8 emphasizes cellular processes involved in the organization and expression of genetic information, including what is commonly called molecular biology, and introduces topics in developmental biology and immunology. Graded pass/fail. Instructor: Stathopoulos.

Bi 9. Cell Biology. *9 units (3-0-6); third term.* Continues coverage of biology at the cellular level, begun in Bi 8. Topics: cytoplasmic structure, membrane structure and function, cell motility, and cell-cell recognition. Emphasis on both the ultrastructural and biochemical approaches to these topics. Instructors: Dunphy, staff.

Bi 10. Cell Biology Laboratory. *6 units (1-3-2); third term. Prerequisite: Bi 8; designed to be taken concurrently with Bi 9.* Introduction to basic methods in cell and molecular biological research, including polymerase chain reaction, molecular cloning, expression and purification of recombinant fusion proteins in bacteria, enzymology, and gel electrophoresis of proteins and nucleic acids. Instructor: Deshaies.

Bi 22. Undergraduate Research. *Units to be arranged; first, second, third terms.* Special problems involving laboratory research in biology; to be arranged with instructors before registration. Graded pass/fail. Instructor: Staff.

Bi 23. Biology Tutorial. *Units to be arranged; maximum of 6 units per term; second, third terms.* Study and discussion of special problems in biology, usually involving regular tutorial sessions with instructors. To be arranged through the instructor before registration. Graded pass/fail. Instructors: Strauss, staff.

Bi 24. Technical Communication for Biologists. *6 units (2-0-4); first term.* This course offers instruction and practice in writing and speaking relevant to professional biologists working in research, teaching, and/or medical careers. Students may write a paper for a scientific journal, based on their previous research and mentored by a faculty member. Alternatively, students may produce a variety of brief writing assignments with a range of audiences and purposes. Oral presentations will be based on writing produced in the course, with feedback from instructors and peers. *Fulfills the Institute scientific writing requirement.* Instructors: Jensen, Youra, Marsen.

Bi 90 abc. Undergraduate Thesis. *12 or more units per term; first, second, third terms. Prerequisites: 18 units of Bi 22 (or equivalent research experience) in the research area proposed for the thesis, and instructor's permission.* Intended to extend opportunities for research provided by Bi 22 into a coherent individual research project, carried out under the supervision of a member of the biology faculty. Normally involves three or more consecutive terms of work in the junior and senior years. The student will formulate a research problem based in part on work already carried out, evaluate previously published work in the field, and present new results in a thesis format. First two terms graded pass/fail; final term graded by letter on the basis of the completed thesis. Instructor: Lester.

Ph/Bi 103 b. Neuroscience for Physicists and Engineers. *9 units (3-0-6).* For course description, see Physics.

Bi/Ch 110. Introduction to Biochemistry. *12 units (4-0-8); first term. Prerequisite: Ch 41 abc or instructor's permission.* Lectures and recitation introducing the molecular basis of life processes, with emphasis on the structure and function of proteins. Topics will include the derivation of protein structure from the information inherent in a genome, biological catalysis, the intermediary metabolism that provides energy to an organism, and the use of DNA manipulations, cloning, and expression of proteins in foreign hosts to study protein structure and function. Instructors: Richards, Campbell.

Bi/Ch 111. Biochemistry of Gene Expression. *12 units (4-0-8); second term. Prerequisites: Bi/Ch 110; Bi 8 and Bi 122 recommended.* Lectures and recitation on the molecular basis of biological structure and function. Emphasizes the storage, transmission, and expression of genetic information in cells. Specific topics include DNA replication, recombination, repair and mutagenesis, transcription, RNA processing, and protein synthesis. Instructors: Campbell, Parker.

Bi/Ch 113. Biochemistry of the Cell. *12 units (4-0-8); third term. Prerequisites: Bi/Ch 110; Bi 9 recommended.* Lectures and recitation on the biochemistry of basic cellular processes in the cytosol and at the cell surface, with emphasis on signal transduction, membrane trafficking, and control of cell division. Specific topics include cell-cell signaling, control of gene expression by cell surface molecules, tumorigenesis, endocytosis, exocytosis, viral entry, and cell cycle regulation. Instructors: Chan, Shan.

Bi 114. Immunology. *12 units (4-0-8); second term. Prerequisites: Bi 8, Bi 9, Bi 122 or equivalent, and Bi/Ch 110 recommended.* The course will cover the molecular and cellular mechanisms that mediate recognition and response in the mammalian immune system. Topics include cellular and humoral immunity, the structural basis of immune recognition, antigen presentation and processing, developmental regulation of gene rearrangement, biochemistry of lymphocyte activation, lymphokines and the regulation of cellular responses, T and B cell development, and mechanisms of tolerance. Instructors: Bjorkman, Rothenberg.

Bi 115. Virology. *6 units (2-0-4); third term. Prerequisites: Bi 8, Bi 9.* Introduction to the chemistry and biology of viruses. Emphasis on replication strategies of animal viruses, with consideration also given to epidemiology of viruses, nature and control of virus diseases, evolution of viruses, and some aspects of bacterial and plant virus replication. Instructor: Strauss. Given in alternate years; not offered 2006–07.

Bi 117. Developmental Biology. *9 units (3-0-6); second term. Prerequisites: Bi 8 and Bi 9.* A survey of the development of multicellular organisms. Topics will include the beginning of a new organism (fertilization), the creation of multicellularity (cellularization, cleavage), reorganization into germ layers (gastrulation), induction of the nervous system (neurulation), and creation of specific organs (organogenesis). Emphasis will be placed on the molecular mechanisms underlying morphogenetic movements, differentiation, and interactions during development, covering both classical and modern approaches to studying these processes. Instructor: Bronner-Fraser.

CNS/Bi/Psy 120. The Neuronal Basis of Consciousness. *9 units (4-0-5).* For course description, see Computation and Neural Systems.

Bi 122. Genetics. *9 units (3-0-6); first term. Prerequisite: Bi 8 or Bi 9, or instructor's permission.* Lecture and discussion course covering basic principles of genetics. Instructors: Hay, Sternberg.

Bi 123. Genetics Laboratory. *12 units (2-8-2); second term. Prerequisite: Bi 122.* Laboratory exercises illustrating the principles of genetics, with emphasis on Mendelian inheritance in multicellular eukaryotes, including *Drosophila melanogaster* and *Caenorhabditis elegans.* Instructors: Hay, staff.

Bi 125. Principles and Methods of Gene Transfer and Gene Manipulation in Eukaryotic Cells. *6 units (2-0-4); second term. Prerequisite: Bi/Ch 110.* Lecture and discussion course dealing with modern approaches to "genetic intervention" in eukaryotic cells. Topics: mutagenesis of cultured animal cells and selection schemes; gene transfer into cultured cells mediated by naked DNA, chromosomes, and viruses; transformation of yeast by chromosomal DNA and plasmids; neoplastic transformation of plant cells by *Agrobacteria* plasmids; nuclear transplantation and gene injection into amphibian eggs and oocytes; selective drug-induced gene amplification in cultured animal cells; somatic cell hybridization. Instructor: Attardi. Given in alternate years; offered 2006–07.

Bi 129. Cellular Dynamics: Advanced Topics in Cell Biology of Neurons and Nonneuronal Cells. *9 units (3-0-6); first term. Prerequisite: Bi 9 or instructor's permission.* Topics to be covered may include proteomics, modeling of signal transduction cascades, protein modification, protein synthesis and degradation, signaling through lipid messengers, calcium signaling, metabolic control, transport within polarized cells, and cytoskeletal dynamics. Instructors: Schuman, Zinn.

CNS/Psy/Bi 131. The Psychology of Learning and Motivation. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

Bi/Ch 132. Biophysics of Macromolecules. *9 units (3-0-6); first term. Recommended prerequisite: Bi/Ch 110.* Structural and functional aspects of nucleic acids and proteins, including hybridization; electrophoretic behavior of nucleic acids; principles and energetics of folding of polypeptide chains in proteins; allostery and cooperativity in protein action; enzyme kinetics and mechanisms; and methods of structure determination, such as X-ray diffraction and magnetic resonance. Structure and function of metalloenzymes. Instructors: Barton, Beauchamp.

Bi/CNS/Psy 133. Neurobiology and Evolution of Emotion: Do Flies Have Feelings? *9 units (3-0-6); third term. Prerequisite: Bi/CNS 150 or instructor's permission. Recommended Bi 156 and SS/Psy/Bi/CNS 140.* Fundamental issues in emotion research at multiple levels of experimental analysis, and in species ranging from humans to mice to flies. Psychological theories and data from studies in humans will be presented to clarify the relationship between emotional behavior, affect, feelings, and moods, which in turn will form the basis for exploring whether and how different animal models can be used to investigate the neural circuit and molecular bases of emotion. Can genetically tractable model organisms such as flies show "emotional behavior," or have "feelings"? What have we learned from animal models about the neural circuit and genetic bases of emotional behavior, and how does it relate to what we know from human studies? Disorders of emotion will also be discussed, including affective disorders in humans, and their potential animal models. Instructors: Anderson, Adolphs.

SS/Psy/Bi/CNS 140. Social Neuroscience. *9 units (3-0-6).* For course description, see Social Science.

Bi 145 ab. Tissue and Organ Physiology. *9 units (4-0-5); first, second terms. Prerequisites: Bi 8, 9, 12, 110. Bi 110 may be taken concurrently.* Reviews of embryology, anatomy, and histology, as well as in-depth discussion of cellular physiology (from a control and digital logic perspective). Topics will include building from cell function to tissues, hematologic, connective tissue, musculoskeletal physiology, and integration of these tissue functions into the function of the cardiovascular system. Cardiovascular system in an organ-based fashion, with pulmonary, renal, gastrointestinal, hepatobiliary, neuroendocrine, and reproductive physiology. Specific topics in advanced physiology, including cardiovascular and pulmonary physiology, exercise, nutrition, congenital abnormalities, selected topics in pathophysiology. Instructors: Fraser, Pierce.

Bi/CNS 150. Neurobiology. *10 units (4-0-6); first term.* Lectures and discussions on general principles of the organization and function of nervous systems, providing both an overview of the subject and a foundation for advanced courses. Topics include neurocytology and gross neuroanatomy; developmental neurobiology; the biophysical basis for action potentials, synaptic transmission, and sensory transduction; and the integration of these processes in sensory and motor pathways of the central nervous system. Laboratory demonstrations offer experience with the experimental preparations discussed in the course. Instructors: Kennedy, Adolphs.

Bi 152. Introduction to Neuroethology. *6 units (2-0-4); second term.* Introduction to the neurobiological study of natural behavior of animals. Topics include such questions as how animals recognize and localize signals in their natural environments, how animals move, how behavior develops, what and how animals learn, and how natural selection shapes the evolution of brain and behavior. Instructor: Konishi. Given in alternate years; offered 2006–07.

Bi 156. Molecular Basis of Behavior. *9 units (3-0-6); second term. Prerequisite: Bi 150 or instructor's permission.* A lecture and discussion course on the neurobiology of behavior. Topics may include biological clocks, eating behavior, sexual behavior, addiction, mental illness, and neurodegenerative diseases. Instructor: Patterson. Given in alternate years; not offered 2006–07.

Bi/CNS 157. Comparative Nervous Systems. *9 units (2-3-4); third term.* An introduction to the comparative study of the gross and microscopic structure of nervous systems. Emphasis on the vertebrate nervous system; also, the highly developed central nervous systems found in arthropods and cephalopods. Variation in nervous system structure with function and with behavioral and ecological specializations and the evolution of the vertebrate brain. Instructor: Allman. Given in alternate years; offered 2006–07.

Bi/CNS 158. Vertebrate Evolution. *9 units (3-0-6); third term.* An integrative approach to the study of vertebrate evolution combining comparative anatomical, behavioral, embryological, genetic, paleontological, and physiological findings. Special emphasis will be given to: (1) the modification of developmental programs in evolution; (2) homeostatic systems for temperature regulation; (3) changes in the life cycle governing longevity and death; (4) the evolution of brain and behavior. Instructor: Allman. Given in alternate years; not offered 2006–07.

Bi/CNS 162. Cellular and Systems Neuroscience Laboratory. *12 units (2-7-3); third term. Prerequisite: Bi 150 or instructor's permission.* A laboratory-based introduction to experimental methods used for electrophysiological studies of the central nervous system. Through the term, students investigate the physiological response properties of neurons in insect and mammalian brains, using extra- and intracellular recording techniques. Students are instructed in all aspects of experimental procedures, including proper surgical techniques, electrode fabrication, stimulus presentation, and computer-based data analysis. Graded pass/fail. Instructors: Laurent, Schuman. Given in alternate years; not offered 2006–07.

ESE/Bi 166. Microbial Physiology. *9 units (3-1-5).* For course description, see Environmental Science and Engineering.

ESE/Bi 168. Microbial Metabolic Diversity. *9 units (3-0-6).* For course description, see Environmental Science and Engineering.

BMB/Bi/Ch 170. Principles of Three-Dimensional Protein Structure. *9 units (3-3-3).* For course description, see Biochemistry and Molecular Biophysics.

CNS/Bi 172. Clinical Neuropsychology. *6 units (3-0-3).* For course description, see Computation and Neural Systems.

BMB/Bi/Ch 174. Biophysical Chemistry. *9 units (3-0-6).* For course description, see Biochemistry and Molecular Biophysics.

CNS/Bi 176. Cognition. *12 units (6-0-6).* For course description, see Computation and Neural Systems.

Bi 177. Principles of Modern Microscopy. *9 units (3-0-6); first term.* Lectures and discussions on the underlying principles behind digital, video, differential interference contrast, phase contrast, confocal, and two-photon microscopy. The course will begin with basic geometric optics, characteristics of lenses and microscopes, and principles of accurate imaging. Specific attention will be given to how different imaging elements such as filters, detectors, and objective lenses contribute to the final image. Course work will include critical evaluation of published images and design strategies for simple optical systems. Emphasis in the second half of the course will be placed on the analysis and presentation of two- and three-dimensional images. No prior knowledge of microscopy will be assumed. Instructor: Fraser.

CNS/Bi/BE/Ph 178. Evolution and Biocomplexity. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

Bi 180. Methods in Molecular Genetics. *12 units (2-8-2); first term. Prerequisites: Bi 122, Bi 10, or instructor's permission.* An introduction to current molecular genetic techniques including basic microbiological procedures, transposon and UV mutagenesis, gene transfer, preparation of DNA, restriction, ligation, electrophoresis (including pulsed-field), electroporation, Southern blotting, PCR, gene cloning, sequencing, and computer searches for homologies. The first half of the course involves structured experiments designed to demonstrate the various techniques. The second half is devoted to individual research projects in which the techniques are applied to original studies on an interesting, but not well studied, organism. Graded pass/fail. Instructor: Bertani. Additional information concerning this course can be found at http://www.its.caltech.edu/~bi180.

Bi 182. Developmental Gene Regulation and Evolution of Animals. *6 units (2-0-4); second term. Prerequisites: Bi 8 and at least one of the following: Bi 111, Bi 114, or Bi 122 (or equivalents).* Lectures on and discussion of the regulatory genome; phylogenetic relationships in animals and the fossil record; how developmental gene regulation works; regulatory basis of development in the simplest systems; making parts of the adult animal body plan; pattern formation and deep regulatory networks; the Precambrian world and a gene-regulatory view of the evolutionary origin of animal forms; processes of *cis*-regulatory evolution; diversification in the arthropods; and the special character of vertebrate evolution. Instructor: Davidson.

CNS/Bi/EE 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4).* For course description, see Computation and Neural Systems.

CNS/Bi/Ph/CS 187. Neural Computation. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

Bi 188. Human Genetics and Genomics. *6 units (2-0-4); second term. Prerequisite: Bi 122; or graduate standing and instructor's permission.* Introduction to the genetics of humans. Subjects covered include human genome structure, genetic diseases and predispositions, the human genome project, forensic use of human genetic markers, human variability, and human evolution. Given in alternate years; not offered 2006–07.

Bi 190. Advanced Genetics. *6 units (2-0-4); third term. Prerequisite: Bi 122.* Lectures and discussions covering advanced principles of genetic analysis. Emphasis on genetic approaches to the study of development in *Saccharomyces*, *Caenorhabditis*, *Drosophila*, and *Arabidopsis*. Instructor: Sternberg. Given in alternate years; offered 2006–07.

CS/CNS/Bi 191 ab. Biomolecular Computation. *9 units (3-0-6) second term; (2-4-3) third term.* For course description, see Computer Science.

Bi 202. Neurobiology of Disease. *9 units (3-0-6); first term. Prerequisite: Bi 150 or instructor's permission.* This course will cover the cellular and molecular basis of diseases of the nervous system, as well as current and future therapeutic approaches. These diseases include disorders of abnormal protein structure (Alzheimer's, Huntington's, Parkinson's, prion), autoimmunity (multiple sclerosis), and developmental disorders of cognition and social communication (schizophrenia, autism). Genetic and environmental etiologies will be explored, and animal models will be compared to the human condition. The role of the reward system in addiction will also be discussed. Instructor: Patterson. Given in alternate years; offered 2006–07.

Bi 204. Developmental Gene Regulatory Networks: Theory and Practice. *6 units (2-0-4); third term. Prerequisite: Bi 182 or equivalent, or instructor's permission.* A seminar about developmental gene regulatory networks (GRNs). It is specifically directed at the gene regulatory networks that control animal development as distinct from any prokaryote or yeast gene networks, or reversible physiological networks of complex organisms. Instructor: Davidson. Given in alternate years; offered 2006–07.

Bi 205. Regulation by Degradation: The Ubiquitin System and Other Pathways. *6 units (2-0-4); third term. Prerequisite: instructor's permission.* In-depth reviews of the current understanding of the ubiquitin system, a large set of regulatory pathways that mediate a remarkably broad range of cellular and metacellular (organismal) functions. Both proteolytic and nonproteolytic roles of the ubiquitin system will be addressed. Other proteolytic pathways, such as the autophagy, the blood clotting cascade, and the complement system will also be reviewed. Instructor: Varshavsky.

Bi 211. Topics in Membrane and Synaptic Physiology. *6 units (3-0-3); first term.* Graduate seminar discussing the original literature on the biophysics and molecular biology of ion channels, neurotransmitter receptors, transporters, and other molecules underlying the excitability of cell membranes. Instructor: Lester. Given in alternate years; not offered 2006–07.

Bi 214. Hematopoiesis: A Developmental System. *6 units (2-0-4); third term. Prerequisite: Bi 114, or Bi 182, or Bi 117 plus Bi/Ch 111, or graduate standing.* An advanced course with lectures and seminar presentations, based on reading from the current literature. The characteristics of blood cells offer unique insights into the molecular basis of lineage commitment and the mechanisms that control the production of diverse cell types from pluripotent precursors. The course will cover the nature of stem cells, the lineage relationships among differentiated cell types, the role of cytokines and cytokine receptors, apoptosis and lineage-specific proliferation, and how differentiation works at the level of gene regulation and regulatory networks. Roles of prominent regulatory molecules in hematopoietic development will be compared with their roles in other developmental systems. Emphasis will be on explanation of cellular and system-level phenomena in terms of molecular mechanisms. Instructor: Rothenberg. Given in alternate years; not offered 2006–07.

Bi 215. Stem Cell Biology and Medicine. *9 units (4-0-5); second term. Prerequisite: cell and molecular biology courses or instructor's permission.* Topics include early embryonic development in various organisms, culture of embryonic stem cells (SCs) as well as adult SCs from various tissues, the therapeutic uses of SCs and current clinical trials, tissue engineering, gene therapy for SC modification, imaging techniques, and SCs in cancer and aging. Instructor: Patterson.

Bi/CNS 216. Behavior of Mammals. *6 units (2-0-4); first term.* A course of lectures, readings, and discussions focused on the genetic, physiological, and ecological bases of behavior in mammals. A basic knowledge of neuroanatomy and neurophysiology is desirable. Instructor: Allman. Given in alternate years; not offered 2006–07.

Bi/CNS 217. Central Mechanisms in Perception. *6 units (2-0-4); first term.* Reading and discussions of behavioral and electrophysiological studies of the systems for the processing of sensory information in the brain. Instructor: Allman. Given in alternate years; offered 2006–07.

Bi 218. Molecular Neurobiology Graduate Seminar. *6 units (2-0-4); second term.* Topics to be announced. Instructor: Anderson. Given in alternate years; offered 2006–07.

CNS/Bi 221. Computational Neuroscience. *9 units (4-0-5).* For course description, see Computation and Neural Systems.

Bi 225. Topics in Cellular and Molecular Genetics. *6 units (2-0-4); second term.* Reading and discussion of current papers on the theory and practice of "genetic intervention" in higher eukaryotic cells. Approaches will include DNA and chromosome-mediated transformation of cells in culture, gene amplification, cell fusion, gene injection into eggs, and use of somatic cell genetics techniques for gene cloning. Emphasis on the use of these approaches to study problems in areas such as cell differentiation, cell cycle control, cell compartmentation, and membrane physiology and assembly. Instructor: Attardi. Given in alternate years; not offered 2006–07.

Bi 227. Methods in Modern Microscopy. *12 units (2-6-4); first term. Prerequisite: instructor's permission.* Discussion and laboratory-based course covering the practical use of the confocal microscope, with special attention to the dynamic analysis of living cells and embryos. Course will begin with basic optics, microscope design, Koehler illumination, and the principles of confocal microscopy. After introductory period, the course will consist of semi-independent weeklong modules organized around different imaging challenges. Early modules will focus on three-dimensional reconstruction of fixed cells and tissues, with particular attention being paid to accurately imaging very dim samples. Later modules will include time-lapse confocal analysis of living cells and embryos, including *Drosophila*, zebra fish, chicken, and *s* embryos. Dynamic analysis will emphasize the use of fluorescent proteins. No prior experience with confocal microscopy will be assumed; however, a basic working knowledge of microscopes is highly recommended. Preference is given to graduate students who will be using confocal microscopy in their research. Instructor: Fraser.

Ch/Bi 231. Advanced Topics in Biochemistry. *6 units (2-0-4).* For course description, see Chemistry.

Ge/Bi 244. Paleobiology Seminar. *5 units.* For course description, see Geological and Planetary Sciences.

Ge/Bi 246. Molecular Geobiology Seminar. *6 units (2-0-4).* For course description, see Geological and Planetary Sciences.

CNS/Bi 247. Cerebral Cortex. *6 units (2-0-4).* For course description, see Computation and Neural Systems.

Bi 250 a. Topics in Molecular and Cellular Biology. *9 units (3-0-6); first term. Prerequisite: graduate standing.* Lectures and discussion covering research methods, logic, techniques and strategies, fundamental and general principles of modern biology, and unsolved problems. Students will learn to critique papers on molecular biology, cell biology, and genetics. Instructors: Deshaies, staff.

Bi/CNS 250 b. Topics in Systems Neuroscience. *9 units (3-0-6); second term. Prerequisite: graduate standing.* The class focuses on quantitative studies of problems in systems neuroscience. Students will study classical work such as Hodgkin and Huxley's landmark papers on the ionic basis of the action potential, and will move from the study of interacting currents within neurons to the study of systems of interacting neurons. Topics will include lateral inhibition, mechanisms of motion tuning, local learning rules and their consequences for network structure and dynamics, oscillatory dynamics and synchronization across brain circuits, and formation and computational properties of topographic neural maps. The course will combine lectures and discussions, in which students and faculty will examine papers on systems neuroscience, usually combining experimental and theoretical/modeling components. Instructors: Laurent, Siapas.

Bi 250 c. Topics in Systems Biology. *9 units (3-0-6); third term. Prerequisite: graduate standing.* The class will focus on quantitative studies of cellular and developmental systems in biology. It will examine the architecture of specific genetic circuits controlling microbial behaviors and multicellular development in model organisms. The course will approach most topics from both experimental and theoretical/computational perspectives. Specific topics include chemotaxis, multistability and differentiation, biological oscillations, stochastic effects in circuit operation, as well as higher-level circuit properties such as robustness. The course will also consider the organization of transcriptional and protein-protein interaction networks at the genomic scale. Instructors: Elowitz, Sternberg.

Bi/BMB 251 abc. Current Research in Cellular and Molecular Biology. *1 unit (1-0-0). Prerequisite: graduate standing.* Presentations and discussion of research at Caltech in biology and chemistry. Discussions of responsible conduct of research are included. Instructors: Sternberg, Deshaies, Hay.

Bi 252. Responsible Conduct of Research. *4 units (2-0-2); third term.* This lecture and discussion course covers relevant aspects of the responsible conduct of biomedical and biological research. Topics include guidelines and regulations, ethical and moral issues, research misconduct, data management and analysis, research with animal or human subjects, publication, conflicts of interest, mentoring, and professional advancement. This course is required of all trainees supported on the NIH training grants in cellular and molecular biology and neuroscience, and is recommended for other graduate students in biology division labs. Undergraduate students require advance instructor's permission. Graded pass/fail. Instructors: Meyerowitz, Sternberg, staff.

SS/Psy/Bi/CNS 255. Topics in Emotion and Social Cognition. *9 units (3-0-6).* For course description, see Social Science.

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

CNS/Bi 286 abc. Special Topics in Computation and Neural Systems. *Units to be arranged.* For course description, see Computation and Neural Systems.

Bi 299. Graduate Research. *Units to be arranged; first, second, third terms.* Students may register for research units after consultation with their adviser.

BUSINESS ECONOMICS AND MANAGEMENT

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BEM/Ec/SS 20. Scientific Writing and Oral Presentation in the Social Sciences. *6 units (2-0-4); second term.* This class provides the opportunity for students to improve their written and oral presentation skills in the social sciences. Students should come prepared with complete drafts of papers from another course or a SURF project, which they will substantially revise and improve in a style typical of peer-reviewed journals in their discipline. These papers must be the students' original work and must be papers with social science content. An initial introduction to the art of scientific writing will be provided by the staff of the Hixon Writing Center. In addition, each student will work closely with an HSS mentor whose own research sis close to the student's paper topic. *Fulfills the Institute scientific writing requirement and the option oral presentation requirement for HSS majors.* Instructor: Yariv.

BEM 101. Introduction to Accounting. *9 units (3-0-6); first term.* An introduction to accounting in business. Topics include financial accounting, cost accounting. Instructor: Wang.

BEM 103. Introduction to Finance. *9 units (3-0-6); first term. Ec 11 recommended.* An introduction to corporate finance. Economic theory is used to study asset valuation and financial decision making in business. Topics include financial decision making under certainty, introduction to valuation of risky assets (stocks and bonds), the corporate investment decision, dividend policy, and the corporate financing decision. Instructor: Schwartz.

BEM 105. Options. *9 units (3-0-6). Prerequisites: BEM 103, some familiarity with statistics. Ec 11 recommended.* An introduction to modern option pricing theory. The focus is the valuation of contingent claims. Both American and European options are considered. The binomial and Black-Scholes option pricing models are derived. The theory is also applied to risky debt and portfolio choice. Instructor: Cvitanic.

BEM 106. Competitive Strategy. *9 units (3-0-6); third term. Prerequisite: Ec 11.* This course develops concepts appropriate for formulating strategy in a competitive environment, using a combination of case analysis and lectures. The course covers differentiation strategies, positioning to neutralize incumbency advantages, the product life cycle, organizational design as competitive strategy, signaling, cooperation strategies, pricing and price discrimination as competitive strategy, strategic use of option theory, and the war of attrition. Instructor: McAfee.

BEM 107. Advanced Corporate Finance: Governance, Transacting, and Valuation. *9 units (3-0-6); third term. Prerequisite: BEM 103.* This course builds on the concepts introduced in BEM 103 and applies them to current issues related to the financial management, regulation, and governance of both ongoing corporations and new start-up companies. The fundamental theme is valuation. The course discusses how valuation is affected by, among others, the role of directors, regulation of mergers and acquisitions, and management incentives. Instructor: Cornell.

BEM 109. Fixed-Income and Credit-Risk Derivatives. *9 units (3-0-6); third term. Prerequisite: BEM 105.* An introduction to the models of interest rates and credit/default risk. The focus is on continuous time models used in Wall Street practice for pricing and hedging fixed income securities. Two main models for credit risk are considered: structural and reduced form. Instructor: Cvitanic.

BEM 110. Venture Capital. *9 units (3-0-6); first term. Prerequisites: BEM 101, 103.* An introduction to the theory and practice of venture capital and start-ups. This course covers the underlying economic principles and theoretical models relevant to the venture investment process, as well as the standard practices used by industry. Special attention is paid to the organization, funding, management, and growth of start-up companies. Instructor: Schwartz.

BEM 116. Advanced Business Strategy for Technology. *9 units (3-0-6); third term. Prerequisite: BEM 106.* This course develops tools to determine strategy for firms facing rapid technological change, great uncertainty, low marginal costs and high fixed costs of production, and short product life cycles. The focus is on firms with high levels of human capital (so-called high-tech firms). Special attention is paid to the product life cycle, patent strategy, pricing, and hiring and retention of talented individuals. Working in teams, students will be asked to formulate strategy in real business situations. Instructor: McAfee.

BEM/Ec 146. Organization Design. *9 units (3-0-6). Prerequisite: Ec 11.* An introduction to the analysis, design, and management of organizations with an emphasis on incentives and information. Principles from economics, political science, and game theory will be applied to problems in project and team management, in organizational computing, and in allocating and pricing shared facilities. Instructor: Camerer.

BEM 190. Undergraduate Research Project. *Units to be arranged; any term. Prerequisites: BEM 103, 106, and instructor's permission.* This course offers advanced undergraduates the opportunity to pursue research on a business problem individually or in small groups. Graded pass/fail.

CHEMICAL ENGINEERING

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ChE 10. Introduction to Chemical Engineering. *3 units (2-0-1); second term; open to freshmen only.* A series of weekly seminars given by chemical engineering faculty or an outside speaker, on a topic of current research. Topics will be presented at an informal, introductory level. Graded pass/fail.

ChE 63 ab. Chemical Engineering Thermodynamics. *9 units (3-0-6); first, second terms.* A comprehensive treatment of classical thermodynamics with engineering and chemical applications and an introduction to statistical thermodynamics. First and second laws. Applications to closed and open systems. Equations of state. Thermochemical calculations. Properties of real fluids. Power generation and refrigeration cycles. Multicomponent systems, excess properties, fugacities, activity coefficients, and models of nonideal solutions. Chemical potential. Phase and chemical reaction equilibria. Introductory statistical thermodynamics. Instructors: Flagan, Asthagiri.

ChE 64. Principles of Chemical Engineering. *9 units (3-0-6); third term. Prerequisite: ChE 63 ab.* Systems approach to conservation of mass and energy. Equilibrium staged separations. Instructor: Seinfeld.

ChE 80. Undergraduate Research. *Units by arrangement.* Research in chemical engineering offered as an elective in any term other than in the senior year. Graded pass/fail.

ChE 90 ab. Senior Thesis. *9 units (0-4-5); first, second, third terms.* A research project carried out under the direction of a chemical engineering faculty member. A grade will not be assigned to ChE 90 prior to completion of the thesis, which normally takes two terms. A P grade will be given for the first term and then changed to the appropriate letter grade at the end of the course.

Ch/ChE 91. Scientific Writing. *3 units (1-0-2).* For course description, see Chemistry.

ChE 101. Chemical Reaction Engineering. *9 units (3-0-6); second term. Prerequisites: ChE 63 ab and ChE 64.* Elements of chemical kinetics and chemically reacting systems. Homogeneous and heterogeneous catalysis. Chemical reactor analysis. Instructor: Arnold.

ChE 103 abc. Transport Phenomena. *9 units (3-0-6); first, second, third terms. Prerequisite: ACM 95/100 abc or concurrent registration*. A rigorous development of the basic differential equations of conservation of momentum, energy, and mass in fluid systems. Solution of problems involving fluid flow, heat transfer, and mass transfer. Instructors: Kornfield, Davis.

ChE 105. Dynamics and Control of Chemical Systems. *9 units (3-0-6); third term. Prerequisites: ChE 101 or equivalent, ACM 95 abc or concurrent registration.* Analysis and design of dynamic chemical systems, spanning biomolecular networks to chemical processing. Topics include control strategies for regulating dynamic performance, formulation of mechanistic and empirical models, linear analysis of feedback systems, introduction to multivariate control. Instructor: Asthagiri.

ChE 110 ab. Optimal Design of Chemical Systems. *9 units (3-0-6); second, third terms. Prerequisites: ChE 63, ChE 101, ChE 103, or equivalents.* Introduction to process design; flow sheets for chemical processes; synthesis of multicomponent separation sequences and reaction paths; synthesis of heat exchange networks; optimization; process economics; simulation of chemical processes; design of a major process. Not offered 2006–07.

ChE 126 ab. Chemical Engineering Laboratory. *9 units (1-6-2); second, third terms. Prerequisites: ChE 63, ChE 101, ChE 103, or equivalents.* Projects illustrative of problems in transport phenomena, unit operations, surface and gas-phase chemical reactions/kinetics, process monitoring and control, and reactor design are performed. Microreactor concepts and applications in gas conversion. Short-term, open-ended research projects emphasizing hands-on experience, oral presentations, and journal-style written reports of scientific results. Instructors: Arnold, Giapis, Vicic.

ChE 130. Biomolecular Engineering Laboratory. *9 units (1-5-3); third term. Prerequisites: ChE 63 ab, ChE 101 (concurrently) or instructor's permission.* Design, construction, and characterization of engineered biological systems that will be implemented in bacteria, yeast, and cell-free systems. Research problems will fall into the general areas of biomolecular engineering and synthetic biology. Emphasis will be on projects that apply rational and evolutionary design strategies toward engineering biological systems that exhibit dynamic, logical, or programmed behaviors. Instructors: Smolke, Vicic.

Ch/ChE 140 ab. Principles and Applications of Semiconductor Photoelectrochemistry. *6 units (4-0-2).* For course description, see Chemistry.

Ch/ChE 147. Polymer Chemistry. *9 units (3-0-6).* For course description, see Chemistry.

ChE/Ch 148. Polymer Physics. *9 units (3-0-6); third term. Prerequisite: Ch/ChE 147 or instructor's permission.* An introduction to the physics that govern polymer structure and dynamics in liquid and solid states, and to the physical basis of characterization methods used in polymer science. The course emphasizes the scaling aspects of the various physical properties. Topics include conformation of a single polymer chain under different solvent conditions; dilute and semi-dilute solutions; thermodynamics of polymer blends and block copolymers; rubber elasticity; polymer gels; linear viscoelasticity of polymer solutions and melts; glass transition and crystallization. Instructor: Wang.

ChE 151 ab. Physical and Chemical Rate Processes. *12 units (3-0-9); first, second terms.* The foundations of heat, mass, and momentum transfer for single and multiphase fluids will be developed. Governing differential equations; laminar flow of incompressible fluids at low and high Reynolds numbers; forced and free convective heat and mass transfer, diffusion, and dispersion. Emphasis will be placed on physical understanding, scaling, and formulation and solution of boundary-value problems. Applied mathematical techniques will be developed and used throughout the course. Instructor: Brady.

ChE 152. Heterogeneous Kinetics and Reaction Engineering. *9 units (3-0-6); first term. Prerequisite: ChE 101 or equivalent.* Survey of heterogeneous reactions and reaction mechanisms on metal and oxide catalysts. Characterization of porous catalysts. Reaction, diffusion, and heat transfer in heterogeneous catalytic systems. Instructor: Giapis.

ChE/Ch 155. Chemistry of Catalysis. *9 units (3-0-6); third term.* Discussion of homogeneous and heterogeneous catalytic reactions, with emphasis on mechanistic principles and on the relationships between the two areas. Topics include homogeneous hydrogenation; catalysis by metals; homogeneous oxidation; catalysis by metal oxides; acid-base catalysis and zeolites. Instructors: Davis, Labinger.

ChE/ESE 158. Aerosol Physics and Chemistry. *9 units (3-0-6); second term. Open to graduate students and seniors with instructor's permission.* Fundamentals of aerosol physics and chemistry; aerodynamics and diffusion of aerosol particles; condensation and evaporation; thermodynamics of particulate systems; nucleation; coagulation; particle size distributions; optics of small particles. Instructor: Seinfeld.

ChE/BE 163. Introduction to Engineering Biological Molecules and Systems. *9 units (3-0-6); third term. Prerequisites: Bi/Ch 110 and ChE 101, or instructor's permission.* Current research problems in biomolecular engineering will serve to introduce principles and methods of molecular evolution, protein design, metabolic engineering, and design of genetic regulatory networks. Instructor: Arnold.

ChE/Ch 164. Introduction to Statistical Thermodynamics. *9 units (3-0-6); second term. Prerequisite: Ch 21 abc or equivalent.* An introduction to the fundamentals and simple applications of statistical thermodynamics. Foundation of statistical mechanics; partition functions for various ensembles and their connection to thermodynamics; fluctuations; noninteracting quantum and classical gases; heat capacity of solids; adsorption; phase transitions and order parameters; linear response theory; structure of classical fluids; computer simulation methods. Instructor: Wang.

ChE/Ch 165. Chemical Thermodynamics. *9 units (3-0-6); first term. Prerequisite: ChE 63 ab or equivalent.* An advanced course emphasizing the conceptual structure of modern thermodynamics and its applications. Review of the laws of thermodynamics; thermodynamic potentials and Legendre transform; equilibrium and stability conditions; metastability and phase separation kinetics; thermodynamics of single-component fluid and binary mixtures; models for solutions; phase and chemical equilibria; surface and interface thermodynamics; electrolytes and polymeric liquids. Instructor: Smolke.

ChE/BE 169. Biomolecular Cell Engineering. *9 units (3-0-6); first term.* Quantitative analysis of molecular mechanisms governing mammalian cell behavior. Topics include topology and dynamics of signaling and genetic regulatory networks, receptor-ligand trafficking, and biophysical models for cell adhesion and migration. Instructor: Asthagiri. Given in alternate years; not offered 2006–07.

ChE 174. Special Topics in Transport Phenomena. *9 units (3-0-6); third term. Prerequisites: ACM 95/100, ChE 151 ab. May be repeated for credit.* Advanced problems in heat, mass, and momentum transfer. Introduction to mechanics of complex fluids; physicochemical hydrodynamics; microstructured fluids; colloidal dispersions; microfluidics; selected topics in hydrodynamic stability theory; transport phenomena in materials processing. Other topics may be discussed depending on class needs and interests. Not offered 2006–07.

ChE 189. Special Topics in Materials Processing. *9 units (3-0-6); third term. Prerequisites: ChE 63, ChE 103, or equivalent.* Fundamental physics and chemistry of partially ionized, chemically reactive, low-pressure plasmas and their roles in electronic materials processing. Basic plasma equations and equilibrium. Plasma and sheath dynamics. Gas-surface interactions. Plasma diagnostics and monitoring. Plasma-assisted etching and deposition in integrated circuit fabrication. Visiting faculty or scientists may present portions of this course. Instructor: Giapis. Given in alternate years; not offered 2006–07.

ChE 280. Chemical Engineering Research. *Offered to Ph.D. candidates in chemical engineering.* Main lines of research now in progress are covered in detail in section two.

CHEMISTRY

Ch 1 ab. General Chemistry. *6 units (3-0-3) first term; 9 units (4-0-5) second term.* Lectures and recitations dealing with the principles of chemistry. First term: electronic structure of atoms, periodic properties, ionic substances, covalent bonding, Lewis representations of molecules and ions, shapes of molecules, Lewis acids and bases, Bronsted acids and bases, hybridization and resonance, bonding in solids. Second term: chemical equilibria, oxidation and reduction, thermodynamics, kinetics, introduction to organic chemistry and the chemistry of life. Graded pass/fail. Instructors: Lewis, Heath. Additional information concerning this course can be found at http://www.its.caltech.edu/~chem1.

Ch/APh 2. Introduction to Energy Sciences. *9 units (4-0-5); third term. Prerequisites: Ch 1 ab, Ph 1 ab, Ma 1 ab.* Energy production and transduction in biological, chemical, and nuclear reactions. Bioenergetics: energy sources and storage; components of biological energy flows: pumps, motors, and solar cells; circuitry of biological energy flows and biological energy transduction pathways. Chemistry of energy production and utilization: fossil fuel utilization and energy conversion pathways; artificial photosynthesis, solar cells, and solar energy conversion. Principles of nuclear energy production: nuclear energy decay processes, fission and fusion reactions, and reactor principles. Not offered on a pass/fail basis. Instructors: Lewis, Bellan, D. Newman. *Satisfies the menu requirement of the Caltech core curriculum.* Not offered 2006–07.

Ch 3 a. Fundamental Techniques of Experimental Chemistry. *6 units (0-5-1); first, second, third terms.* Introduces the basic principles and techniques of synthesis and analysis and develops the laboratory skills and precision that are fundamental to experimental chemistry. Freshmen who have gained advanced placement into Ch 41 or Ch 21, or who are enrolled in Ch 10, are encouraged to take Ch 3 a in the fall term.Graded pass/fail. Instructor: Staff.

Ch 3 b. Experimental Procedures of Synthetic Chemistry. *8 units (1-6-1); third term. Prerequisites: Ch 1 a, Ch 1 b, and Ch 3 a.* Instruction in fundamental synthesis, separation, and characterization procedures used in chemical research. Instructor: Staff.

Ch 4 ab. Synthesis and Analysis of Organic and Inorganic Compounds. *9 units (1-6-2). Prerequisites: Ch 1 (or the equivalent) and Ch 3 a.* Previous or concurrent enrollment in Ch 41 is strongly recommended. Introduction to methods of synthesis, separation, purification, and characterization used routinely in chemical research laboratories. Ch 4 a emphasizes spectroscopic methods of analysis; Ch 4 b stresses applications of chromatography in addition to more classical separation techniques. Ch 4 a, first term; Ch 4 b, second term only. Instructor: Staff.

Ch 5 ab. Advanced Techniques of Synthesis and Analysis. *Ch 5 a 12 units (1-9-2); Ch 5 b 9 units (1-6-2); third, second terms, respectively. Prerequisite: Ch 4 ab. Ch 102 strongly recommended for Ch 5 b.* Modern synthetic chemistry. Specific experiments may change from year to year. Experiments illustrating the multistep syntheses of natural products (Ch 5 a), coordination complexes, and organometallic complexes (Ch 5 b) will be included. Methodology will include advanced techniques of synthesis and instrumental characterization. Terms may be taken independently. Instructor: Dougherty. Part b not offered 2006–07.

Ch 6 ab. Application of Physical Methods to Chemical Problems. *10 units (0-6-4); second, third terms. Prerequisites: Ch 1, Ch 4 ab, and Ch 21 or equivalents (may be taken concurrently).* Introduction to the application of modern physical methods to chemical problems, with emphasis in the area of molecular spectroscopy. Techniques including X-ray crystallography, laser Raman spectroscopy, microwave spectroscopy, electron spin resonance, ultraviolet photoelectron spectroscopy, and Fourier transform ion cyclotron resonance spectroscopy are used to examine the structure, properties, and reaction dynamics of molecules in the gas phase, in solution, and at surfaces. Instructors: Okumura, Beauchamp, Collier.

Ch 7. Advanced Experimental Methods in Bioorganic Chemistry. *9 units (1-6-2); third term. Prerequisites: Ch 41 abc, and Bi/Ch 110, Ch 4 ab. Enrollment by instructor's permission. Preference will be given to students who have taken Ch 5 a or Bi 10.* This advanced laboratory course will provide experience in the powerful contemporary methods for polypeptide and oligonucleotide synthesis. Experiments will address nucleic acid and amino acid protecting group strategies, biopolymer assembly and isolation, and product characterization. A strong emphasis will be placed on understanding the chemical basis underlying the successful utilization of these procedures. In addition, experiments to demonstrate the application of commercially available enzymes for useful synthetic organic transformations will be illustrated. Instructor: Hsieh-Wilson.

Ch 10 abc. Frontiers in Chemistry. *3 units (2-0-1); first, second terms. 8 units (1-6-1); third term. Open for credit to freshmen and sophomores. Prerequisites: Ch 10 c prerequisites are Ch 10 ab, Ch 3 a, and either Ch 1 ab, Ch 41 ab, or Ch 21 ab, and instructor's permission.* Ch 10 ab is a weekly seminar by a member of the chemistry department on a topic of current research; the topic will be presented at an informal, introductory level. The other weekly session will acquaint students with the laboratory techniques and instrumentation used on the research topics. Ch 10 c is a research-oriented laboratory course, which will be supervised by a chemistry faculty member. Weekly class meetings will provide a forum for participants to discuss their research projects. Graded pass/fail. Instructors: Barton, Dervan.

Ch 14. Chemical Equilibrium and Analysis. *6 units (2-0-4); third term.* A systematic treatment of ionic equilibria in solution. Topics covered include acid-base equilibria in aqueous and nonaqueous solutions, complex ion formation, chelation, oxidation-reduction reactions, and some aspects of reaction mechanisms. Instructors: Rees, Richards.

Ch 15. Chemical Equilibrium and Analysis Laboratory. *10 units (0-6-4); first term. Prerequisites: Ch 1 ab, Ch 3 a, Ch 14, or instructor's permission.* Laboratory experiments are used to illustrate modern instrumental techniques that are currently employed in industrial and academic research. Emphasis is on determinations of chemical composition, measurement of equilibrium constants, evaluation of rates of chemical reactions, and trace-metal analysis. Instructor: Staff.

Ch 21 abc. The Physical Description of Chemical Systems. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 ab, Ph 2 ab, Ma 2 ab.* Atomic and molecular quantum mechanics, spectroscopy, thermodynamics, statistical mechanics, and chemical kinetics. Instructors: McKoy, Blake, Okumura.

Ch 24 ab. Introduction to Biophysical Chemistry. *9 units (3-0-6); second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc, Ch 21 a or Ph 2 ab.* Fundamental physical chemistry, with emphasis on those topics most important in biology. Thermodynamics and its applications to aqueous solutions and living systems, membrane potentials and the thermodynamics of transport, reaction kinetics and mechanisms, transport properties, applications of molecular spectroscopy in biology, and statistical mechanics with applications to biological polymers. Instructors: Rees, S. Chan.

Ch 41 abc. Organic Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 1 ab or instructor's permission.* The synthesis, structures, and mechanisms of reactions of organic compounds. Instructors: Grubbs, Dervan, Stoltz.

Ch 80. Chemical Research. *Offered to B.S. candidates in chemistry. Units in accordance with work accomplished. Prerequisite: consent of research supervisor.* Experimental and theoretical research requiring a report containing an appropriate description of the research work.

Ch 81. Independent Reading in Chemistry. *Units by arrangement. Prerequisite: instructor's permission.* Occasional advanced work involving reading assignments and a report on special topics. No more than 12 units in Ch 81 may be used as electives in the chemistry option.

Ch 90. Oral Presentation. *3 units (2-0-1); second term.* Training in the techniques of oral presentation of chemical and biochemical topics. Practice in the effective organization and delivery of technical reports before groups. Graded pass/fail. Instructors: Zewail, Bikle.

Ch/ChE 91. Scientific Writing. *3 units (1-0-2); third term.* Training in the writing of scientific research papers. Each student must complete a 3,000-word paper styled after an article in the *Journal of the American Chemical Society* on a subject of chemical or biochemical relevance. The manuscript may be based on a paper submitted by the student for a previous class or on a SURF report, but it must be the student's original writing and be within the intellectual scope of the chemistry and chemical engineering division. Each student will work individually with a faculty member under the supervision of the course instructor. *Fulfills the Institute scientific writing requirement.* Instructor: Weitekamp.

Ch 102. Introduction to Inorganic Chemistry. *9 units (3-0-6); third term. Prerequisite: Ch 41 ab.* Structure and bonding of inorganic species with special emphasis on spectroscopy, ligand substitution processes, oxidation-reduction reactions, and biological inorganic chemistry. Letter grades only. Instructor: Peters.

Bi/Ch 110. Introduction to Biochemistry. *12 units (4-0-8).* For course description, see Biology.

Bi/Ch 111. Biochemistry of Gene Expression. *12 units (4-0-8).* For course description, see Biology.

Ch 112. Inorganic Chemistry. *9 units (3-0-6); first term. Prerequisite: Ch 102 or instructor's permission.* Introduction to group theory, ligand field theory, and bonding in coordination complexes and organotransition metal compounds. Systematics of synthesis, bonding, and reactivities of commonly encountered classes of transition metal compounds. Instructor: Bercaw.

Bi/Ch 113. Biochemistry of the Cell. *12 units (4-0-8).* For course description, see Biology.

Ch 117. Introduction to Electrochemistry. *6 units (2-0-4); second term.* Discussion of the structure of electrode-electrolyte interface, the mechanism by which charge is transferred across it, and experimental techniques used to study electrode reactions. Topics change from year to year but usually include diffusion currents, polarography, coulometry, irreversible electrode reactions, the electrical double layer, and kinetics of electrode processes. Not offered 2006–07.

Ch 120 abc. Nature of the Chemical Bond. *9 units (3-0-6) first term; 6 units (2-0-4) second term; 9 units (1-1-7) third term. Prerequisite: general exposure to quantum mechanics (e.g., Ph 2 ab, Ph 12 abc, or equivalent).* Modern ideas of chemical bonding, with an emphasis on qualitative concepts and how they are used to make predictions of structures, energetics, excited states, and properties. Part a: The quantum mechanical basis for understanding bonding, structures, energetics, and properties of materials (polymers, ceramics, metals alloys, semiconductors, and surfaces). The emphasis is on explaining chemical, mechanical, electrical, and thermal properties of materials in terms of atomistic concepts. Part b: The quantum mechanical basis for understanding transition metal systems with a focus on chemical reactivity. There will be an emphasis on organometallic complexes, on homogeneous catalysis, and on heterogeneous catalysis. Part c: The student does an individual research project using modern quantum chemistry computer programs to calculate wavefunctions, structures, and properties of real molecules. Not offered 2006–07.

Ch 121 ab. Atomic Level Simulations of Materials and Molecules. *9 units (1-1-7) second, third terms. Prerequisites: Ma 2 ab, Ph 2 ab, Ch 1 ab, or equivalent. Recommended: Ch 41 abc, Ch 21 a.* Methods for predicting the structures and properties of molecules and solids. The course will highlight theoretical foundations and applications to current problems in the following areas: biological systems (proteins, DNA, carbohydrates, lipids); polymers (crystals, amorphous systems, copolymers); semiconductors (group IV, III-V, surfaces, defects); inorganic systems (ceramics, zeolites, superconductors, and metals); and organometallics and catalysis (heterogeneous and homogeneous). Both terms will involve the use of computers for building and calculating systems of interest. Part a covers the basic methods. Part b will focus on simulations applied to problems in petroleum chemistry. Ch 120 a is recommended but not required for Ch 121 a. Not offered 2006–07.

Ch 122 abc. Methods for the Determination of the Structure of Molecules. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or instructor's permission.* Modern methods used in the determination of the structure of molecules. All three terms can be taken independently. Ch 122 a (small molecule X-ray crystallography) will be offered first term. Parts b and c not offered 2006–07. Instructor: Day.

Ch 125 abc. The Elements of Quantum Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or an equivalent brief introduction to quantum mechanics.* A first course in molecular quantum mechanics consisting of a quantitative treatment of quantum mechanics with applications to systems of interest to chemists. The basic elements of quantum mechanics, the electronic structure of atoms and molecules, the interactions of radiation fields and matter, scattering theory, and reaction rate theory. Instructors: Kuppermann, McKoy, Weitekamp.

Ch 126. Molecular Spectra and Molecular Structure. *9 units (3-0-6); third term. Prerequisite: Ch 21 and Ch 125 a taken concurrently, or instructor's permission.* Quantum mechanical foundations of the spectroscopy of molecules. Topics include quantum theory of angular momentum, rovibrational Hamiltonian for polyatomic molecules, molecular symmetry and permutation-inversion groups, electronic spectroscopy, interaction of radiation and matter. Instructor: Collier.

Ge/Ch 127. Nuclear Chemistry. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ge/Ch 128. Cosmochemistry. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ch 130. Spectroscopy. *9 units (3-0-6); third term.* Discussion of various topics in lasers and their applications. Group theory with applications to molecular structure and spectroscopy will also be discussed. Not offered 2006–07.

Bi/Ch 132. Biophysics of Macromolecules. *9 units (3-0-6).* For course description, see Biology.

Ch 135 ab. Chemical Dynamics. *9 units (3-0-6); part a, third term; part b, second term. Prerequisites: Ch 21 abc and Ch 41 abc, or equivalent, or instructor's permission.* Part a: introduction to the dynamics of chemical reactions. Topics include scattering cross sections, rate constants, intermolecular potentials, reactive scattering, nonadiabatic processes, statistical theories of unimolecular reactions, and the application of laser and molecular beam techniques to the study of reaction mechanisms. Part b: the quantum description of chemical reactions. The scattering matrix. The calculation of reaction cross sections, probabilities, and rate constants. Collision lifetimes and resonances. Classical trajectories. The two terms can be taken independently. Instructors: Okumura, Marcus, Kuppermann.

Ch/ChE 140 ab. Principles and Applications of Semiconductor Photoelectrochemistry. *6 units (4-0-2); second, third terms. Prerequisite: APh/EE 9 or instructor's permission.* The properties and photoelectrochemistry of semiconductors and semiconductor/liquid junction solar cells will be discussed. Topics include optical and electronic properties of semiconductors; electronic properties of semiconductor junctions with metals, liquids, and other semiconductors, in the dark and under illumination, with emphasis on semiconductor/liquid junctions in aqueous and nonaqueous media. Problems currently facing semiconductor/liquid junctions and practical applications of these systems will be highlighted. The course will meet for four one-hour lectures per week and will be in a tutorial format with instruction predominantly from graduate students and postdoctoral fellows with expertise in the field. Instructor: Lewis. Given in alternate years; not offered 2006–07.

Ch 142. Frontiers in Chemical Biology. *4 units (2-0-2); second term. Prerequisite: Bi/Ch 110 or instructor's permission.* A discussion of enzyme structure and function, and ligand-protein-nucleic acid interactions. Not offered 2006–07.

Ch 143. Basic FT NMR Spectroscopy. *9 units (3-2-4); second term. Prerequisite: Ch 41 abc.* The course will cover NMR basics and applications, with emphasis on FT NMR and the principles of multipulse NMR techniques used in structural analysis, including determination of relaxation times, INEPT, DEPT, NOSEY, and COSY. A number of NMR techniques will be illustrated with the Chapman-Russell *FT NMR Problems* videodisc-based computer program, which features on-screen spectra at a variety of magnetic fields with, and without, decoupling, 2-D spectra, and so on. The practical use of NMR will be further demonstrated by laboratory exercises using modern pulse FT NMR techniques with high-field spectrometers for structural analysis. Instructor: J. D. Roberts.

Ch 144 ab. Advanced Organic Chemistry. *9 units (3-0-6); first term. Prerequisite: Ch 41 abc; Ch 21 abc recommended.* An advanced survey of selected topics in modern physical organic chemistry. Topics vary from year to year and may include structural and theoretical organic chemistry; molecular recognition/supramolecular chemistry; reaction mechanisms and the tools to study them; reactive intermediates; materials chemistry; pericyclic reactions; and photochemistry. In 2006–07, only part a will be offered (first term). Instructor: Dougherty.

Ch 145. Bioorganic Chemistry of Proteins. *9 units (3-0-6); second term. Prerequisite: Ch 41 abc; Bi/Ch 110 recommended.* An advanced survey of current and classic topics in bioorganic chemistry/chemical biology. The content will vary from year to year and may include the structure, function, and synthesis of peptides and proteins; enzyme catalysis and inhibition; carbohydrates and glycobiology; chemical genetics; genomics and proteomics; posttranslational modifications; chemical tools to study cellular dynamics; and enzyme evolution. Instructor: Hsieh-Wilson.

Ch 146. Bioorganic Chemistry of Nucleic Acids. *9 units (3-0-6); third term. Prerequisite: Ch 41 ab.* The course will examine the bioorganic chemistry of nucleic acids, including DNA and RNA structures, molecular recognition, and mechanistic analyses of covalent modification of nucleic acids. Topics include synthetic methods for the construction of DNA and RNA; separation techniques; recognition of duplex DNA by peptide analogs, proteins, and oligonucleotide-directed triple helical formation; RNA structure and RNA as catalysts (ribozymes). Given in alternate years; not offered 2006–07.

Ch/ChE 147. Polymer Chemistry. *9 units (3-0-6); second term. Prerequisite: Ch 41 abc.* An introduction to the chemistry of polymers, including synthetic methods, mechanisms and kinetics of macromolecule formation, and characterization techniques. Not offered 2006–07.

ChE/Ch 148. Polymer Physics. *9 units (3-0-6).* For course description, see Chemical Engineering.

Ch 153. Advanced Inorganic Chemistry. *9 units (2-0-7); second term. Prerequisites: Ch 112 and Ch 21 abc or concurrent registration.* Topics in modern inorganic chemistry. Electronic structure, spectroscopy, and photochemistry with emphasis on examples from the modern research literature. Instructor: Gray.

Ch 154 ab. Organometallic Chemistry. *9 units (3-0-6); second, third terms. Prerequisite: Ch 112 or equivalent.* A general discussion of the reaction mechanisms and the synthetic and catalytic uses of transition metal organometallic compounds. Second term: a survey of the elementary reactions and methods for investigating reaction mechanisms. Third term: contemporary topics in inorganic and organometallic synthesis, structure and bonding, and applications in catalysis. Instructors: Bercaw, Peters.

ChE/Ch 155. Chemistry of Catalysis. *9 units (3-0-6).* For course description, see Chemical Engineering.

Ch 163. Lectures-Seminars in Physical Chemistry. *6 units (2-0-4); third term.* Not offered 2006–07.

ChE/Ch 164. Introduction to Statistical Thermodynamics. *9 units (3-0-6).* For course description, see Chemical Engineering.

ChE/Ch 165. Chemical Thermodynamics. *9 units (3-0-6).* For course description, see Chemical Engineering.

Ch 166. Nonequilibrium Statistical Mechanics. *9 units (3-0-6); third term. Prerequisite: Ch 21 abc or equivalent.* Transport processes in dilute gases; Boltzmann equation; Brownian motion; Langevin and Fokker-Planck equations; linear response theory; time-correlation functions and applications; nonequilibrium thermodynamics. Instructor: Marcus.

BMB/Bi/Ch 170. Principles of Three-Dimensional Protein Structure. *9 units (3-3-3).* For course description, see Biochemistry and Molecular Biophysics.

ESE/Ge/Ch 171. Atmospheric Chemistry I. *9 units (3-0-6).* For course description, see Environmental Science and Engineering.

ESE/Ge/Ch 172. Atmospheric Chemistry II. *3 units (3-0-0).* For course description, see Environmental Science and Engineering.

BMB/Bi/Ch 174. Biophysical Chemistry. *9 units (3-0-6).* For course description, see Biochemistry and Molecular Biophysics.

ESE/Ch/Ge 175 ab. Environmental Organic Chemistry. *9 units (3-0-6).* For course description, see Environmental Science and Engineering.

Ch 180. Chemical Research. *Units by arrangement. Offered to M.S. candidates in chemistry.* Graded pass/fail.

Ch 212. Bioinorganic Chemistry. *9 units (3-0-6); third term. Prerequisites: Ch 112 and Bi/Ch 110 or equivalent.* Current topics in bioinorganic chemistry will be discussed, including metal storage and regulation, metalloenzyme structure and reactions, biological electron transfer, metalloprotein design, and metal-nucleic acid interactions and reactions. Instructor: Barton. Given in alternate years; not offered 2006–07.

Ch 213 abc. Advanced Ligand Field Theory. *12 units (1-0-11); first, second, third terms. Prerequisite: Ch 21 abc or concurrent registration.* A tutorial course of problem solving in the more advanced aspects of ligand field theory. Recommended only for students interested in detailed theoretical work in the inorganic field. Instructors: Gray, staff.

Ch 221. Electron Transfer Reactions in Chemistry and Biology. *6 units; second term. Prerequisite: Ch 21 abc.* Fundamentals of electron transfer reactions. Molecular (statistical) theory, dielectric continua, electronic matrix elements, Franck-Condon principle, relevant thermodynamics, reorganization energy, quantum effects, charge transfer spectra, solvent dynamics. Reactions in solution at metal electrode-liquid, modified electrode-liquid, semiconductor electrode-liquid, and liquid-liquid interfaces. STM theory. Reactions in photosynthetic reaction centers and in other proteins. Not offered 2006–07.

Ch 224. Advanced Topics in Magnetic Resonance. *9 units (2-0-7); third term. Prerequisite: Ch 125 abc or Ph 125 abc or concurrent registration or equivalent; Ch 122 b or equivalent.* A detailed presentation of some of the important concepts in magnetic resonance unified by the spin density operator formalism. Topics will include both classic phenomena and recent development, especially in solid-state and two-dimensional NMR. Instructor: Weitekamp. Not offered 2006–07.

Ch 227 ab. Advanced Topics in Chemical Physics. *9 units (3-0-6); part a second term; part b third term. Prerequisite: Ch 125 abc or Ph 125 abc or equivalent.* The general quantum mechanical theory of molecular collisions will be presented in detail. Quasi-classical, semi-classical, and other approximations. Applications to inelastic and reactive molecule-molecule and inelastic electron-molecule collisions. Part a not offered 2006–07. Instructor: Heath.

Ch 228. Dynamics and Complexity in Physical and Life Sciences. *9 units (3-0-6); third term.* This course is concerned with the dynamics of molecular systems, with particular focus on complexity, the elementary motions that lead to functions in chemical and biological assemblies. It will address principles of dynamics as they relate to the nature of the chemical bond. An overview of modern techniques, such as those involving lasers, NMR, and diffraction, for unraveling dynamics in complex systems. Applications from areas of physics, chemistry, and biology—from coherence and chaos to molecular recognition and self-assembly. Instructor: Zewail.

Ch/Bi 231. Advanced Topics in Biochemistry. *6 units (2-0-4); third term.* Transcriptional Regulation in Eukaryotes. Topics: the subunit structure of eukaryotic RNA polymerases and their role in transcriptional reactions; the composition of eukaryotic promoters, including regulatory units; general and specific transcription factors; developmental regulatory circuits and factors; structural motifs involved in DNA binding and transcriptional initiation and control. Not offered 2006–07.

Ch 242 ab. Chemical Synthesis. *9 units (3-0-6); first, second terms. Prerequisite: Ch 41 abc.* An integrated approach to synthetic problem solving featuring an extensive review of modern synthetic reactions with concurrent development of strategies for synthesis design. Part a will focus on the application of modern methods of stereocontrol in the construction of stereochemically complex acyclic systems. Part b will focus on strategies and reactions for the synthesis of cyclic systems. Instructors: Stoltz, staff.

Ch 244. Topics in Chemical Biology. *9 units; second term.* Current topics at the interface of chemistry and biology. Not offered 2006–07.

Ch 247. Organic Reaction Mechanisms. *6 units (2-0-4); third term.* A mechanistic view of free-radical reactions using examples from biological systems. Topics: initiation, termination, and propagation of radical reactions in vivo, mechanisms of lipid damage, spin labeling, photosynthesis, oxygen radicals and oxygen toxicity, and radical reactions in proteins and nucleic acids. Not offered 2006–07.

Ch 250. Advanced Topics in Chemistry. *Units and term to be arranged.* Content will vary from year to year; topics are chosen according to interests of students and staff. Visiting faculty may present portions of this course. Not offered 2006–07.

Ch 280. Chemical Research. *Hours and units by arrangement.* By arrangement with members of the faculty, properly qualified graduate students are directed in research in chemistry.

CIVIL ENGINEERING

CE 90 abc. Structural Analysis and Design. *9 units (3-0-6); first, second, third terms. Prerequisite: ME 35 abc.* Structural loads; influence lines for statically determinate beams and trusses; deflection of beams; moment area and conjugate beam theorems; approximate methods of analysis of indeterminate structures; slope deflection and moment distribution techniques. Generalized stiffness and flexibility analyses of indeterminate structures. Design of selected structures in timber, steel, and reinforced concrete providing an introduction to working stress, load and resistance factor, and ultimate strength approaches. In each of the second and third terms a design project will be undertaken involving consideration of initial conception, cost-benefit, and optimization aspects of a constructed facility. Not offered 2006–07.

ME/CE 96. Mechanical Engineering Laboratory. *6 or 9 units as arranged with instructor.* For course description, see Mechanical Engineering.

CE 100. Special Topics in Civil Engineering. *Units to be based upon work done, any term.* Special problems or courses arranged to meet the needs of first-year graduate students or qualified undergraduate students. Graded pass/fail.

Ae/APh/CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/CE/ME 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6).* For course description, see Aeronautics.

CE/Ae/AM 108 abc. Computational Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission.* Numerical analysis by the finite element method covering fundamental concepts and computer implementation. Solution of systems of linear equations and eigenvalue problems. Solution of the partial differential equations of heat transfer, solid and structural mechanics, and fluid mechanics. Transient and nonlinear problems. Not offered 2006–07.

CE 115 ab. Soil Mechanics. *9 units (3-0-6); first term. 9 units (2-3-4); second term. Prerequisite: instructor's permission.* Study of the engineering behavior of soil through examination of its chemical, physical, and mechanical properties. Classification and identification of soils, surface chemistry of clays, interparticle reactions, soil structure. Linear constitutive relations for soils, including steady-state and transient water flow. Second term: nonlinear soil behavior, theories of yielding, plasticity, constitutive models, and problems of plastic stability. Failure modes of footings, walls, and slopes. Not offered 2006–07.

CE 150. Foundation Engineering. *9 units (3-0-6); third term. Prerequisite: CE 115 ab.* Methods of subsoil exploration. Study of types and methods of design and construction of foundations for structures, including single and combined footings, mats, piles, caissons, retaining walls, cofferdams, and methods of underpinning. Text: *Foundation Analysis*, Scott. Not offered 2006–07.

CE 160 abc. Structural and Earthquake Engineering. *9 units (3-0-6); first, second, third terms. Prerequisite: CE 90 or equivalent.* Topics forming the foundation for structural analysis and design are covered. Techniques for linear and nonlinear, static and dynamic analysis, including analysis of structure-foundation and structure-fluid systems, the nature of loadings due to wind and earthquake, concepts in design. Special consideration is given to behavior and design of specific structural systems such as buildings, bridges, concrete dams, liquid-storage tanks, tunnels and pipelines, cable structures, and offshore structures. Special emphasis on engineering for earthquakes. Instructor: Staff.

CE 180. Experimental Methods in Earthquake Engineering. *9 units (1-5-3); third term. Prerequisite: AM 151 abc or equivalent.* Laboratory work involving calibration and performance of basic transducers suitable for the measurement of strong earthquake ground motion, and of structural response to such motion. Study of principal methods of dynamic tests of structures, including generation of forces and measurement of structural response. Not offered 2006–07.

CE/Ge 181. Engineering Seismology. *9 units (3-0-6); first term.* Characteristics of potentially destructive earthquakes from the engineering point of view. Determination of location and size of earthquakes; magnitude, intensity, frequency of occurrence; engineering implications of geological phenomena, including earthquake mechanisms, faulting, fault slippage, and effects of local geology on earthquake ground motion. Instructor: Heaton.

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.

Ae/AM/CE/ME 214 abc. Computational Solid Mechanics. *9 units (3-0-6).* For course description, see Aeronautics.

CE 300. Research in Civil Engineering. *Hours and units by arrangement.* Research in the field of civil engineering. By arrangements with members of the staff, properly qualified graduate students are directed in research. For courses in Environmental Science and Engineering, see that section.

COMPUTATION AND NEURAL SYSTEMS

CNS 100. Introduction to Computation and Neural Systems. *1 unit (1-0-0); first term.* This course is designed to introduce undergraduate and first-year CNS graduate students to the wide variety of research being undertaken by CNS faculty. Topics from all the CNS research labs are discussed and span the range from biology to engineering. Graded pass/fail. Instructor: Perona.

CNS/Bi/Psy 120. The Neuronal Basis of Consciousness. *9 units (4-0-5); third term.* What are the correlates of consciousness in the brain? The course provides a framework for beginning to address this question using a reductionist point of view. It focuses on the neurophysiology of the primate visual system, but also discusses alternative approaches more suitable for work with rodents. Topics to be covered include the anatomy and physiology of the primate's visual system (striate and extrastriate cortical areas, dorsal/ventral distinction, visual-frontal connections), iconic and working memory, selective visual attention, visual illusions, clinical studies (neglect, blind sight, split-brain, agnosia), direct stimulation of the brain, delay and trace associative conditioning, conscious and unconscious olfactory processing, and philosophical approaches to consciousness. Instructor: Koch. For more information, see http://klab.caltech.edu/cns120.

Psy/CNS 130. Introduction to Human Memory. *9 units (3-0-6).* For course description, see Psychology.

CNS/Psy/Bi 131. The Psychology of Learning and Motivation. *9 units (3-0-6); second term.* This course will serve as an introduction to basic concepts, findings, and theory from the field of behavioral psychology, covering areas such as principles of classical conditioning, blocking and conditioned inhibition, models of classical conditioning, instrumental conditioning, reinforcement schedules, punishment and avoidance learning. The course will track the development of ideas from the beginnings of behavioral psychology in the early 20th century to contemporary learning theory. Instructor: O'Doherty.

Bi/CNS/Psy 133. Neurobiology and Evolution of Emotion: Do Flies Have Feelings? *9 units (3-0-6).* For course description, see Biology.

SS/Psy/Bi/CNS 140. Social Neuroscience. *9 units (3-0-6).* For course description, see Social Science.

EE/CNS/CS 148 ab. Selected Topics in Computational Vision. *9 units (3-0-6).* For course description, see Electrical Engineering.

Bi/CNS 150. Neurobiology. *10 units (4-0-6).* For course description, see Biology.

CS/CNS/EE 156 ab. Learning Systems. *9 units (3-0-6).* For course description, see Computer Science.

Bi/CNS 157. Comparative Nervous Systems. *9 units (2-3-4).* For course description, see Biology.

Bi/CNS 158. Vertebrate Evolution. *9 units (3-0-6).* For course description, see Biology.

Bi/CNS 162. Cellular and Systems Neuroscience Laboratory. *12 units (2-7-3).* For course description, see Biology.

CS/CNS 171. Introduction to Computer Graphics Laboratory. *12 units (3-6-3).* For course description, see Computer Science.

CNS/Bi 172. Clinical Neuropsychology. *6 units (3-0-3); second term. Prerequisite: Bi 150 or instructor's permission.* Lecture course discussing the relationship between cerebral structures and behavior, in particular with respect to the clinical literature. Cerebral functions are considered in light of acquired behavioral deficits such as aphasia, apraxia, agnosia, callosal syndrome (split-brain), hemineglect, dementia, amnesia, and anosognosia. Not offered 2006–07.

CS/CNS 174. Computer Graphics Projects. *12 units (3-6-3).* For course description, see Computer Science.

CNS/Bi 176. Cognition. *12 units (6-0-6); third term.* The cornerstone of current progress in understanding the mind, the brain, and the relationship between the two is the study of human and animal cognition. This course will provide an in-depth survey and analysis of behavioral observations, theoretical accounts, computational models, patient data, electrophysiological studies, and brain-imaging results on mental capacities such as attention, memory, emotion, object representation, language, and cognitive development. Not offered 2006–07.

CNS/Bi/BE/Ph 178. Evolution and Biocomplexity. *9 units (3-0-6); first term. Prerequisites: Bi 2, preferably Bi 8, or instructor's permission; programming skills.* An introduction to Darwin's theory of evolution from a theoretical, experimental, and computational point of view, with special emphasis on the mechanisms responsible for the evolution of complexity from simplicity. Experiments conducted with digital organisms. Topics covered include the principal ideas of Darwinism, measures of complexity, information content of genomes, the "natural" Maxwell Demon, Eigen's theory of molecular evolution, evolution on neutral networks, "epistasis" and the evolution of recombination, and the evolution of mutation rate. Not offered 2006–07.

CNS 180. Research in Computation and Neural Systems. *Units by arrangement with faculty. Offered to precandidacy students.*

CNS/EE/BE 182. Introduction to Neuromorphic and Bioinspired Mixed-Signal VLSI. *9 units (3-0-6); second term. Prerequisite: EE 20 or equivalent. EE 114, CNS 100, CNS/Bi/Ph/CS 187 recommended.* This course is a technical introduction to the field of neuromorphic and bioinspired mixed-signal VLSI. Topics include transistor physics and nonidealities (e.g., mismatch), basic neuromorphic circuits and their relationship to neural counterparts; architectures for implementations (e.g., silicon retina), and the role of neurally inspired computational architectures in the context of electrical engineering and computer engineering. Instructors: Delbrück, Liu.

CNS/Bi/EE 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4); second term.* Lecture, laboratory, and discussion course aimed at understanding visual information processing, in both machines and the mammalian visual system. The course will emphasize an interdisciplinary approach aimed at understanding vision at several levels: computational theory, algorithms, psychophysics, and hardware (i.e., neuroanatomy and neurophysiology of the mammalian visual system). The course will focus on early vision processes, in particular motion analysis, binocular stereo, brightness, color and texture analysis, visual attention and boundary detection. Students will be required to hand in approximately three homework assignments as well as complete one project (mathematical analysis, computer modeling, or psychophysics). Instructors: Perona, Shimojo, Koch. Given in alternate years; not offered 2006–07.

CNS/Bi/Ph/CS 187. Neural Computation. *9 units (3-0-6); first term. Prerequisite: familiarity with digital circuits, probability theory, linear algebra, and differential equations. Programming will be required.* This course investigates computation by neurons. Of primary concern are models of neural computation and their neurological substrate, as well as the physics of collective computation. Thus, neurobiology is used as a motivating factor to introduce the relevant algorithms. Topics include rate-code neural networks, their differential equations, and equivalent circuits; stochastic models and their energy functions; associative memory; supervised and unsupervised learning; development; spike-based computing; single-cell computation; error and noise tolerance. Instructor: Winfree.

CNS/CS/EE 188 a. Computation Theory and Neural Systems. *9 units (3-0-6); second term. Prerequisite: Ma 2.* Introduction to computational models and methods that are inspired by, and related to, neural systems. Specific topics include computing elementary and symmetric Boolean functions with neural/linear threshold (LT) circuits and AND, OR, NOT (AON) circuits. Computing arithmetic functions with LT circuits and AON circuits, including COMPARISON, ADDITION, PRODUCT, SORTING, and COUNTING. Algebraic techniques and their applications in the construction of minimal weight linear threshold functions. The class includes a project that focuses on creating an interactive Web-based linear threshold calculator. Instructor:

Bruck. Additional information concerning this course can be found at http://paradise.caltech.edu/cns188. Not offered 2006–07.

CNS/CS/EE 188 b. Topics in Computation and Biological Systems. *9 units (3-0-6); third term. Prerequisite: CNS/CS/EE 188 a.* Advanced topics related to computational methods in biology. Topics might change from year to year. Examples include spectral analysis techniques and their applications in threshold circuits complexity and in computational learning theory. The role of feedback in computation. The logic of computation in gene regulation networks. The class includes a project that has the goal of learning how to understand, criticize, and present the ideas and results in research papers. Instructor: Bruck. Additional information concerning this course can be found at http://paradise.caltech.edu/cns188. Not offered 2006–07.

CS/CNS/Bi 191 ab. Biomolecular Computation. *9 units (3-0-6) second term; (2-4-3) third term.* For course description, see Computer Science.

Bi/CNS 216. Behavior of Mammals. *6 units (2-0-4).* For course description, see Biology.

Bi/CNS 217. Central Mechanisms in Perception. *6 units (2-0-4).* For course description, see Biology.

CNS/Bi 221. Computational Neuroscience. *9 units (4-0-5); third term. Prerequisite: Bi/CNS 150 or instructor's permission.* Lecture and discussion aimed at understanding computational aspects of information processing within the nervous system. The course will emphasize single neurons and how their biophysical properties relate to neuronal coding, i.e., how information is actually represented in the brain at the level of action potentials. Topics include biophysics of single neurons, signal detection and signal reconstruction, information theory, population coding and temporal coding in sensory systems of invertebrates and in the primate cortex. Students are required to hand in three homework assignments, discuss one set of papers in class, and participate in the debates. Not offered 2006–07.

CNS/Bi 247. Cerebral Cortex. *6 units (2-0-4); second term.* Prerequisite: Bi/CNS 150 or equivalent. A general survey of the structure and function of the cerebral cortex. Topics include cortical anatomy, functional localization, and newer computational approaches to understanding cortical processing operations. Motor cortex, sensory cortex (visual, auditory, and somatosensory cortex), association cortex, and limbic cortex. Emphasis is on using animal models to understand human cortical function and includes correlations between animal studies and human neuropsychological and functional imaging literature. Instructor: Andersen. Given in alternate years; not offered 2006–07.

Bi/CNS 250 b. Topics in Systems Neuroscience. *9 units (3-0-6).* For course description, see Biology.

CNS/SS 251. Human Brain Mapping: Theory and Practice. *9 units (3-1-5); second term.* A course in functional brain imaging. An overview of contemporary brain imaging techniques, usefulness of brain imaging compared to other techniques available to the modern neuroscientist. Review of what is known about the physical and biological bases of the signals being measured. Design and implementation of a brain imaging experiment and analysis of data (with a particular emphasis on fMRI). Instructor: O'Doherty.

Psy/SS/CNS 254. Neural Foundations of Preference Formation and Consumer Choice. *9 units (3-0-6).* For course description, see Psychology.

SS/Psy/Bi/CNS 255. Topics in Emotion and Social Cognition. *9 units (3-0-6).* For course description, see Social Science.

CNS 280. Research in Computation and Neural Systems. *Hours and units by arrangement. For graduate students admitted to candidacy in computation and neural systems.*

CNS/Bi 286 abc. Special Topics in Computation and Neural Systems. *Units to be arranged. First, second, third terms.* Students may register with permission of the responsible faculty member.

COMPUTER SCIENCE

CS 1. Introduction to Computation. *9 units (3-4-2); first term.* CS 1 is an introduction to the automated processing of information, including computer programming. This course gives students the conceptual background necessary to understand and construct programs (i.e., specify computations, understand evaluation models, use and understand major constructs, including functions and procedures, scoping and environments, data storage, side-effects, conditionals, recursion and looping, and higher-order functions). CS 1 introduces key issues that arise in computation (e.g., universality, computability, complexity, representation, abstraction management). This course puts the components of computer science in context, serving as an overview for students specializing in computational disciplines and alerting all students to important subtleties that may arise when applying computation in their studies, research, and work. At the end of this course, students should be able to read and write (synthesize, analyze, understand) small programs (100 lines) and have the intellectual framework necessary to rapidly assimilate new computer languages as the need arises. Instructors: Pinkston, Vanier.

CS 2. Introduction to Programming Methods. *9 units (2-4-3); second term. Prerequisite: CS 1 or equivalent.* CS 2 is a challenging course in programming languages and computer science, emphasizing modes of algorithmic expression. The course will include such topics as performance analysis of algorithms; proofs of program correctness; recursive and higher-order procedures; data structures, including lists, trees, graphs, and arrays; objects and abstract data types. The course includes weekly laboratory exercises and written homework covering the lecture material and program design. Instructor: Barr.

CS 3. Introduction to Software Engineering. *9 units (2-4-3); third term. Prerequisite: CS 2 or equivalent.* CS 3 is an advanced introduction to the fundamentals of computer science and software engineering methodology. Topics will be chosen from the following: abstract data types; object-oriented models and methods; logic, specification, and program composition; abstract models of computation; probabilistic algorithms; nondeterminism; distributed algorithms and data structures. The weekly laboratory exercises allow the students to investigate the lecture material by writing nontrivial applications. Instructor: Vanderwaart.

Ma/CS 6 abc. Introduction to Discrete Mathematics. *9 units (3-0-6).* For course description, see Mathematics.

CS 11. Computer Language Shop. *3 units (0-3-0); first, second, third terms. Prerequisite: CS 1 strongly recommended.* CS 11 is a self-paced lab that provides students with extra practice and supervision in transferring their programming skills to a particular programming language; the course can be used for any language of the student's choosing, subject to approval by the instructor. A series of exercises guide the student through the pragmatic use of the chosen language, building his or her familiarity, experience, and style. More advanced students may propose their own programming project as the target demonstration of their new language skills. Lab staff will critique the student's technique and craftsmanship, offering expert feedback on areas for attention and helping the student with any conceptual difficulties that may arise while mastering the particular language. CS 11 may be repeated for credit of up to a total of 9 units. Instructors: Vanier, Pinkston.

CS 21. Decidability and Tractability. *9 units (3-0-6); second term. Prerequisite: CS 2 (may be taken concurrently).* This course introduces the formal foundations of computer science, the fundamental limits of computation, and the limits of efficient computation. Topics will include automata and Turing machines, decidability and undecidability, reductions between computational problems, and the theory of NP-completeness. Instructor: Umans.

CS 24. Introduction to Computing Systems. *9 units (3-3-3); third term. Prerequisites: CS 2; and CS 21 or CS/EE/Ma 129 a.* Basic introduction to computer systems, including hardware-software interface, computer architecture, and operating systems. Course emphasizes computer system abstractions and the hardware and software techniques necessary to support them, including virtualization (e.g., memory, processing, communication), dynamic resource management, and common-case optimization, isolation, and naming. Instructors: Martin, Vanderwaart.

CS 38. Introduction to Algorithms. *9 units (3-0-6); third term. Prerequisites: CS 2; Ma/CS 6 a or Ma 121 a; and CS 21 or CS/EE/Ma 129 a.* This course introduces techniques for the design and analysis of efficient algorithms. Major design techniques (the greedy approach, divide and conquer, dynamic programming, linear programming) will be introduced through a variety of algebraic, graph, and optimization problems. Methods for identifying intractability (via NP-completeness) will be discussed. Instructor: Chandy.

CS 40/140 ab. Programming Laboratory. *9 units (1-8-0); second, third terms. Prerequisite: CS 21 and CS 38, or instructor's permission.* Undergraduates must enroll for CS 40; graduates must enroll for CS 140. This laboratory course is meant to expose students to programming in the large. The lectures cover both object-oriented program design techniques and other methodologies with the goal of demonstrating proper design techniques for large programming projects. These methodologies are then applied to the design and implementation of a significant programming project. This project is of a large enough scale that the students must work in large teams in order to design and implement the system in the two-term course. Throughout the course, students will be expected to present their designs and implementations at scheduled design reviews. The emphasis in the course is not only on achieving the task, but also on properly analyzing the problem space, presenting a clear problem specification, and implementing a modular and a maintainable design. Not offered 2006–07.

CS 47/147. Advanced Object-Oriented Programming. *9 units (3-3-3); first term. Prerequisites: CS 2, and CS 21 and CS 38, or instructor's permission.* Undergraduates must enroll for CS 47; graduates must enroll for CS 147. This course covers the advanced object-oriented programming techniques typically used in large programming projects. Fundamental programming techniques such as object design, inheritance of implementation and/or interface, and polymorphism are also discussed. Other, more advanced, programming concepts covered include smart pointers, garbage collection, object permanence, patterns, and Internet programming. Instructor: Vanderwaart.

EE/CS 51. Principles of Microprocessor Systems. *9 units (3-0-6).* For course description, see Electrical Engineering.

EE/CS 52. Microprocessor Systems Laboratory. *12 units (1-11-0).* For course description, see Electrical Engineering.

EE/CS 53. Microprocessor Project Laboratory. *12 units (0-12-0).* For course description, see Electrical Engineering.

EE/CS 54. Advanced Microprocessor Projects Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor.* For course description, see Electrical Engineering.

CS/EE/ME 75 abc. Introduction to Multidisciplinary Systems Engineering. *3 units (2-0-1) first term; 3–6 units second term; 12 units (2-9-1) or up to 18 units (2-15-1), with instructor's permission, third term.* This course presents the fundamentals of modern multidisciplinary systems engineering in the context of a substantial design project. Students from a variety of disciplines will conceive, design, implement, and operate a system involving electrical, information, and mechanical engineering components. Specific tools will be provided for setting project goals and objectives, managing interfaces between component subsystems, working in design teams, and tracking progress against tasks. Students will be expected to apply knowledge from other courses at Caltech in designing and implementing specific subsystems. During the first two terms of the course, students will attend project meetings and learn some basic tools for project design, while taking courses in CS, EE, and ME that are related to the course project. During the third term, the entire team will build, document, and demonstrate the course design project, which will differ from year to year. Freshmen must receive permission from the lead instructor to enroll. Instructors: Murray, Burdick, Chandy, Perona.

EE/CS 80 abc. Senior Thesis. *9 units.* For course description, see Electrical Engineering.

CS 81 abc. Undergraduate Laboratory in Computer Science. *Units in accordance with work accomplished. Consent of both research adviser and course supervisor required before registering.* Supervised experimental research in computer science by undergraduates. Topic must be approved by the supervisor, and a formal final report must be presented on completion of research. Graded pass/fail. Instructor: Staff.

CS 90. Undergraduate Research in Computer Science. *Units in accordance with work accomplished. Consent of both research adviser and course supervisor required before registering.* Supervised research in computer science by undergraduates. Topic must be approved by the supervisor, and a formal final report must be presented on completion of research. Graded pass/fail. Instructor: Staff.

CS 101 abc. Special Topics in Computer Science. *Units in accordance with work accomplished; offered by announcement. Prerequisites: CS 21 and CS 38, or instructor's permission.* The topics covered vary from year to year, depending on the students and staff. Primarily for undergraduates.

CS 102 abc. Seminar in Computer Science. *3, 6, or 9 units as arranged with the instructor. Instructor's permission required.*

CS 103 abc. Reading in Computer Science. *3, 6, or 9 units as arranged with the instructor. Instructor's permission required.*

ACM/CS 114 ab. Parallel Algorithms for Scientific Applications. *9 units.* For course description, see Applied and Computational Mathematics.

Ma/CS 117 abc. Computability Theory. *9 units (3-0-6).* For course description, see Mathematics.

CS 118. Logic Model Checking for Formal Software Verification. *9 units (3-3-3); second term.* An introduction to the theory and practice of logic model checking as an aid in the formal proofs of correctness of concurrent programs and system designs. The specific focus is on automata-theoretic verification. The course includes a study of the theory underlying formal verification, the correctness of programs, and the use of software tools in designs. Not offered 2006–07.

CS/EE/Ma 129 abc. Information and Complexity. *9 units (3-0-6), first and second terms; (1-4-4) third term. Prerequisite: basic knowledge of probability and discrete mathematics.* A basic course in information theory and computational complexity with emphasis on fundamental concepts and tools that equip the student for research and provide a foundation for pattern recognition and learning theory. *First term:* what information is and what computation is; entropy, source coding, Turing machines, uncomputability. *Second term:* topics in information and complexity; Kolmogorov complexity, channel coding, circuit complexity, NP-completeness. *Third term:* theoretical and experimental projects on current research topics. Part c not offered 2006–07. Instructors: Abu-Mostafa, Winfree.

ME/CS 132. Advanced Robotics: Navigation and Vision. *9 units (3-6-0).* For course description, see Mechanical Engineering.

CS 134 a. Computing Systems. *9 units (3-3-3); first term. Prerequisite: CS 21 and CS 24 or instructor's permission.* Operating systems, monolithic and microkernels, virtual machines. Naming, memory management, segmentation, paging, and virtual memory. File systems and I/O. Threads, processes, scheduling, locks, semaphores, and mutual exclusion. Security policies, access-control, capabilities, and language-based security. Instructor: Hickey.

CS 134 b. Computing Systems, Compilers, and Languages Laboratory. *12 units (3-6-3); second term. Prerequisite: CS 134 a or instructor's permission.* Programming models and languages for operating systems. Execution environments, storage management, and operating system interfaces. Binding mechanisms, abstraction, optimization, and code generation. Parsing and lexical analysis. Students will build a working compiler. Instructor: Hickey.

CS 134 c. Computing Systems Laboratory. *12 units (3-6-3); third term. Prerequisite: CS 134 b or instructor's permission.* This laboratory class offers students the opportunity for independent work covering recent research in operating systems and programming languages. In coordination with the instructor, students select a laboratory project to be implemented during the term. Instructor: Hickey.

CS 136 abc. Programming Languages Laboratory. *9 units (3-3-3) first term; 12 units (3-6-3) second term; 12 units (2-9-1) third term.* Design and analysis of programming languages and compilers. Topics include type systems and type theory, binding mechanisms, control-flow mechanisms, abstraction mechanisms, high-level languages, functional languages, object-oriented languages, logic programming. Advanced interpreter and compiler construction, optimization, native code generation, storage management, execution environments, run-time security, byte-code interpreters and verifiers. Logical frameworks and automated theorem provers. Not offered 2006–07.

CS/EE 137 ab. Electronic Design Automation. *9 units (3-3-3); first, second terms. Prerequisites: basic algorithms and computational theory (CS 138 a, may take CS 138 b concurrently), some exposure to VLSI and/or architecture (CS 181 or CS 184), or instructor's permission.* Formulation, automation, and analysis of design mapping problems, with emphasis on VLSI and computational realizations. Major themes include formulating and abstracting problems, figures of merit (e.g., energy, delay, throughput, area, mapping time), representation, traditional decomposition of flow (logic optimization, covering, scheduling, retiming, assignment, partitioning, placement, routing), and techniques for solving problems (e.g., greedy, dynamic programming, search, [integer] linear programming, graph algorithms, randomization). This is a two-term sequence. The first term will cover the major intellectual ground and present students with a series of contained projects as a chance to exercise their understanding of the material. In the second term, students will work through all the phases of formulation, design, automation, and analysis of some particular automation problem, preferably one that arises in the student's own research. Not offered 2006–07.

CS 138 abc. Computer Algorithms. *9 units (3-0-6); first, second, third terms. Prerequisites: CS 21 and CS 38, or instructor's permission.* Design and analysis of algorithms. Techniques for problems concerning graphs, flows, number theory, string matching, data compression, geometry, linear algebra and coding theory. Optimization, including linear programming. Randomization. Basic complexity theory and cryptography. Not offered 2006–07.

CS 139 abc. Concurrency in Computation. *9 units (3-0-6); first, second, third terms. Prerequisites: CS 21 and CS 38, or instructor's permission.* Design and verification of concurrent algorithms. Topics: different models of concurrent computations; process synchronization by shared variables and synchronization primitives; distributed processes communicating by message exchange; the concepts of synchronization, indivisible actions, deadlock, and fairness; semantics and correctness proofs; implementation issues; and application to VLSI algorithm design. Parallel machine architecture issues include mapping a parallel algorithm on a network of processors, and classical parallel algorithms and their complexity. Not offered 2006–07.

CS 141 abc. Distributed Computation Laboratory. *9 units (3-3-3); first, second, third terms. Prerequisites: CS 3, CS 21 and CS 38, or instructor's permission.* This laboratory course deals with the systematic design and implementation of high-confidence scalable networks of communicating objects that discover other objects, configure themselves into collaborating groups of objects, and adapt to their environment. Teams of students explore theories and methods of implementation to obtain predictability and adaptability in distributed systems. Each team of students is expected to submit a research paper at the end of the third term, schedule demonstrations periodically, and maintain documents describing their project status. Instructor: Chandy. Given in alternate years; not offered 2006–07.

CS/EE 145 abc. Networking. *9 units (3-3-3) first, second terms; (0-0-9) third term. Prerequisite: Ma 2 ab; instructor's permission required for part c.* This course introduces the basic mechanisms and protocols in communication networks, and mathematical models for their analysis. Part a covers topics such as digitization, switching, switch design, routing, error control (ARQ), flow control, layering, queuing models, optimization models, basics of protocols in the Internet, wireless networks, and optical networks. Part b covers current research topics in the design, analysis, control, and optimization of networks, protocols, and applications. In part c, students are expected to execute a substantial project in networking, write up a report describing their work, and make a presentation. CS 145 b may be repeated for credit with the instructor's permission. Not offered 2006–07.

EE/CNS/CS 148 ab. Selected Topics in Computational Vision. *9 units (3-0-6).* For course description, see Electrical Engineering.

CS 150. Probability and Algorithms. *9 units (3-0-6); second term. Prerequisites: CS 138 a and Ma 5 abc.* Elementary randomized algorithms and algebraic bounds in communication, hashing, and identity testing. Game tree evaluation. Topics may include randomized parallel computation; independence, k-wise independence and derandomization; rapidly mixing Markov chains; expander graphs and their applications; clustering algorithms. Instructor: Schulman.

CS 151. Complexity Theory. *9 units (3-0-6); third term. Prerequisites: CS 21 and CS 38, or instructor's permission.* This course describes a diverse array of complexity classes that are used to classify problems according to the computational resources (such as time, space, randomness, or parallelism) required for their solution. The course examines problems whose fundamental nature is exposed by this framework, the known relationships between complexity classes, and the numerous open problems in the area. Instructor: Umans.

CS/CNS/EE 156 ab. Learning Systems. *9 units (3-0-6); first, second terms. Prerequisites: Ma 2 and CS 2, or equivalent.* Introduction to the theory, algorithms, and applications of automated learning. How much information is needed to learn a task, how much computation is involved, and how it can be accomplished. Special emphasis will be given to unifying the different approaches to the subject coming from statistics, function approximation, optimization, pattern recognition, and neural networks. Not offered 2006–07.

CS/CNS 171. Introduction to Computer Graphics Laboratory. *12 units (3-6-3); first term. Prerequisites: Ma 2 and extensive programming experience.* This course introduces the basic ideas behind computer graphics and its fundamental algorithms. Topics include graphics input and output, the graphics pipeline, sampling and image manipulation, three-dimensional transformations and interactive modeling, basics of physically based modeling and animation, simple shading models and their hardware implementation, and fundamental algorithms of scientific visualization. Students will be required to perform significant implementations. Instructor: Barr.

CS/CNS 174. Computer Graphics Projects. *12 units (3-6-3); third term. Prerequisites: Ma 2 and CS/CNS 171 or CS 175 or instructor's permission.* This laboratory class offers students an opportunity for independent work covering recent computer graphics research. In coordination with the instructor, students select a computer graphics modeling, rendering, interaction, or related algorithm and implement it. Students are required to present their work in class and discuss the results of their implementation and any possible improvements to the basic methods. May be repeated for credit with instructor's permission. Instructor: Barr.

CS 175. Geometric Modeling. *9 units (3-3-3); third term. Prerequisite: instructor's permission.* This course will cover both classical and state-of-the-art approaches to geometric modeling as needed in computer-aided geometric design and graphics. Subjects treated include classical splines and their theory and practice (Bernstein Bezier form, de Casteljau algorithm, knot insertion, polar forms and blossoming, degree elevation) as well as more recent approaches based on subdivision (Chaikin's algorithm, subdivision schemes of Loop, Catmull-Clark, and Butterfly). Both the underlying mathematical theory and its implementation in the form of highly efficient algorithms will be taught. Instructor: Schröder.

CS 176. Introduction to Computer Graphics Research. *9 units (3-3-3); second term. Prerequisite: CS/CNS 171, or 173, or 174, or CS 175.* The course will go over recent research results in computer graphics, covering subjects from mesh processing (acquisition, compression, smoothing, parameterization, adaptive meshing), simulation for purposes of animation, rendering (both photo- and nonphotorealistic), geometric modeling primitives (image based, point based), and motion capture and editing. Other subjects may be treated as they appear in the recent literature. The goal of the course is to bring students up to the frontiers of computer graphics research and prepare them for their own research. Instructors: Desbrun, Schröder.

CS 177. Discrete Differential Geometry: Theory and Applications. *9 units (3-3-3); first term.* Topics include, but are not limited to, discrete exterior calculus; Whitney forms; DeRham and Whitney complexes; Morse theory; computational and algebraic topology; discrete simulation of thin shells, fluids, electromagnetism, elasticity; surface parameterization; Hodge decomposition. Instructors: Desbrun, Tong.

CS 180. Master's Thesis Research. *Units (total of 45) are determined in accordance with work accomplished.*

CS/EE 181 abc. VLSI Design Laboratory. *12 units (3-6-3); first, second, third terms.* Digital integrated system design, with projects involving the design, verification, and testing of high-complexity CMOS microcircuits. First-term lecture and homework topics emphasize disciplined design, and include CMOS logic, layout, and timing; computer-aided design and analysis tools; and electrical and performance considerations. Each student is required in the first term to complete individually the design, layout, and verification of a moderately complex integrated circuit. Advanced topics second and third terms include self-timed design, computer architecture, and other topics that vary year by year. Projects are large-scale designs done by teams. Instructor: Martin.

CS/EE 184 ab. Computer Architecture. *9 units (3-3-3); second, third terms. Prerequisites: CS 21 and CS 24, or instructor's permission.* Organization and design of physical computational systems, basic building blocks for computations, understanding and exploiting structure in computational problems, design space, costs, and trade-offs in computer organization, common machine abstractions, and implementation/optimization techniques. The course will develop the fundamental issues and trade-offs that define computer organizational and architectural styles, including RISC, VLIW, Super Scalar, EPIC, SIMD, Vector, MIMD, reconfigurable, FPGA, PIM, and SoC. Basic topics in the design of computational units, instruction organization, memory systems, control and data flow, interconnect, and the hardware-software abstraction will also be covered. Not offered 2006–07.

CS 185 abc. Asynchronous VLSI Design Laboratory. *9 units (3-3-3); first, second, third terms. Prerequisite: CS 139.* The design of digital integrated circuits whose correct operation is independent of delays in wires and gates. (Such circuits do not use clocks.) Emphasis is placed on high-level synthesis, design by program transformations, and correctness by construction. The first term introduces delay-insensitive design techniques, description of circuits as concurrent programs, circuit compilation, standard-cell layout and other computer-aided design tools, and electrical optimizations. The second term is reserved for advanced topics, and for the presentation and review of mid-size projects, which will be fabricated in CMOS or GaAs technologies, and tested. Not offered 2006–07.

CNS/Bi/Ph/CS 187. Neural Computation. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

CNS/CS/EE 188 a. Computation Theory and Neural Systems. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

CNS/CS/EE 188 b. Topics in Computation and Biological Systems. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

CS/CNS/Bi 191 ab. Biomolecular Computation. *9 units (3-0-6) second term; (2-4-3) third term.* This course investigates computation by molecular systems, emphasizing models of computation based on the underlying physics, chemistry, and organization of biological cells. Topics will be selected from computation by self-assembly, molecular folding, signal transduction, genetic regulatory networks, and transcription; simulation and design of biochemical systems; physical limits of computation, reliability, and the role of noise; reversible computation; DNA-based computers; *in vitro* evolution; molecular ecosystems. Part a develops fundamental results. Part b is a reading and research course: classic and current papers will be discussed, and students will do projects on current research topics. Instructor: Winfree. Given in alternate years; offered 2006–07.

Ph/CS 219 abc. Quantum Computation. *9 units (3-0-6); first, second, third terms.* For course description, see Physics.

SS/CS 241 ab. Introduction to Social and Information Sciences. *9 units (3-0-6).* For course description, see Social Science.

CS 274 abc. Topics in Computer Graphics. *9 units (3-3-3); first, second, third terms. Prerequisite: instructor's permission.* Each term will focus on some topic in computer graphics, such as geometric modeling, rendering, animation, human-computer interaction, or mathematical foundations. The topics will vary from year to year. May be repeated for credit with instructor's permission. Not offered 2006–07.

CS 280. Research in Computer Science. *Units in accordance with work accomplished. Approval of student's research adviser and option adviser must be obtained before registering.*

CS 282 abc. Reading in Computer Science. *6 units or more by arrangement; first, second, third terms. Instructor's permission required.*

CS 286 abc. Seminar in Computer Science. *3, 6, or 9 units, at the instructor's discretion. Instructor's permission required.*

CONTROL AND DYNAMICAL SYSTEMS

CDS 90 abc. Senior Thesis in Control and Dynamical Systems. *9 units (0-0-9); first, second, third terms. Prerequisites: CDS 110 ab or CDS 140 ab (may be taken concurrently).* Research in control and dynamical systems, supervised by a Caltech faculty member. The topic selection is determined by the adviser and the student and is subject to approval by the CDS faculty. First and second terms: midterm progress report and oral presentation during finals week. Third term: completion of thesis and final presentation. Not offered on a pass/fail basis. Instructor: Murray.

CDS 101. Design and Analysis of Feedback Systems. *6 units (2-0-4); first term. Prerequisites: Ma 1 and Ma 2 or equivalents.* An introduction to feedback and control in physical, biological, engineering, and information sciences. Basic principles of feedback and its use as a tool for altering the dynamics of systems and managing uncertainty. Key themes throughout the course will include input/output response, modeling and model reduction, linear vs. nonlinear models, and local vs. global behavior. This course is taught concurrently with CDS 110 a, but is intended for students who are interested primarily in the concepts and tools of control theory and not the analytical techniques for design and synthesis of control systems. Instructors: Murray, Mabuchi.

CDS 104. Introductory Concepts for Dynamical Systems. *6 units (2-0-4); third term. Prerequisites: Ma 1, Ma 2 (or equivalent); it is recommended that this course be taken concurrently with CDS 273.* This course teaches basic concepts in mathematics and dynamics that are required for CDS 110 and CDS 140. It is intended as a tutorial for nonmajors who plan to do further course work in CDS but may not have adequate preparation in linear algebra and ordinary differential equations. Topics to be covered include linear ODEs in one variable, linear algebra, eigenvalues and eigenvectors, coupled linear ODEs, stability of OEDs. Extensive use of examples based on modeling of physical, biological, and information systems using differential equations and linear algebra. Instructor: Koon.

CDS 110 ab. Introductory Control Theory. *9 units (3-0-6); first, second terms. Prerequisites: Ma 1 and Ma 2 or equivalents; ACM 95/100 may be taken concurrently.* An introduction to analysis and design of feedback control systems, including classical control theory in the time and frequency domain. Modeling of physical, biological, and information systems using linear and nonlinear differential equations. Stability and performance of interconnected systems, including use of block diagrams, Bode plots, the Nyquist criterion, and Lyapunov functions. Robustness and uncertainty management in feedback systems through stochastic and deterministic methods. Introductory random processes, Kalman filtering, and norms of signals and systems. The first term of this course is taught concurrently with CDS 101, but includes additional lectures, reading, and homework that is focused on analytical techniques for design and synthesis of control systems. Instructor: Murray.

CDS 111. Applications of Control Technology. *9 units (3-3-3); third term. Prerequisite: CDS 110 or equivalent.* Application of modern control design techniques to physical systems. The goal of this course is to teach students how to design and implement feedback controllers on physical systems, and to allow students to evaluate different control design methodologies on experimental hardware. Not offered 2006–07.

Ae/CDS 125 abc. Space Missions and Systems Engineering. *9 units (3-0-6).* For course description, see Aeronautics.

CDS 140 ab. Introduction to Dynamics. *9 units (3-0-6); first, second terms. Prerequisite: ACM 95 or equivalent.* Basics in topics in dynamics in Euclidean space, including equilibria, stability, Lyapunov functions, periodic solutions, Poincaré-Bendixon theory, Poincaré maps. Attractors and structural stability. The Euler-Lagrange equations, mechanical systems, small oscillations, dissipation, energy as a Lyapunov function, conservation laws. Introduction to simple bifurcations and eigenvalue crossing conditions. Discussion of bifurcations in applications, invariant manifolds, the method of averaging, Melnikov's method, and the Smale horseshoe. Instructors: Marsden, Koon.

CDS 190. Independent Work in Control and Dynamical Systems. *9 units (0-0-9); first, second, third terms; maximum two terms. Prerequisite: CDS 110 ab or CDS 140 ab.* Research project in control and dynamical systems, supervised by a CDS faculty member.

CDS 201. Applied Operator Theory. *9 units (3-0-6); first term. Prerequisite: ACM 95/100 or equivalent.* Invariant subspaces, Jordan form, Cayley-Hamilton theorem, matrix exponential, singular value decomposition, some Banach and Hilbert spaces, operators, duals, adjoints, induced norms, and spectral theory. Calculus in linear spaces, the inverse and implicit function theorems. Taught concurrently with AM 125 a. Instructor: Beck.

CDS 202. Geometry of Nonlinear Systems. *9 units (3-0-6); second term. Prerequisite: CDS 201 or AM 125 a.* Basic differential geometry, oriented toward applications in control and dynamical systems. Topics include smooth manifolds and mappings, tangent and normal bundles. Vector fields and flows. Distributions and Frobenius's theorem. Matrix Lie groups and Lie algebras. Exterior differential forms, Stokes' theorem. Instructor: Marsden.

CDS 205. Geometric Mechanics. *9 units (3-0-6); third term. Prerequisites: CDS 202, CDS 140.* The geometry and dynamics of Lagrangian and Hamiltonian systems, including symplectic and Poisson manifolds, variational principles, Lie groups, momentum maps, rigid-body dynamics, Euler-Poincaré equations, stability, and an introduction to reduction theory. More advanced topics (taught in a course the following year) will include reduction theory, fluid dynamics, the energy momentum method, geometric phases, bifurcation theory for mechanical systems, and nonholonomic systems. Given in alternate years; offered 2006–07.

CDS 212. Introduction to Modern Control. *9 units (3-0-6); first term. Prerequisites: ACM 95/100 abc or equivalent; CDS 110 ab or equivalent.* Introduction to modern control systems with emphasis on the role of control in overall system analysis and design. Examples drawn from throughout engineering and science. Open versus closed loop control. State-space methods, time and frequency domain, stability and stabilization, realization theory. Time-varying and nonlinear models. Uncertainty and robustness. Instructor: Doyle.

CDS 213. Robust Control. *9 units (3-0-6); second term. Prerequisites: CDS 212, CDS 201.* Linear systems, realization theory, time and frequency response, norms and performance, stochastic noise models, robust stability and performance, linear fractional transformations, structured uncertainty, optimal control, model reduction, m analysis and synthesis, real parametric uncertainty, Kharitonov's theorem, uncertainty modeling. Instructor: Doyle.

CDS 270. Advanced Topics in Systems and Control. *Hours and units by arrangement.* Topics dependent on class interests and instructor. May be repeated for credit.

CDS 273. Frontiers in Control and Dynamical Systems. *6 units (1-0-5); third term. Prerequisite: Students with limited background in CDS techniques are encouraged to take CDS 104 concurrently.* The course will explore applications of tools from CDS to new problem domains. The course is organized around small teams consisting of CDS and non-CDS students who work on projects of mutual interest in some faculty member's research area. A final project report and short presentation are required. May be repeated for credit. Instructors: Mabuchi, Murray.

CDS 280. Advanced Topics in Geometric Mechanics or Dynamical Systems Theory. *Hours and units by arrangement. Prerequisite: instructor's permission.* Topics will vary according to student and instructor interest. Examples include chaotic transport theory, invariant manifold techniques, multidimensional geometric perturbation theory, the dynamics of coupled oscillators, rigid-body dynamics, numerical methods in dynamical systems theory. May be repeated for credit. Instructor: Marsden.

CDS 300 abc. Research in Control and Dynamical Systems. *Hours and units by arrangement.* Research in the field of control and dynamical systems. By arrangement with members of the staff, properly qualified graduate students are directed in research. Instructor: Staff.

ECONOMICS

Ec 11. Introduction to Economics. *9 units (3-2-4); first, third terms.* An introduction to economic methodology, models, and institutions. Includes both basic microeconomics and an introduction to modern approaches to macroeconomic issues. Students are required to participate in economics experiments. Instructors: Plott, McAfee.

BEM/Ec/SS 20. Scientific Writing and Oral Presentation in the Social Sciences. *6 units (2-0-4).* For course description, see Business Economics and Management.

Ec 98 abc. Senior Research and Thesis. *Prerequisite: instructor's permission.* Senior economics majors wishing to undertake research may elect a variable number of units, not to exceed 12 in any one term, for such work under the direction of a member of the economics faculty.

Ec 101. Selected Topics in Economics. *9 units (3-0-6); offered by announcement.* Instructors: Staff, visiting lecturers.

Ec 105. Industrial Organization. *9 units (3-0-6). Prerequisite: Ec 11 or equivalent.* A study of how technology affects issues of market structure and how market structure affects observable economic outcomes, such as prices, profits, advertising, and research and development expenditures. Emphasis will be on how the analytic tools developed in the course can be used to examine particular industries in detail. Instructor: Iaryczower.

Ec 106. Topics in Applied Industrial Organization. *9 units (3-0-6); third term. Prerequisite: Ec 11; Ec 116 recommended.* Topics include simulation of mergers in oligopolistic industries, valuation of intellectual property, price setting and concentration in the pharmaceutical market, and statistical analysis of combined tobacco and asbestos exposure. A term paper will be required. Not offered 2006–07.

Ec 116. Contemporary Socioeconomic Problems. *9 units (3-0-6); first term. Prerequisites: Ec 11 and PS 12 or equivalents.* An analytical investigation of the economic aspects of certain current social issues. Topics: the economics of education, medical-care systems, urban affairs, and the welfare system. Not offered 2006–07.

Ec 121 ab. Theory of Value. *9 units (3-0-6); first, second terms. Prerequisites: Ec 11 and Ma 2 (may be taken concurrently).* A study of consumer preference, the structure and conduct of markets, factor pricing, measures of economic efficiency, and the interdependence of markets in reaching a general equilibrium. Instructor: Border.

Ec 122. Econometrics. *9 units (3-0-6); first term. Prerequisite: Ma 112 a.* The application of statistical techniques to the analysis of economic data. Instructor: Sherman.

Ec 123. Macroeconomics. *9 units (3-0-6); third term. Prerequisite: Ec 11.* The role of time and uncertainty in understanding the behavior of economic aggregates such as investment, employment, and price levels. Emphasis is on representative-agent recursive equilibrium models. Topics include practical dynamic programming; job search, matching, and unemployment; asset pricing; monetary and fiscal policy; and taxation and insurance. Not offered 2006–07.

Ec/SS 129. Economic History of the United States. *9 units (3-0-6); second term. Prerequisite: Ec 11 or SS 13.* An examination of certain analytical and quantitative tools and their application to American economic development. Not offered 2006–07.

Ec/SS 130. Economic History of Europe from the Middle Ages to the Industrial Revolution. *9 units (3-0-6). Prerequisite: Ec 11 or SS 13.* Employs the theoretical and quantitative techniques of economics to help explore and explain the development of the European cultural area between 1000 and 1850. Topics include the rise of commerce, the demographic transition, the industrial revolution, and changes in property rights and capital markets. Not offered 2006–07.

Ec 132. Auctions. *9 units (3-0-6); second term. Prerequisite: Ec 11.* The course covers basic topics in auction theory (private and common value auctions, revenue equivalence, reserve prices, budget constraints, risk aversion, etc.) and discusses more advanced theory such as mechanism design, multi-unit auctions, and interdependent valuations. Experimental studies of auctions will be reviewed where appropriate. The course will also discuss practical considerations that arise when designing auctions to sell licenses in a particular industry. Instructor: Goeree.

Ec 140. Economic Progress. *9 units (3-0-6); third term. Prerequisites: Ec 11 and Ma 2; Ec 122 recommended.* This course examines the contemporary literature on economic growth and development from both a theoretical and historical/empirical perspective. Topics include a historical overview of economic progress and the lack thereof; simple capital accumulation models; equilibrium/planning models of accumulation; endogenous growth models; empirical tests of convergence; the measurement and role of technological advancement; and the role of trade, institutions, property rights, human capital, and culture. Instructors: Border, Hoffman. Given in alternate years; offered 2006–07.

Ec 145. Public Finance. *9 units (3-0-6). Prerequisite: Ec 11 or equivalent.* An intermediate-level course on the economics of the public sector. Material is chosen from welfare economics, public expenditure theory and practice, taxation theory and practice, federalism, and public choice theory. Not offered 2006–07.

BEM/Ec 146. Organization Design. *9 units (3-0-6).* For course description, see Business Economics and Management.

Ec/PS 160 abc. Laboratory Experiments in the Social Sciences. *9 units (3-3-3).* An examination of recent work in laboratory testing in the social sciences with particular reference to work done in social psychology, economics, and political science. Students are required to design and conduct experiments. Instructor: Plott.

PS/Ec 172. Noncooperative Games in the Social Sciences. *9 units (3-0-6).* For course description, see Political Science.

PS/Ec 173. Cooperation and Social Behavior. *9 units (3-0-6).* For course description, see Political Science.

Ec 181. Convex Analysis and Economic Theory. *9 units (3-0-6); third term. Prerequisites: Ma 2 ab, Ec 121 a.* Introduction to the use of convex analysis in economic theory. Includes a rigorous discussion of separating hyperplane theorems, continuity and differentiability properties of convex and concave functions, support functions, subdifferentials, Fenchel conjugacy, saddle-point theory, theorem of the alternative, and linear programming. Emphasis is on the finite-dimensional case, but infinite-dimensional spaces will be discussed. Applications to the theory of cost and production functions, decision theory, and game theory. Instructor: Border.

Ec/PS 190. Undergraduate Research. *Units to be arranged; any term. Prerequisite: advanced economics course and instructor's permission.* This course offers advanced undergraduates the opportunity to pursue research in political science or economics. Graded pass/fail.

ELECTRICAL ENGINEERING

EE 5. Introduction to Embedded Systems. *6 units (2-3-1); first term.* This course is intended to give the student a basic understanding of the major hardware and software principles involved in the specification and design of embedded systems. Topics include basic digital logic, CPU and embedded system architecture, and embedded systems programming principles (events, user interfaces, and multitasking). The class is intended for students who wish to gain a basic understanding of embedded systems or for those who would like an introduction to the material before taking EE/CS 51/52. Graded pass/fail. Instructor: George.

APh/EE 9 ab. Solid-State Electronics for Integrated Circuits. *6 units (2-2-2).* For course description, see Applied Physics.

EE 20 ab. Electronics Laboratory. *9 units (3-6-0); first, second terms. Prerequisites: Ma 1 abc, Ph 1 abc, EE 20 a for EE 20 b.* Fundamentals of electronics through the progressive construction of a radio transceiver—electronic components, phasors, transmission lines, filters, speakers, audio amplifiers, transistors, radio amplifiers, oscillators, mixers, noise, intermodulation, antennas, and propagation. Instructor: Antsos.

EE 40. Introduction to Solid-State Sensors and Actuators. *9 units (3-0-6); third term. Prerequisites: APh/EE 9 ab and EE 20 ab.* This course provides an introduction to various sensors and actuators. The fundamental principles of the devices will be emphasized, together with their electrical implementation, such as biasing and signal processing circuits. Devices that will be discussed include optical sensors, solar cells, CCDs, CMOS imagers, temperature sensors, magnetic sensors, mechanical sensors, acoustic sensors (microphones), speakers, electrical generators, motors, etc. Instructor: Tai.

EE/CS 51. Principles of Microprocessor Systems. *9 units (3-0-6); second term.* The principles and design of microprocessor-based computer systems. Lectures cover both hardware and software aspects of microprocessor system design such as interfacing to input and output devices, user interface design, real-time systems, and table-driven software. The homework emphasis is on software development, especially interfacing with hardware, in assembly language. Instructor: George.

EE/CS 52. Microprocessor Systems Laboratory. *12 units (1-11-0); third term. Prerequisite: EE/CS 51 or equivalent.* The student will design, build, and program a specified microprocessor-based system. This structured laboratory is organized to familiarize the student with electronic circuit construction techniques, modern development facilities, and standard design techniques. The lectures cover topics in microprocessor system design such as display technologies, interfacing with analog systems, and programming microprocessors in high-level languages. Instructor: George.

EE/CS 53. Microprocessor Project Laboratory. *12 units (0-12-0); first, second, third terms. Prerequisite: EE/CS 52 or equivalent.* A project laboratory to permit the student to select, design, and build a microprocessor-based system. The student is expected to take a project from proposal through design and implementation (possibly including PCB fabrication) to final review and documentation. Instructor: George.

EE/CS 54. Advanced Microprocessor Projects Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor; first, second, third terms. Prerequisite: instructor's permission.* A project laboratory to permit the student to design and build a microprocessor-based system of significant complexity. The student must propose, design, implement, and document a project that uses microprocessors and includes a significant hardware and/or software component. The laboratory is for the experienced student who can work independently and who has taken or has had experience equivalent to EE/CS 53. Instructor: George.

CS/EE/ME 75 abc. Introduction to Multidisciplinary Systems Engineering. *3 units (2-0-1) first term; 3–6 units second term; 12 units*

(2-9-1) or up to 18 units (2-15-1) third term. For course description, see Computer Science.

EE/CS 80 abc. Senior Thesis. *9 units; first, second, third terms. Prerequisite: instructor's permission, which should be obtained during the junior year to allow sufficient time for planning the research.* Individual research project, carried out under the supervision of a member of the electrical engineering or computer science faculty. Project must include significant design effort. Written report required. Open only to senior electrical engineering, computer science, or electrical and computer engineering majors. Not offered on a pass/fail basis. Instructor: Potter.

EE 90. Analog Electronics Project Laboratory. *9 units (1-8-0); third term. Prerequisites: EE 20 ab and EE 40.* A structured laboratory course that gives the student the opportunity to design and build a sequence of simple analog electronics projects. The goal is to gain familiarity with circuit design and construction, component selection, CAD support, and debugging techniques. Instructor: Megdal.

EE 91 ab. Experimental Projects in Electronic Circuits. *Units by arrangement; first, second terms. 12 units minimum each term. Prerequisites: EE 20 ab. Recommended: EE/CS 51 and 52, and EE 114 ab (may be taken concurrently). Open to seniors; others only with instructor's permission.* An opportunity to do advanced original projects in analog or digital electronics and electronic circuits. Selection of significant projects, the engineering approach, modern electronic techniques, demonstration and review of a finished product. DSP/microprocessor development support and analog/digital CAD facilities available. Text: literature references. Instructor: Megdal.

EE 99. Advanced Work in Electrical Engineering. *Units to be arranged.* Special problems relating to electrical engineering will be arranged. For undergraduates; students should consult with their advisers. Graded pass/fail.

EE 111. Signals, Systems, and Transforms. *9 units (3-0-6); first term. Prerequisites: Ma 1, Ma 2. EE 20 ab recommended.* An introduction to continuous and discrete time signals and systems. Study of the Fourier transform, Fourier series, the Laplace transform, Z-transforms, and the fast Fourier transform as applied in electrical engineering. Various types of systems, with emphasis on linear and time invariant systems. Transfer functions, difference and differential equations, state space representations, system realizations with block diagrams, and analysis of transient and steady state responses. Sampling theorems for analog to digital conversion. Instructor: Abu-Mostafa.

EE 112 ab. Introduction to Digital Signal Processing. *9 units (3-0-6); second, third terms. Prerequisite: EE 111 or equivalent.* Fundamentals of digital signal processing, sampling theory and digital to analog conversion, digital filter design, structures for filtering, quantization effects, roundoff noise and limit cycles, linear prediction, optimal transforms for quantization, and related applications. The course also covers applications of signal processing ideas in diverse fields such as speech, music, communication systems, image processing, optics, and molecular biology. Instructor: Vaidyanathan. Given in alternate years; offered 2006–07.

EE 113. Feedback and Control Circuits. *9 units (3-3-3); first term. Prerequisite: EE 20 ab or equivalent.* This class studies the design and implementation of feedback and control circuits. The course begins with an introduction to basic feedback circuits, using both op amps and transistors. These circuits are used to study feedback principles, including circuit topologies, stability, and compensation. Following this, basic control techniques and circuits are studied, including PID (Proportional-Integrated-Derivative) control, digital control, and fuzzy control. There is a significant laboratory component to this course, in which the student will be expected to build, analyze, test, and measure the circuits and systems discussed in the lectures. Instructor: George.

EE 114 ab. Analog Circuit Design. *12 units (4-0-8); first, second terms. Prerequisite: EE 20 ab or equivalent, EE 114 a or equivalent.* Analysis and design of analog circuits at the transistor level. Emphasis on intuitive design methods, quantitative performance measures, and practical circuit limitations. Circuit performance evaluated by hand calculations and computer simulations. Recommended for seniors and graduate students. First term deals with continuous time and amplitude signals; physics of bipolar and MOS transistors, low-frequency behavior of single-stage and multistage amplifiers, current sources, active loads, differential amplifiers, operational amplifiers, and supply and temperature independent biasing. Second term covers high-frequency response of amplifiers, feedback in electronic circuits, stability of feedback amplifiers, and noise in electronic circuits. A number of the following topics will be covered each year: translinear circuits, switched capacitor circuits, data conversion circuits (A/D and D/A), continuous-time $G_m.C$ filters and phase locked loops. Instructor: Hajimiri.

ACM/EE 116. Introduction to Stochastic Processes and Modeling. *9 units (3-0-6).* For course description, see Applied and Computational Mathematics.

Ph/EE 118 ab. Low-Noise Electronic Measurement. *9 units (3-0-6).* For course description, see Physics.

EE 119 abc. Advanced Digital Systems Design. *9 units (3-3-3). Prerequisites: EE/CS 52 or CS/EE 181 a.* Advanced digital design as it applies to the design of systems using PLDS and ASICs (in particular, gate arrays and standard cells). The course covers both design and implementation details of various systems and logic device technologies. The emphasis is on the practical aspects of ASIC design, such as timing, testing, and fault grading. Topics include synchronous design, state machine design, ALU and CPU design, application-specific parallel computer design, design for testability, PALs, FPGAs, VHDL, standard cells, timing analysis, fault vectors, and fault grading. Students are expected to design and implement both systems discussed in the class as well as self-proposed systems using a variety of technologies and tools. Instructor: George. Given in alternate years; not offered 2006–07.

EE/Ma 126 ab. Information Theory. *9 units (3-0-6); first, second terms. Prerequisite: Ma 2.* Shannon's mathematical theory of communication, 1948–present. Entropy, relative entropy, and mutual information for discrete and continuous random variables. Shannon's source and channel coding theorems. Mathematical models for information sources and communication channels, including memoryless, first-order Markov, ergodic, and Gaussian. Calculation of capacity-cost and rate-distortion functions. Kolmogorov complexity and universal source codes. Side information in source coding and communications. Network information theory, including multiuser data compression, multiple access channels, broadcast channels, and multiterminal networks. Discussion of philosophical and practical implications of the theory. This course, when combined with EE 112 ab, EE/Ma 127 ab, EE 161, and/or EE 167 should prepare the student for research in information theory, coding theory, wireless communications, and/or data compression. Instructors: Effros, Ho.

EE/Ma 127 ab. Error-Correcting Codes. *9 units (3-0-6); second, third terms. Prerequisite: Ma 2.* This course, which is a sequel to EE/Ma 126 a, but which may be taken independently, will develop from first principles the theory and practical implementation of the most important techniques for combatting errors in digital transmission or storage systems. Topics include algebraic block codes, e.g., Hamming, Golay, Fire, BCH, Reed-Solomon (including a self-contained introduction to the theory of finite fields); convolutional codes; and concatenated coding systems. Emphasis will be placed on the associated encoding and decoding algorithms, and students will be asked to demonstrate their understanding of these algorithms with software projects. In the third term, the modern theory of "turbo" and related codes (e.g., regular and irregular LDPC codes), with suboptimal iterative decoding based on belief propagation, will be presented. Instructors: McEliece, Ho.

EE 128 ab. Signal Processing with Multirate Systems, Filter Banks, and Wavelets. *9 units (3-0-6); second, third terms. Prerequisite: EE 111 a or equivalent.* Sampling rate alterations, decimation and interpolation, filter bank theory and design, wavelet transforms and relation to filter banks, orthonormal filter banks and wavelets, time-frequency representations and orthonormal bases for time-frequency representations. Applications in compression and digital communications. This class is an extension of EE 112 ab, though it is not a prerequisite. Instructor: Vaidyanathan. Given in alternate years; not offered 2006–07.

CS/EE/Ma 129 abc. Information and Complexity. *9 units (3-0-6) first, second terms; (1-4-4) third term.* For course description, see Computer Science.

APh/EE 130. Electromagnetic Theory. *9 units (3-0-6).* For course description, see Applied Physics.

APh/EE 131. Optical Wave Propagation. *9 units (3-0-6).* For course description, see Applied Physics.

APh/EE 132. Optoelectronic Materials and Devices. *9 units (3-0-6).* For course description, see Applied Physics.

CS/EE 137 ab. Electronic Design Automation. *9 units (3-3-3).* For course description, see Computer Science.

CS/EE 145 abc. Networking. *9 units.* For course description, see Computer Science.

EE/CNS/CS 148 ab. Selected Topics in Computational Vision. *9 units (3-0-6); first, third terms. Prerequisites: undergraduate calculus, linear algebra, geometry, statistics, computer programming.* The class will focus on an advanced topic in computational vision: recognition, vision-based navigation, 3-D reconstruction. Instructor: Perona. Additional information concerning this course can be found at http://www.vision.caltech.edu/html-files/courses.html.

EE 150. Topics in Electrical Engineering. *Units and terms to be arranged.* Content will vary from year to year, at a level suitable for advanced undergraduate or beginning graduate students. Topics will be chosen according to the interests of students and staff. Visiting faculty may present all or portions of this course from time to time. Instructor: Staff.

EE 151. Electromagnetic Engineering. *12 units (3-2-7); first term. Prerequisites: EE 20 ab or equivalent and ACM 95/100 abc.* Electric fields, magnetic fields, and Maxwell's equations, and their engineering applications. Foundations of circuit theory, plane wave propagation, guided wave propagation, resonators, and antennas. Instructor: Psaltis.

EE 153. Microwave Circuits and Antennas. *12 units (3-2-7); third term. Prerequisite: EE 20 ab.* High-speed circuits for wireless communications, radar, and broadcasting. Design, fabrication, and measurements of microstrip filters, directional couplers, low-noise amplifiers, oscillators, detectors, and mixers. Design, fabrication, and measurements of wire antennas and arrays. Instructor: Antsos.

CS/CNS/EE 156 ab. Learning Systems. *9 units (3-0-6).* For course description, see Computer Science.

EE/Ge 157 abc. Introduction to the Physics of Remote Sensing. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 or equivalent.* Introduction to the interaction of electromagnetic waves with natural surfaces and atmospheres. Scattering of microwaves by surfaces and volume scatterers. Microwave and thermal emission from atmospheres and surfaces. Spectral reflection of natural surfaces and atmospheres in the near-infrared and visible regions of the spectrum. Review of modern spaceborne sensors and associated technology and data analysis. Emphasis on sensor design, new techniques, ongoing developments, and data interpretation. Examples of applications in geology, planetology, oceanography, astronomy, and atmospheric research. Part c will emphasize retrieval of atmospheric profiles, with applications to data sets obtained from missions such as MLS, AIRS, TES, and MISR. Instructor: Van Zyl.

EE/Ge 158 ab. Application of Digital Images and Remote Sensing in the Field. *3 units (0-2-1); second term. 6 units (0-5-1); third term. Prerequisite: EE/Ge 157 abc or instructor's permission.* Processing of digital images and their application during a five-day field trip in the second term. During spring break students will visit areas in eastern California that have been used as test areas for visible and near-infrared, thermal infrared, and microwave scattering methods. Satellite, aircraft, and ground spectrometer data will be processed by the students in the lab and compared with surface observations in the field. Individual projects may be chosen to emphasize instrumental or geological interests of each student. Not offered 2006–07.

EE 160. Communication-System Fundamentals. *9 units (3-0-6); second term. Prerequisite: EE 111.* Laws of radio and guided transmission, noise as a limiting factor, AM and FM signals and signal-to-noise ratio, sampling and digital transmission, errors, information theory, error correction. Emphasis will be on fundamental laws and equations and their use in communication-system designs, including voice, video, and data. Instructor: Hassibi.

EE 161. Wireless Communications. *9 units (3-0-6); third term. Prerequisite: EE 160.* This course will cover the fundamentals of wireless channels and channel models, wireless communication techniques, and wireless networks. Topics include statistical models for time-varying narrowband and wideband channels, fading models for indoor and outdoor systems, macro- and microcellular system design, channel access and spectrum sharing using TDMA, FDMA, and CDMA, time-varying channel capacity and spectral efficiency, modulation and coding for wireless channels, antenna arrays, diversity combining and multiuser detection, dynamic channel allocation, and wireless network architectures and protocols. Not offered 2006–07.

EE 163 ab. Communication Theory. *9 units (3-0-6); second, third terms. Prerequisite: EE 111; ACM/EE 116 or equivalent.* Least mean square error linear filtering and prediction. Mathematical models of communication processes; signals and noise as random processes; sampling and quantization; modulation and spectral occupancy; intersymbol interference and synchronization considerations; signal-to-noise ratio and error probability; optimum demodulation and detection in digital baseband and carrier communication systems. Instructor: Quirk.

EE 164. Stochastic and Adaptive Signal Processing. *9 units (3-0-6); third term. Prerequisite: ACM/EE 116 or equivalent.* Fundamentals of linear estimation theory are studied, with applications to stochastic and adaptive signal processing. Topics include deterministic and stochastic least-squares estimation, the innovations process, Wiener filtering and spectral factorization, state-space structure and Kalman filters, array and fast array algorithms, displacement structure and fast algorithms, robust estimation theory and LMS and RLS adaptive fields. Instructor: Hassibi.

EE/BE 166. Optical Methods for Biomedical Imaging and Diagnosis. *9 units (3-1-5); third term. Prerequisite: EE 151 or equivalent.* Topics include Fourier optics, scattering theories, shot noise limit, energy transitions associated with fluorescence, phosphorescence, and Raman emissions. Study of coherent anti-Stokes Raman spectroscopy (CARS), second harmonic generation and near-field excitation. Scattering, absorption, fluorescence, and other optical properties of biological tissues and the changes in these properties during cancer progression, burn injury, etc. Specific optical technologies employed for biomedical research and clinical applications: optical coherence tomography, Raman spectroscopy, photon migration, acousto-optics (and opto-acoustics) imaging, two photon fluorescence microscopy, and second- and third-harmonic microscopy. Instructor: Yang.

EE 167. Data Compression. *9 units (3-0-6); third term. Prerequisite: EE 126 or instructor's permission.* An introduction to the basic results, both theoretical and practical, of data compression. Review of relevant background from information theory. Fixed model and adaptive Huffman and arithmetic codes. The Lempel-Ziv algorithm and its variants. Scalar and vector quantization, including the Lloyd-Max quantizers, and the generalized Lloyd algorithm. Transform coding. Karhuenen-Loeve and discrete cosine transforms. The bit allocation problem. Subband coding. Practical algorithms for image and video compression. Instructors: Dolinar, Kiely.

EE/APh 180. Solid-State Devices. *9 units (3-0-6); second term. Prerequisite: EE 20 ab.* Starting with the phenomenological statement of physical processes, the operation of a device is derived from fundamental principles and the device's materials and design. Subjects include the motion of charge carriers in solids, equilibrium statistics, the electronic structure of solids, doping, nonequilibrium states, the pn junction, the junction transistor, the Schottky diode, the field-effect transistor, the light-emitting diode, and the photodiode. Instructor: Scherer. Given in alternate years; offered 2006–07.

CS/EE 181 abc. VLSI Design Laboratory. *12 units (3-6-3).* For course description, see Computer Science.

CNS/EE/BE 182. Introduction to Neuromorphic and Bioinspired Mixed-Signal VLSI. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

APh/EE 183 abc. Fundamentals of Electronic Devices. *9 units (3-0-6).* For course description, see Applied Physics.

CS/EE 184 ab. Computer Architecture. *9 units (3-3-3).* For course description, see Computer Science.

EE 185. MEMS Technology and Devices. *9 units (3-0-6); first term. Prerequisites: APh/EE 9 ab, EE 187, or instructor's permission.* Microelectro-mechanical systems (MEMS) have been broadly used for biochemical, medical, RF, and lab-on-a-chip applications. This course will cover both MEMS technologies (e.g., micro- and nanofabrication) and devices. For example, MEMS technologies include anisotropic wet etching, RIE, deep RIE, micro/nano molding and advanced packaging. This course will also cover various MEMS devices used in microsensors and actuators. Examples will include pressure sensors, accelerometers, gyros, FR filters, digital mirrors, microfluidics, micro total-analysis system, biomedical implants, etc. Instructor: Tai.

CNS/Bi/EE 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4).* For course description, see Computation and Neural Systems.

EE 187. VLSI and ULSI Technology. *9 units (3-0-6); first term. Prerequisites: APh/EE 9 ab, EE/APh 180 or instructor's permission.* This course is designed to cover the state-of-the-art micro/nanotechnologies for the fabrication of ULSI including BJT, CMOS, and BiCMOS. Technologies include lithography, diffusion, ion implantation, oxidation, plasma deposition and etching, etc. Topics also include the use of chemistry, thermal dynamics, mechanics, and physics. Not offered 2006–07.

CNS/CS/EE 188 a. Computation Theory and Neural Systems. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

CNS/CS/EE 188 b. Topics in Computation and Biological Systems. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

EE 226. Advanced Information and Coding Theory. *9 units (3-0-6); first term.* A selection of topics in information theory and coding theory not normally covered in EE/Ma 126 ab or EE/Ma 127 ab. These topics include constrained noiseless codes, constructive coding theorems for erasure channels, density evolution, repeat-accumulate and related codes, and network coding. Instructors: Ho, McEliece.

EE 243 abc. Quantum Electronics Seminar. *6 units (3-0-3); first, second, third terms.* Advanced treatment of topics in the field of quantum electronics. Each weekly seminar consists of a review and discussion of results in the areas of quantum electronics and optoelectronics. Not offered 2006–07.

EE 291. Advanced Work in Electrical Engineering. *Units to be arranged.* Special problems relating to electrical engineering. Primarily for graduate students; students should consult with their advisers.

ENGINEERING (GENERAL)

E 2. Frontiers in Engineering and Applied Science. *1 unit; first term. Open for credit to freshmen and sophomores.* Weekly seminar by a member of the EAS faculty to discuss his or her area of engineering and group's research at an introductory level. The course can be used to learn more about different areas of study within engineering and applied science. Graded pass/fail. Instructor: Rutledge.

E 10. Technical Seminar Presentations. *3 units (1-0-2); first, second, third terms. (Seniors required to take E 10 are given priority in registration. NOTE: Those who neither preregister nor attend the organizational meeting may not be permitted to enroll.)* Guidance and practice in organizing and preparing topics for presentation and in speaking with the help of visual aids, including whiteboards, overhead projectors, and video projectors. Instructor: Fender.

E 11. Written Technical Communication in Engineering and Applied Science. *3 units (1-0-2); first, second, third terms.* This class provides the opportunity for students to gain experience in technical writing in engineering and applied science. Students will choose a technical topic of interest, possibly based on a previous research or course project, and write a paper in a form that would be appropriate as an engineering report or a technical conference paper. The topic of ethical considerations for engineers and scientists as they arise in the publication and peer review process will also be discussed. A Caltech faculty member, a postdoctoral scholar, or technical staff member serves as a technical mentor for each student, to provide feedback on the content and style of the report. *Fulfills the Institute scientific writing requirement.* Instructors: Epalle, Readhead.

E 102. Entrepreneurial Development. *9 units (3-0-6); second term.* An introduction to the basics of getting a high-technology business started, including early-stage patent, organizational, legal, and financing issues; growing a company; taking a company public; and mergers and acquisitions. Lectures include presentations by invited experts in various specialties and keynote guest lecturers of national stature in technology start-ups. Instructor: Pickar.

E/ME 103. Management of Technology. *9 units (3-0-6); third term.* A course intended for students interested in learning how rapidly evolving technologies are harnessed to produce useful products. Students will work through Harvard Business School case studies, supplemented by lectures to elucidate the key issues. There will be a term project. The course is team-based and designed for students considering working in companies (any size, including start-ups) or eventually going to business school. Topics include technology as a growth agent, financial fundamentals, integration into other business processes, product development pipeline and portfolio management, learning curves, risk assessment, technology trend methodologies (scenarios, projections), motivation, rewards and recognition. Industries considered will include electronics (hardware and software), aerospace, medical, biotech, etc. E 102 and E/ME 105 are useful but not required precursors. Instructor: Pickar.

E/ME 105. Product Design for the Developing World. *9 units (3-0-6); first term. Prerequisite: advanced course work in engineering.* The course will emphasize products appropriate for the developing world—for those people subsisting on less than one dollar a day. It will provide the student with a working knowledge of contemporary methods of product design to meet the constraints of cost, performance, quality, and time to market as applied to the developing world. Areas covered include design for X (X = manufacturability/assembly, environmental issues, including sustainability, failure modes and effects analysis, test, etc.). The integration of customer needs and financial return will be discussed with specific examples. Instructor: Pickar.

E 150 abc. Engineering Seminar. *1 unit (1-0-0); each term.* All candidates for the M.S. degree in applied mechanics, electrical engineering, materials science, and mechanical engineering are required to attend any graduate seminar in any division each week of each term. Graded pass/fail. Instructor: Goodwin.

ENGLISH

En 1 ab. English As a Second Language. *9 units (3-0-6 or 4-0-5); first, second terms.* A program in the fundamentals of English composition for nonnative speakers of English, required for foreign students in need of supplementary instruction before entering freshman humanities courses. Students will be assigned to either En 1 b or the two-term sequence of En 1 ab on the basis of a diagnostic examination. *Not available for credit toward the humanities–social science requirement.* Instructors: Fonseca, Geasland.

En 2. Basic English Composition. *9 units (2-2-5); first term.* A course in the fundamentals of English composition for native speakers of English, required for students in need of supplementary instruction before entering freshman humanities courses. Students will be assigned to En 2 on the basis of a diagnostic examination. *Not available for credit toward the humanities–social science requirement.* Instructor: Fonseca.

Hum/En 5. Major British Authors. *9 units (3-0-6).* For course description, see Humanities.

Hum/En 6. American Literature and Culture. *9 units (3-0-6).* For course description, see Humanities.

Hum/En 7. Modern European Literature. *9 units (3-0-6).* For course description, see Humanities.

F/En 30. Introduction to Film. *9 units (3-0-6).* For course description, see Film.

En 84. Writing Science. *9 units (3-0-6).* Instruction and practice in writing about science and technology for general audiences. The course considers how to convey complex technical information in clear, engaging prose that nonspecialists can understand and appreciate. Readings in different genres (e.g., magazine and newspaper journalism, reflective essays, case studies, popularizations) raise issues for discussion and serve as models for preliminary writing assignments and for a more substantial final project on a topic of each student's choice. Includes oral presentation. *Satisfies the Institute scientific writing requirement and the option oral communication requirement for humanities majors.* Instructors: Marsen, Youra.

En 85. Writing Poetry. *9 units (3-0-6); third term.* Students will develop their poetic craft by creating poems in a variety of forms. The lecturer will provide guidance and direction, supervise class discussions of students' works, and assign outside reading as needed. Students may apply one term of En 85, 86, 87, and 88 to the additional HSS requirements, and all other courses in this series will receive Institute credit. Instructor: Hall. Not offered 2006–07.

En 86. Fiction and Creative Nonfiction Writing. *9 units (3-0-6); second term.* The class is conducted as a writing workshop in the short-story and personal essay/memoir form. Modern literary stories and essays are discussed, as well as the art and craft of writing well, aspects of "the writing life," and the nature of the publishing world today. Students are urged to write fiction or nonfiction that reflects on the nature of life. Humor is welcome, although not genre fiction such as formula romance, horror, thrillers, fantasy, or sci-fi. Students may apply one term of En 85, 86, 87, and 88 to the additional HSS requirements, and all other courses in this series will receive Institute credit. Instructor: Gerber.

En 87. Writing Fiction: The Imaginary. *9 units (3-0-6); first term.* Students will develop their talents for writing imaginary short stories other than science fiction. A number of models will be proposed to them for inspiration, e.g., folk tales, tales of the supernatural, fables, stories of "magic realism," examples of surrealism and the "absurd," and so on. The lecturer will provide guidance and direction, supervise class discussions of students' works, and assign outside reading as needed. Students may apply one term of En 85, 86, 87, and 88 to the additional HSS requirements, and all other courses in this series will receive Institute credit. Instructors: Hall, Magun.

En 88. Memoir: Writing the Self. *9 units (3-0-6); third term.* Whereas a diarist writes from an ever-moving present, the art of memoir demands *re-membering*, standing far enough back to shape experience and give it meaning, to discover a "story line" one never suspected existed, to find continuity in seeming randomness. Students may apply one term of En 85, 86, 87, and 88 to the additional HSS requirements, and all other courses in this series will receive Institute credit. Instructor: Magun.

En 92. Literature of the Holocaust. *9 units (3-0-6); third term.* Elie Wiesel has written: "At Auschwitz, not only man died, but also the idea of man . . . It was its own heart the world incinerated at Auschwitz." This class will explore the reverberation of this premise in the literature that grew out of the holocaust experience, as well as the shifting aesthetics of "holocaust literature" over the last half century. Put simply, can there be "an aesthetics of atrocity"? What are the responsibilities of art and literature to history? Should a perpetrator of genocide ever engage our moral imagination? In an attempt to grapple with these questions, students will read works, both fiction and nonfiction, by a range of authors, including Primo Levi, Elie Wiesel, Ida Fink, Cynthia Ozick, Tadeusz Borowski, Bernard Schlink, and W. G. Sebold. Not offered 2006–07.

En 93. Women on the Edge. *9 units (3-0-6); third term.* This class will consider how women's writing in the 20th century often flouts the conventional portrayal of woman as ministering angel preoccupied with the needs of family without much regard to her own. Writers to be read include Kate Chopin, Colette, Marguerite Duras, Sylvia Plath, Angela Carter, Jeanette Winterson, Toni Morrison, Elfriede Jelinek. Instructor: Magun. Not offered 2006–07.

En 98. Reading in English. *9 units (1-0-8). Prerequisite: instructor's permission.* An individual program of directed reading in English or American literature, in areas not covered by regular courses. Instructor: Staff.

En 99 ab. Senior Tutorial for English Majors. *9 units (1-0-8).* Students will study research methods and write a research paper. Required of students in the English option. Instructor: Staff.

En 114 ab. Shakespeare. *9 units (3-0-6); offered by announcement. Not open to freshmen.* A close study of Shakespeare's plays with an emphasis on his language, dramatic structures, characters, and themes. Each term will concentrate on a detailed consideration of three or four of Shakespeare's major plays. The first term is not a prerequisite for the second. Instructors: La Belle, Marneus.

En 116. Milton and the Epic Tradition. *9 units (3-0-6); third term.* Epic poetry is a competitive and self-referential genre. Virgil imitates and revises Homer, Dante makes Virgil his guide through hell and most of purgatory before leaving him behind, and Milton transforms the entire epic tradition. Since Milton's engagement with and criticism of the epic are essential elements of *Paradise Lost and Paradise Regained*, we will focus on his dialogue with Homer, Virgil, and Dante and their differing conceptions of heroism. Instructor: Pigman. Not offered 2006–07.

En 121. Literature and Its Readers. *9 units (3-0-6); third term.* The course will investigate readers who have made adventurous uses of their favorite works of literature, from Greek antiquity through the 20th century. Sometimes those readers count, at least temporarily, as literary critics, as when the philosopher Aristotle made Sophocles' *Oedipus the King* the central model in his wildly successful essay on the literary form of tragedy. Other readers have been even more experimental, as when Sigmund Freud, studying the same play, made the "Oedipus complex" a meeting point for his theory of psychology, his vision of human societies, and his fascination with literary narrative. It will discuss some basic questions about the phenomenon of literary reading. Does a book have a single meaning? Can it be used rightly or wrongly? Instructor: Haugen.

En 122. The 18th-Century English Novel. *9 units (3-0-6); third term.* The realistic novel as a surprising, even experimental moment in the history of fiction. How and why did daily life become a legitimate topic for narrative in the 18th century? The realistic turn clearly attracted new classes of readers, but did it also make the novel a better vehicle for commenting on society at large? Why were the formal conventions of realistic writing so tightly circumscribed? Authors may include Cervantes, Defoe, Richardson, Fielding, Sterne, Walpole, Boswell, and Austen. Instructor: Haugen.

En 123. The 19th-Century English Novel. *9 units (3-0-6); first term.* A survey of the 19th-century novel from Austen through Conrad, with special emphasis upon the Victorians. Major authors may include Austen, Shelley, Dickens, Eliot, Thackeray, Gaskell, Brontë, Collins, Trollope, Stoker, Hardy. Instructor: Pigman.

En 124. 20th-Century British Fiction. *9 units (3-0-6); third term.* A survey of the 20th-century British and Irish novel, from the modernist novel to the postcolonial novel. Major authors may include Conrad, Joyce, Woolf, Forster, Lawrence, Orwell, Amis, Lessing, Rushdie. Instructor: Pigman.

En 125 ab. British Romantic Literature. *9 units (3-0-6); second term.* A selective survey of English writing in the late 18th and early 19th centuries. Major authors may include Blake, Wordsworth, Coleridge, Byron, Keats, Percy Shelley, Mary Shelley, and Austen. Particular attention will be paid to intellectual and historical contexts and to new understandings of the role of literature in society. Not offered 2006–07.

En 126. Gothic Fiction. *9 units (3-0-6); third term.* The literature of horror, fantasy, and the supernatural, from the late 18th century to the present day. Particular attention will be paid to gothic's shifting cultural imperative, from its origins as a qualified reaction to Enlightenment rationalism, to the contemporary ghost story as an instrument of social and psychological exploration. Issues will include atmosphere and the gothic sense of space; gothic as a popular pathology; and the gendering of gothic narrative. Fiction by Walpole, Shelley, Brontë, Stoker, Poe, Wilde, Angela Carter, and Toni Morrison. Film versions of the gothic may be included. Not offered 2006–07.

En 128. Modern and Contemporary Irish Literature. *9 units (3-0-6); offered by announcement.* The development of Irish fiction, poetry, and drama from the early 20th-century Irish literary renaissance, through the impact of modernism, to the Field Day movement and other contemporary developments. Topics may include the impact of political violence and national division upon the literary imagination; the use of folk and fairy-tale traditions; patterns of emigration and literary exile; the challenge of the English language and the relation of Irish writing to British literary tradition; and recent treatments of Irish literature in regional, postcolonial, and global terms. Works by Joyce, Yeats, Synge, Friel, O'Brien, Heaney, Boland, and others. Instructor: Gilmartin.

En 129. Enlightenment Fiction. *9 units (3-0-6); third term.* What was the fate of fiction in an Age of Reason? Historians have questioned whether a conventional sense of the Enlightenment adequately accounts for European culture in the 18th century, and the literary imagination can seem particularly unsuited to generalizations about progress, optimism, reason, and social order. This course will consider experimental narratives and philosophical satires from the English and Continental tradition, as well as early Romantic responses to the Enlightenment. Readings may include Defoe, Sterne, Voltaire, Diderot, Mary Shelley, Hoffman, and fairy tales from the brothers Grimm. Instructor: Gilmartin.

En 132. American Literature Until the Civil War. *9 units (3-0-6); second term.* The course will analyze the literature of this period, from the Puritans through Melville, to determine how various writers understood their relationship to a new world of seemingly unlimited possibility. Authors covered may include Mary Rowlandson, Benjamin Franklin, Hannah Foster, Harriet Jacobs, Emerson, Thoreau, Harriet Beecher Stowe, Hawthorne, and Melville. Instructor: Weinstein.

En 133. 19th-Century American Women Writers. *9 units (3-0-6).* This course will analyze many of the most popular novels written in the 19th century. How might we account for their success in the 19th century and their marginalization (until recently) in the 20th century? Why were so many of these texts "sentimental"? How might we understand the appeal of "sentimental" literature? What are the ideological implications of sentimentalism? Authors may include Stowe, Warner, Cummins, Alcott, Phelps, Fern, etc. Not offered 2006–07.

En 134. The Career of Herman Melville. *9 units (3-0-6).* The course will focus on Melville's works from *Typee* through *Billy Budd*. Special emphasis will be placed on Melville's relations to 19th-century American culture. Instructor: Weinstein. Not offered 2006–07.

En 135. The Literature of American Reform. *9 units (3-0-6); third term.* The course will consider how American literature—from its inception to the present day—has been used as a vehicle for reform. To what extent is literature capable of bringing about social change? What changes, if any, did these texts effect? Do texts that seek to effect social change require a different analytical vocabulary than the one we conventionally use when discussing literary texts? A range of reform movements, including abolitionism, feminism, Native American rights, in view of these and other questions, will be considered. Texts may include *Uncle Tom's Cabin*, *White-Jacket*, *Ramona*, *Looking Backward*, *The Jungle*, *The Grapes of Wrath*, *Uncle Tom's Children*, and *Silent Spring*. Not offered 2006–07.

En 137. African American Literature. *9 units (3-0-6); second term.* This course analyzes some of the great works of American literature written by African Americans. This body of writing gives rise to two crucial questions: How does African American literature constitute a literary tradition of its own? How is that tradition inextricable from American literary history? From slave narratives to Toni Morrison's *Beloved*, from the Harlem Renaissance to Alice Walker, from Ralph Ellison to Walter Mosley, African American literature has examined topics as diverse and important as race relations, class identification, and family life. We shall analyze these texts not only in relation to these cultural issues, but also in terms of their aesthetic and formal contributions. Instructor: Weinstein.

En 138. Twain and His Contemporaries. *9 units (3-0-6); third term.* This course will study the divergent theories of realism that arose in the period after the Civil War and before World War I. Authors covered may include Howells, James, Charlotte Perkins Gilman, Twain, Sarah Orne Jewett, Jacob Riis, Stephen Crane, and W. E. B. DuBois. Not offered 2006–07.

En 141. James and Wharton. *9 units (3-0-6); third term.* The course covers selected novels, short fiction, and nonfiction writings of friends and expatriates Henry James and Edith Wharton. It will consider formal questions of style and genre as well as the literature's preoccupation with describing and defining American modernity, despite the authors' shared ambivalence toward their native country. Students will read as many as, but no more than, five novels. Texts covered may include *The Portrait of a Lady*, *Daisy Miller*, *The Ambassadors*, *selections from The Decoration of Houses*, *The House of Mirth*, *The Custom of the Country*, and *The Age of Innocence*. Not offered 2006–07.

En 146. Hollywood in the '40s. *9 units (3-0-6); offered by announcement.* This course covers Hollywood filmmaking during the most tumultuous decade in its history, from the last days of the Depression, through the extraordinary boom of World War II, to the postwar bust and the death of the studio system. It considers specific films (e.g., *Boom Town*, *Mrs. Miniver*, *They Were Expendable*, *Gentleman's Agreement*, *Out of the Past*) as well as general strategies of filmmaking at a time when the ever-changing domestic and world situation made the movie-going public's tastes and needs less predictable than ever. Topics include the rise of market research and public relations in Hollywood, the emergence and evolution of particular genres (the combat film, the home front melodrama, film noir), the "maturing" of the postwar audience, and the European art film. Instructor: Jurca.

En 150. Fundamentals of the Art of Poetry. *9 units (3-0-6); third term.* What is poetry? Why and how should one read it? What "weapons" does the good poem deploy in order to give pleasure? How does an inexperienced reader develop into an expert and a sensitive one? To illustrate the nature, functions, and resources of poetry, a wide-ranging selection of poems will be read and discussed. Instructor: Mandel.

En 151. Plots and Conspiracies in U.S. Literature. *9 units (3-0-6); first term.* An exploration of why democratic America, identified as a country of openness and transparency, has produced a body of literature (fiction and nonfiction) committed to the notion that secret maneuverings and cabals are the driving force of national and private life. Readings will cover the 19th and 20th centuries and include such writers as Don DeLillo, Barbara Kingsolver, and Mike Davis. Instructor: Tichi.

En 170. Drama from the Middle Ages to Molière. *9 units (3-0-6); third term.* A study of major dramatic works from the 15th to the mid-17th century. Students will read medieval plays like Abraham and Isaac and Everyman; British Renaissance works including Marlowe's Doctor Faustus and two Shakespearean plays; several Spanish comedias of the Golden Age, among them the original Don Juan play; and Molière's masterpieces: *Tartuffe* and *The Misanthrope*. Not offered 2006–07.

En 171. Drama from Molière to Wilde. *9 units (3-0-6).* A study of French plays of the age of Louis XIV, featuring Molière and Racine; English comedies of the 17th and 18th centuries, including Sheridan's *The Rivals;* masterpieces of German drama of the Romantic age, among them Schiller's *Maria Stuart* and Goethe's *Faust; The Inspector General* by the Russian Nikolay Gogol; Edmond Rostand's *Cyrano de Bergerac;* Oscar Wilde's *The Importance of Being Earnest*, and other works as time permits. Not offered 2006–07.

En 172. Drama from Ibsen to Beckett. *9 units (3-0-6); second term.* A wide international range of plays will be studied, beginning with major texts by Ibsen and Chekhov, and concluding with Ionesco and Beckett. In between, students will read important plays by G. B. Shaw, Sean O'Casey, Pirandello, Bertolt Brecht, T. S. Eliot, Arthur Miller, and others. Instructor: Mandel.

En 180. Special Topics in English. *9 units (3-0-6). See registrar's announcement for details.* Instructor: Staff.

En 181 a. Classics of Science Fiction: 1940–70. *9 units (3-0-6); third term.* This course will aim to examine, critically, the achievements of one of the many "golden ages" of science fiction. Among the authors examined will be Pohl and Kornbluth, Bradbury, Bester, Vonnegut, Wyndham, Heinlein, Dick, Herbert, Ballard, Le Guin, Asimov, Clarke, Silverberg, Aldiss. The course will aim to give formal and generic definition to the texts examined and to reinsert them into the period of their original publication. Instructor: Sutherland.

En 181 b. Hardy: The Wessex Novels. *9 units (3-0-6); third term.* This course will examine the body of work that the late Victorian novelist Thomas Hardy published under the general title *The Wessex Novels*, that is, the sequence of works from *Far from the Madding Crowd* to *Jude the Obscure*. The six main novels will be read critically to give a sense of the totality of this greatest British regional novelist's achievement. Instructor: Sutherland.

En 181 c. Classics of Science Fiction: The 1960s. *9 units (3-0-6); third term.* This course will aim to examine critically the achievements of one of the many "golden ages" of science fiction. Among the authors dealt with (but not necessarily restricted to) in the course will be Pohl and Kornbluth, Bester, Dick, Asimov, Clarke, Aldiss, Ballard, Le Guin, Aldiss, Wyndham. The course will aim to give formal and generic definition to the texts covered and to reinsert them into the period of their original conception and publication. Instructor: Sutherland.

En 181 d. Jane Austen, the Six Novels. *9 units (3-0-6); third term.* This course will examine in sequence, and in depth, the major novels of Jane Austen: *Northanger Abbey*, *Sense and Sensibility*, *Pride and Prejudice*, *Emma*, *Mansfield Park*, and *Persuasion*. In addition to intensive reading, attention will be given to the many adaptations of Austen's novels in other media. Instructor: Sutherland.

ENGLISH AS A SECOND LANGUAGE

Please see page 231 for requirements regarding English competency. All of the following courses are open to international graduate students only.

ESL 101 ab. Oral Communication and Pronunciation. *3 units (3-0-0); first and second terms.* Communication and pronunciation in spoken English. Development of pronunciation, vocabulary, listening comprehension, and accuracy and fluency in speaking. Aspects of American culture will be discussed. The first term is required for all first-year international students designated by the ESL screening process. Passing the class is based on attendance and effort. Graded pass/fail. Instructors: Geasland, Laib.

ESL 102. Advanced Spoken English for Academic Purposes. *Noncredit; first and third terms.* Development of fluency and communication strategies. Emphasis on presentation skills and interpersonal communication on scientific topics. Strongly recommended for first-time international graduate teaching assistants. Instructors: Geasland, Laib.

ESL 103. English in Everyday Life. *Noncredit; first, second, third terms.* Expressions, vocabulary, slang, and idioms used in daily life. Conversation and discussion, with feedback from instructors. Occasional grammar and pronunciation review. Comprehension of newspaper and magazine articles, as well as films and television programs. Instructors: Geasland, Laib.

ESL 104. Pronunciation Improvement and Accent Reduction. *Noncredit; second term.* Aspects of American English pronunciation. Vowels and consonants, word and syllable stress, sentence stress and rhythm, intonation, and linking. Intensive practice and techniques for achieving correct pronunciation through self-monitoring. Instructors: Geasland, Laib.

ESL 105. Oral Presentation and Public Speaking. *Noncredit; second, third terms.* Oral presentation in a variety of settings, including oral exams, seminars, conferences, and the classroom. Focus on the organization of ideas, delivery techniques, pronunciation, grammar, and vocabulary. Frequent in-class presentations by students based on their current research interests, followed by critiques. Improvement of confidence and delivery skills. Instructors: Geasland, Laib.

ESL 106. Writing Seminar. *Noncredit; third term.* Strategies for improving academic writing. Emphasis on grammar, word choice, organization, logical connectors, and punctuation. Classroom exercises and editing practice based on student writing samples. Instructors: Geasland, Laib.

ENVIRONMENTAL SCIENCE AND ENGINEERING

ESE 1. Introduction to Environmental Science and Engineering. *9 units (3-0-6); third term. Prerequisites: Ph 1 ab, Ch 1 ab, and Ma 1 ab.* An introduction to the array of major scientific and engineering issues related to environmental quality on a local, regional, and global scale. Fundamental aspects of major environmental problems will be addressed with an overall focus on the dynamic interplay among the atmosphere, biosphere, geosphere, and hydrosphere. Underlying scientific principles based on biology, chemistry, and physics will be presented. Engineering solutions to major environmental problems will be explored. Not offered on a pass/fail basis. Instructor: Staff. *Satisfies the menu requirement of the Caltech core curriculum.* Not offered 2006–07.

ESE 90. Undergraduate Laboratory Research in Environmental Science and Engineering. *Units by arrangement; any term. Approval of research supervisor required prior to registration.* Independent research on current environmental problems; laboratory or field work is required. A written report is required for each term of registration. Graded pass/fail. Instructor: Staff.

ESE 100. Special Topics in Environmental Science and Engineering. *6 or more units as arranged. Prerequisite: instructor's permission.* Special courses of reading, problems, or research for first-year graduate students or qualified undergraduates. Graded pass/fail. Instructor: Staff.

ESE 101. Current Problems in Environmental Science and Engineering. *3 units; first term.* A discussion course that focuses on current research by ESE faculty, and open research questions in the field. Required for first-year ESE graduate students. Instructor: Staff.

ACM/ESE 118. Methods in Applied Statistics and Data Analysis. *9 units (3-0-6).* For course description, see Applied and Computational Mathematics.

ESE 142. Aquatic Chemistry. *9 units (3-0-6); first term. Prerequisite: Ch 1 or instructor's permission.* Principles of inorganic and physical chemistry applied to natural and engineered aquatic systems. Biogeochemical processes controlling the major ion composition of aquatic systems and the behavior of the trace inorganic constituents of such systems are examined. Fundamental aspects of thermodynamics and quantitative description of the composition of natural waters are stressed. Instructor: Hering.

Ge/ESE 143. Organic Geochemistry. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

ESE 144. Applications of Aquatic Chemistry. *9 units (3-0-6); second term. Prerequisite: ESE 142.* Case studies are used to illustrate the effects of biogeochemical processes on the composition of ground and surface waters. Systems to be examined include natural waters subject to varying levels of perturbations as a result of human activities, and engineered systems, such as constructed wetlands or water treatment systems. Quantitative equilibrium and kinetic modeling are emphasized. Given in alternate years; not offered 2006–07. Instructor: Hering.

ESE/Ge 148 abc. Global Environmental Science. *9 units each term. Prerequisites: Ch 1, Ma 2, Ph 2, or equivalents.* Global change on timescales of years to centuries.

a. Climate Change. *(3-0-6); first term.* Radiative transfer and the greenhouse effect. Scattering and absorption by gases, clouds, and aerosols. Feedbacks due to water vapor, clouds, ice, and vegetation. Chemistry of greenhouse gases. Climates of the past. Ice ages. The global-warming debate. Economic and political aspects of climate change. Instructor: Wennberg.

b. Atmosphere-Ocean Circulations. *(3-0-6); second term.* Large-scale motions in Earth's atmosphere and oceans. Effects of planetary rotation and density stratification. Observing systems and data assimilation. Numerical weather prediction. Climate modeling. Parameterizations. Dynamical aspects of El Niño, global warming, and the ozone hole. Instructor: Ingersoll.

c. Biogeochemical Cycles. *(3-0-6); third term.* Global biogeochemical cycles, fluxes, and reservoirs in the solid earth, oceans, biosphere, and atmosphere. The hydrologic cycle, weathering and erosion, soil formation, nutrient cycling and limitation, ecosystem function and metrics, photosynthesis and primary production, heterotropic recycling, carbon cycle dynamics, atmospheric trace gases, and stable-isotope tracers. Variability in biogeochemical cycles over Earth history, and recent modification by human activities. Instructor: Sessions.

Ge/ESE 149. Marine Geochemistry. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

ESE 150 abc. Seminar in Environmental Science and Engineering. *1 unit (1-0-0); each term.* Seminar on current developments and research within the field of environmental engineering science, with special consideration given to work at the Institute. Graded pass/fail. Instructor: Leadbetter.

ESE/Ge 152. Atmospheric Radiation. *9 units (3-0-6); second term. Prerequisite: ESE/Ge 148 a or instructor's permission.* The basic physics of absorption and scattering by molecules, aerosols, and clouds. Theory of radiative transfer. Band models and correlated-k distributions and scattering by nonspherical particles. Solar insolation, thermal emission, heating rates and applications to climate. Instructor: Yung.

ESE/Ge 153. Atmosphere and Ocean Dynamics. *9 units (3-0-6); third term. Prerequisite: ESE 148 b or an introductory fluid dynamics course.* Fluid dynamics of the atmosphere and oceans, beginning with linear wave dynamics and wave–mean flow interaction theory and leading to theories of the maintenance of large-scale circulations. Topics include barotropic Rossby waves, flow-over topography; shallow-water dynamics and potential vorticity; quasi-geostrophic theory; barotropic and baroclinic instability; wave–mean flow interaction; maintenance of the global-scale circulation of the atmosphere; structure of wind-driven ocean circulation. Instructor: Ingersoll.

Ge/ESE 154. Readings in Paleoclimate. *3 units (1-0-2).* For course description, see Geological and Planetary Sciences.

Ge/ESE 155. Paleoceanography. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

ChE/ESE 158. Aerosol Physics and Chemistry. *9 units (3-0-6).* For course description, see Chemical Engineering.

ESE 159. Environmental Analysis Laboratory. *9 units (1-6-2); third term. Prerequisite: any 100-level ESE course or instructor's permission.* Introduction to modern laboratory techniques and basic sampling principles in environmental water, air, and biological analysis. Modular experiments will address sampling, measurement, and data analysis based around a region of local environmental interest. Regions may include the Arroyo Seco watershed, San Gabriel Mountains, or Caltech campus. Principles of basic experimental design, laboratory technique, elementary statistics, and scientific writing will be emphasized. Instructors: Leadbetter, Flagan.

ESE/Bi 166. Microbial Physiology. *9 units (3-1-5); first term. Recommended prerequisite: one year of general biology.* A course on growth and functions in the prokaryotic cell. Topics covered: growth, transport of small molecules, protein excretion, membrane bioenergetics, energy metabolism, motility, chemotaxis, global regulators, and metabolic integration. Instructor: Leadbetter.

ESE/Bi 168. Microbial Metabolic Diversity. *9 units (3-0-6); second term. Prerequisites: ESE 142, ESE/Bi 166.* A course on the metabolic diversity of microorganisms. Basic thermodynamic principles governing energy conservation will be discussed, with emphasis placed on photosynthesis and respiration. Students will be exposed to genetic, genomic, and biochemical techniques that can be used to elucidate the mechanisms of cellular electron transfer underlying these metabolisms. Instructor: Newman.

Ge/ESE 170. Microbial Ecology. *9 units (3-2-4).* For course description, see Geological and Planetary Sciences.

ESE/Ge/Ch 171. Atmospheric Chemistry I. *9 units (3-0-6); third term. Prerequisite: Ch 1 or equivalent.* A detailed course about chemical transformation in Earth's atmosphere. Kinetics, spectroscopy, and thermodynamics of gas- and aerosol-phase chemistry of the stratosphere and troposphere; sources, sinks, and lifetimes of trace atmospheric species; stratospheric ozone chemistry; oxidation mechanisms in the troposphere. Instructors: Seinfeld, Wennberg.

ESE/Ge/Ch 172. Atmospheric Chemistry II. *3 units (3-0-0); first term. Prerequisite: ESE/Ge/Ch 171 or equivalent.* A lecture and discussion course about active research in atmospheric chemistry. Potential topics include halogen chemistry of the stratosphere and troposphere; aerosol formation in remote environments; coupling of dynamics and photochemistry; development and use of modern remote-sensing and in situ instrumentation. Graded pass/fail. Instructors: Seinfeld, Wennberg. Given in alternate years; not offered 2006–07.

ESE/Ge 173. Topics in Atmosphere and Ocean Dynamics. *9 units (3-0-6); first term. Prerequisite: ESE/Ge 153 or equivalent.* A lecture and discussion course on current research in atmosphere and ocean dynamics. Topics covered vary from year to year and may include geostrophic turbulence, atmospheric convection and cloud dynamics, wave dynamics and large-scale circulations in the tropics, middle-atmosphere dynamics, dynamics of El Niño and the southern oscillation, maintenance of the ocean thermocline, and dynamics of the southern ocean. Instructor: Schneider.

ESE/Ch/Ge 175 ab. Environmental Organic Chemistry. *9 units (3-0-6); second, third terms.* A detailed analysis of the important chemical reactions and physico-chemical processes governing the behavior and fate of organic compounds in the surface and subsurface aquatic environments. The course is focused on physical organic chemistry relevant to natural waters. Fundamental aspects of thermodynamics, kinetics, mechanisms, and transport are stressed. Instructors: Hoffmann, Dalleska.

ESE 200. Advanced Topics in Environmental Science and Engineering. *Units by arrangement, any term.* Course to explore new approaches to environmental problems. The topics covered vary from year to year, depending on the interests of the students and staff.

ESE 250. Advanced Environmental Seminar. *Units by arrangement, not to exceed 4 units (2-0-2); each term. Prerequisite: instructor's permission.* A seminar course for advanced graduate students and staff to discuss current research and technical literature on environmental problems. As the subject matter changes from term to term, it may be taken any number of times. Not offered 2006–07.

ESE 300. Thesis Research.

For other closely related courses see listings under Chemistry, Chemical Engineering, Civil Engineering, Mechanical Engineering, Biology, Geology, Economics, and Social Science.

Graduate students may also enroll in graduate courses offered by the Scripps Institution of Oceanography under an exchange program. Graduate students majoring in environmental science and engineering, who may take a subject minor in oceanography for the Ph.D. degree, should consult the executive officer for more information.

FILM

F/En 30. Introduction to Film. *9 units (3-0-6).* This course examines film as an art and as an institution from 1895 through the present. Students will acquire the basic vocabulary and techniques of film analysis, focusing on questions of form (mise-en-scène, cinematography, editing, sound) and narrative, as well as an understanding of the historical development of the medium with an emphasis on the American, European, and Asian contexts. Topics will include the early cinema of illusion, the actuality film, the transition to sound, the Hollywood star system, Italian neorealism, the French New Wave, Dogma 95, and Hong Kong action cinema. Not offered 2006–07.

F 101. Classical Hollywood Cinema. *9 units (3-0-6); offered by announcement.* This course examines the period of classical filmmaking in Hollywood from roughly 1925 through the 1950s. It emphasizes the study of films as texts with distinctive formal properties as well as the special features of Hollywood filmmaking. Topics include the rise of the studio system, technical transformations (sound, color, deep focus), genres (the musical, the Western), cultural contexts (the Depression, the Cold War), and the economic history of the film corporations. Students will develop an understanding of how a significant body of films, including *The Jazz Singer*, *Public Enemy*, *Citizen Kane*, *Sunset Boulevard*, and *Singin' in the Rain*, functioned as commercial, aesthetic, and cultural artifacts during the "Golden Age" of Hollywood. Not offered 2006–07.

F 102. Hollywood in the '40s. *9 units (3-0-6); offered by announcement.* This course covers Hollywood filmmaking during the most tumultuous decade in its history, from the last days of the Depression, through the extraordinary boom of World War II, to the postwar bust and the decline of the studio system. It considers specific films (e.g., *Sullivan's Travels*, *Casablanca*, *Mrs. Miniver*, *The Best Years of Our Lives*, and *Gentleman's Agreement*) as well as general strategies of filmmaking at a time when the ever-changing domestic and world situation made the movie-going public's tastes and needs less predictable than ever. Topics include the rise of market research and public relations in Hollywood, the emergence and evolution of particular genres (the combat film, the homefront melodrama, film noir), wartime propaganda, the "maturing" of the movies, and the role of film in postwar reconversion. Not offered 2006–07.

L/F 104. French Cinema. *9 units (3-0-6).* For course description, see Languages.

H/F 131. History on Film. *9 units (2-2-5).* For course description, see History.

H/F 133. Topics in Film History. *9 units (2-2-5).* For course description, see History.

H/F 134. The Science Fiction Film. *9 units (2-2-5).* For course description, see History.

H/F 136. Ethnic Visions. *9 units (2-2-5).* For course description, see History.

GEOLOGICAL AND PLANETARY SCIENCES

Geology, Geobiology, Geochemistry, Geophysics, Planetary Science

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Ge 1. Earth and Environment. *9 units (3-3-3); third term.* An introduction to the ideas and approaches of earth and environmental sciences, including both the special challenges and viewpoints of this kind of science as well as the ways in which basic physics, chemistry, and biology relate to these sciences. In addition to a wide-ranging lecture-oriented component, there will be a required field trip component (two weekend days), and a special research topic (often lab-oriented) chosen from many alternatives and to be carried out in small groups each led by a professor. The lectures and topics cover such issues as solid earth structure and evolution, plate tectonics, oceans and atmospheres, climate change, and the relationship between geological and biological evolution. Not offered on a pass/fail basis. Instructor: M. Brown. *Satisfies the menu requirement of the Caltech core curriculum.*

Ge 10. Frontiers in Geological and Planetary Sciences. *3 units (2-0-1); third term. The course may be taken multiple times.* Weekly seminar by a member of the Division of Geological and Planetary Sciences or a visitor to discuss a topic of his or her current research at an introductory level. The course is designed to introduce students to research and research opportunities in the division and to help students find faculty sponsors for individual research projects. Graded pass/fail. Instructors: Farley, Rossman.

Ge 11 abc. Introduction to Earth and Planetary Sciences. *9 units each term. Prerequisites: Ch 1, Ma 1, and Ph 1; or instructor's permission.* Comprehensive, integrated overview of Earth and planets. Although designed as a sequence, any one term can be taken as a stand-alone course. Biologists are particularly welcome in Ge 11 b, as are physicists and astronomers in Ge/Ay 11 c.

a. Earth as a Planet. *(3-3-3); first term.* Systematic introduction to the physical and chemical processes that have shaped Earth as a planet over geological time, and the observable products of these processes—rock materials, minerals, land forms. Geophysics of Earth. Plate tectonics; earthquakes; igneous activity. Weathering, erosion, and sedimentary rocks. Metamorphism and metamorphic rocks. Rock deformation and mountain building. Role of aqueous, atmospheric, glacial, and tectonic processes in shaping Earth's surface and our environment. Earth resources. Field trips, interpretation of geological maps, and laboratory study of Earth materials (minerals and rocks). Instructor: Eiler.

b. Earth and the Biosphere. *(3-3-3); second term.* Systematic analysis of the origin and evolution of life in the solar system, and its impact on the atmosphere, hydrosphere, and climate of Earth. Archean surface environments and production of oxygen. Bacterial evolution, photosynthesis, genes as fossils. Banded iron stones, algal mats, stromatolites, global glaciation, and molecular evolution. Biological fractionation of stable isotopes. Numerical calibration of the geological time scale, the Cambrian evolutionary explosion, mass extinction events, and human evolution. The course usually includes one major field trip, and laboratory studies of fossils, Precambrian rocks, and geological processes. Instructor: Kirschvink.

Ge/Ay 11 c. Planetary Sciences. *(3-0-6); third term.* A broad introduction to what is known about the origin, evolution, and present state of the solar system. Observations of young solar-mass stars, disks, and extrasolar planets, as well as meteorite properties and planet formation models, are the constraints on solar-system origin. Based on data from Earth-based observations, planetary spacecraft, and extraterrestrial materials, the evolution and present states of planetary objects are addressed systematically by considering small bodies (comets and asteroids), the terrestrial planets, the giant planets, and finally, the icy bodies of the outer solar system. Instructor: Ingersoll.

Ge 11 d. Geophysics. *9 units (3-0-6); second term. Prerequisites: Ma 2, Ph 2.* An introduction to the geophysics of the solid earth; formation of planets; structure and composition of Earth; interactions between crust, mantle, and core; surface and internal dynamics; mantle convection; imaging of the interior; seismic tomography. Instructors: Gurnis, Clayton.

Ge 13. Scientific Writing Tutorial in the Geological and Planetary Sciences. *3 units (1-0-2); third term.* This class provides the opportunity for students to gain experience in writing a substantial paper in the style typical of peer-reviewed journals, such as *Annual Reviews of Earth and Planetary Sciences*, *Geology*, *Science*, or *Nature*. Grading will be evaluated jointly by each student's adviser and the course instructor. *Fulfills the Institute scientific writing requirement.* Instructor: Kirschvink.

Ge 40. Special Problems for Undergraduates. *Units to be arranged; any term.* This course provides a mechanism for undergraduates to undertake honors-type work in the geologic sciences. By arrangement with individual members of the staff. Graded pass/fail.

Ge 41 abc. Undergraduate Research and Bachelor's Thesis. *Units to be arranged; first, second, third terms.* Guidance in seeking research opportunities and in formulating a research plan leading to preparation of a bachelor's thesis is available from the division undergraduate research counselors, Professors Rossman and Kirschvink. Graded pass/fail.

Ge 100 abc. Geology Club. *1 unit (1-0-0); first, second, third terms.* Presentation of papers on research in geological and planetary sciences by guest speakers. Graded pass/fail. Instructor: Kirschvink.

Ge 101. Introduction to Geology and Geochemistry. *12 units (4-0-8); first term. Prerequisite: graduate standing or instructor's permission.* Historical deduction in the geological and planetary sciences. Plate tectonics as a unifying theory of geology. Igneous and metamorphic processes, structural geology and geomorphology; weathering and sedimentary processes. Nucleosynthesis and chemical history of the solar system; distribution of the elements in the earth; isotopic systems as tracers and clocks; evolution of the biosphere; global geochemical and biogeochemical cycles; geochemical constraints on deep Earth structure. Instructor: Asimow.

Ge 102. Introduction to Geophysics. *9 units (3-0-6); second term. Prerequisites: Ma 2, Ph 2, or Ge 108, or equivalents.* An introduction to the physics of the earth. The present internal structure and dynamics of the earth are considered in light of constraints from the gravitational and magnetic fields, seismology, and mineral physics. The fundamentals of wave propagation in earth materials are developed and applied to inferring Earth structure. The earthquake source is described in terms of seismic and geodetic signals. The following are also considered: the contributions that heat-flow, gravity, paleomagnetic, and earthquake mechanism data have made to our understanding of plate tectonics, the driving mechanism of plate tectonics, and the energy sources of mantle convection and the geodynamo. Instructor: Simons.

Ge 103. Introduction to the Solar System. *9 units (3-0-6); third term. Prerequisite: instructor's permission.* Formation and evolution of the solar system. Interiors, surfaces, atmospheres of the sun, planets, and satellites. Orbital dynamics, chaos, and tidal friction. Cratering. Comets and asteroids. Magnetic fields, dynamos, solar wind, heliosphere, magnetospheres. Extrasolar planetary systems. Instructor: Ingersoll.

Ge 104. Introduction to Geobiology. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* Coevolution of life and Earth. Basic concepts in geology and biology are presented in the context of significant events in Earth's history. The course provides a brief introduction to essential concepts in biology and geology to provide a common foundation for all students. Important geobiological processes and major events are discussed, including fossilization, the earliest records of life, evolution of photosynthesis and the oxygenation of Earth's environment, origin of animals at the Precambrian-Cambrian boundary, extinction of invertebrates at the Permian-Triassic boundary, and the Eocene-Paleocene thermal crisis. A weekend field trip to modern and ancient geobiological sites. Instructors: Grotzinger, Newman.

Ge 106. Introduction to Field and Structural Geology. *12 units (3-6-3) or 6 units (1-4-1); third term. Prerequisite: Ge 11 ab.* The 6-unit option introduces methods of geologic mapping, intended for students outside the geology option who desire a practical introduction to the documentation of Earth history; required for all students planning to take Ge 120. Geology majors must enroll in the 12-unit option, which additionally introduces continuum mechanics, interpretation of deformed rocks, and the tectonics of mountain belts. Instructor: Wernicke.

Ge 108. Applications of Physics to the Earth Sciences. *9 units (3-0-6); first term. Prerequisites: Ph 2 and Ma 2 or equivalent.* An intermediate course in the application of the basic principles of classical physics to the earth sciences. Topics will be selected from: mechanics of rotating bodies, the two-body problem, tidal theory, oscillations and normal modes, diffusion and heat transfer, wave propagation, electro- and magneto-statics, Maxwell's equations, and elements of statistical and fluid mechanics. Instructor: Brown.

Ge 109. Oral Presentation. *3 units (1-0-2); third term.* Practice in the effective organization and delivery of reports before groups. Successful completion of this course is required of all candidates for degrees in the division. Graded pass/fail. Instructors: Bikle, staff.

Ge 111 ab. Applied Geophysics Seminar and Field Course. An introduction to the theory and application of basic geophysical field techniques consisting of a comprehensive survey of a particular field area using a variety of methods (e.g., gravity, magnetic, electrical, GPS, seismic studies, and satellite remote sensing). The course will consist of a seminar held in the third term, which will discuss the scientific background for the chosen field area, along with the theoretical basis and implementation of the various measurement techniques. The 6–10 day field/data analysis component is covered in Ge 111 b. May be repeated for credit with an instructor's permission. Instructors: Simons, Clayton, Stock.

a. Applied Geophysics Seminar. *6 units (3-3-0); third term. Prerequisite: instructor's permission.*

b. Applied Geophysics Field Course. *9 units (0-3-6); summer. Prerequisite: Ge 111 a.*

Ge 112. Geomorphology and Stratigraphy. *12 units (3-5-4); first term. Prerequisite: Ge 11 ab.* This course is an introduction to Earth's landscapes and strata. We explore the nature of fluvial, lacustrine, glacial, volcanic, tectonic, and various marine landforms and sediments, whose character and sequencing enable us to understand geologic history and processes. The focus will be on modern, active systems and the interpretation of paleoenvironments and paleoclimates of the past million years. But the nature and genesis of sequence architecture of sedimentary basins will also be introduced. Field trips and laboratory exercises. Instructor: Sieh.

Ge 114 ab. Mineralogy.

a. *9 units (3-4-2); first term.* Atomic structure, composition, physical properties, occurrence, and identifying characteristics of the major mineral groups. The laboratory work involves the characterization and identification of important minerals by their physical and optical properties. Instructor: Rossman.

b. *3 units (0-2-1); first term. Prerequisite: concurrent enrollment in Ge 114 a or instructor's permission.* Additional laboratory studies of optical crystallography and the use of the petrographic microscope. Instructor: Rossman.

Ge 115 ab. Petrology and Petrography. Systematic study of rocks and rock-forming minerals with emphasis on use of the petrographic microscope and megascopic identification; interpretation of mineral assemblages, textures, and structures; problems of genesis.

a. Igneous Petrology and Petrography. *12 units (3-6-3) or 6 units (3-0-3) with instructor's permission; second term. Prerequisite: Ge 114 ab.* The mineralogical and chemical composition, origin, occurrence, and classification of igneous rocks, considered mainly in the light of chemical equilibrium and of experimental studies. Detailed consideration of the structures, phase relations, and identification of the major igneous minerals. Instructor: Stolper.

b. Metamorphic Petrology and Petrography. *12 units (3-6-3) or 6 units (3-0-3) with instructor's permission; third term. Prerequisite: Ge 115 a.* The mineralogic and chemical composition, occurrence, and classification of metamorphic rocks; interpretation of mineral assemblages in the light of chemical equilibrium and experimental studies. Detailed consideration of structure, phase relations, composition, and determination of the major metamorphic minerals. Instructor: Eiler.

Ge 120. Summer Field Geology. *12 units (0-12-0); summer. Prerequisites: Ge 11 ab, Ge 106, or instructor's permission.* Intensive course in techniques of field observation and documentation. The course includes two and one-half weeks of mapping in a well-exposed area of the southwestern United States, and the preparation of a report in September prior to registration week. Instructors: Saleeby, Avouac.

Ge 121 ab. Advanced Field and Structural Geology. *12 units (0-9-3); first, third terms. Prerequisites: Ge 120 or equivalent, or instructor's permission.* Field mapping and supporting laboratory studies in topical problems related to Southern California tectonics and petrogenesis. Each year the sequence offers a breadth of experience in igneous, metamorphic, and sedimentary rocks. Instructors: Wernicke (first term), Saleeby (third term).

Ge 122. Geologic Hazard Assessment. *12 units (1-8-3); summer term. Prerequisites: Ge 120 or equivalent, or instructor's permission.* Two and one-half weeks of intensive GIS-lab- and field-based description and evaluation of the deposits and landforms related to a geologic hazard. Field location will vary from year to year, but will focus on a particular locale, either within the United States or abroad, where a seismic, volcanic, slope-stability, or other hazard can be documented and evaluated. In September, the field component will be held in the Mono Basin, eastern California. Instructor: Sieh.

Ge 124 ab. Paleomagnetism and Magnetostratigraphy. Application of paleomagnetism to the solution of problems in stratigraphic correlation and to the construction of a high-precision geological timescale. Given in alternate years; offered 2006–07. Instructor: Kirschvink.

a. *6 units (0-0-6); second term.* A field trip to the southwest United States or Mexico to study the physical stratigraphy and magnetic zonation, followed by lab analysis.

b. *9 units (3-3-3); third term. Prerequisite: Ge 11 ab.* The principles of rock magnetism and physical stratigraphy; emphasis on the detailed application of paleomagnetic techniques to the determination of the history of the geomagnetic field.

Ge/Ch 127. Nuclear Chemistry. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* A survey course in the properties of nuclei, and in atomic phenomena associated with nuclear-particle detection. Topics include rates of production and decay of radioactive nuclei; interaction of radiation with matter; nuclear masses, shapes, spins, and moments; modes of radioactive decay; nuclear fission and energy generation. Instructor: Burnett. Given in alternate years; not offered 2006–07.

Ge/Ch 128. Cosmochemistry. *9 units (3-0-6); third term. Prerequisite: instructor's permission.* Examination of the chemistry of the interstellar medium, of protostellar nebulae, and of primitive solar-system objects with a view toward establishing the relationship of the chemical evolution of atoms in the interstellar radiation field to complex molecules and aggregates in the early solar system. Emphasis will be placed on identifying the physical conditions in various objects, timescales for physical and chemical change, chemical processes leading to change, observational constraints, and various models that attempt to describe the chemical state and history of cosmological objects in general and the early solar system in particular. Instructor: Blake. Given in alternate years; not offered 2006–07.

Ge 131. Planetary Structure and Evolution. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* A critical assessment of the physical and chemical processes that influence the initial condition, evolution, and current state of planets, including our planet and planetary satellites. Topics to be covered include a short survey of condensed-matter physics as it applies to planetary interiors, remote sensing of planetary interiors, planetary modeling, core formation, physics of ongoing differentiation, the role of mantle convection in thermal evolution, and generation of planetary magnetic fields. Instructor: Stevenson.

Ge/Ay 132. Atomic and Molecular Processes in Astronomy and Planetary Sciences. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* Fundamental aspects of atomic and molecular spectra that enable one to infer physical conditions in astronomical, planetary, and terrestrial environments. Topics will include the structure and spectra of atoms, molecules, and solids; transition probabilities; photoionization and recombination; collisional processes; gas-phase chemical reactions; and isotopic fractionation. Each topic will be illustrated with applications in astronomy and planetary sciences, ranging from planetary atmospheres and dense interstellar clouds to the early universe. Instructor: Blake. Given in alternate years; not offered 2006–07.

Ge/Ay 133. The Formation and Evolution of Planetary Systems. *9 units (3-0-6); first term.* Review current theoretical ideas and observations pertaining to the formation and evolution of planetary systems.

Topics to be covered include low-mass star formation, the protoplanetary disk, accretion and condensation in the solar nebula, the formation of gas giants, meteorites, the outer solar system, giant impacts, extrasolar planetary systems. Instructor: Blake.

Ge 135. Tectonics and Crustal Structure of Southern California. *9 units (3-3-3); first term. Prerequisite: Ge 11 ab or Ge 101, or equivalents.* Development of the Southern California region basement and its disruption by Neogene to recent tectonics, the Neogene stratigraphic record of these tectonics, the structure and kinematics of the modern plate juncture system, and the geophysical expression of these features. Three one-day weekend local field trips spaced throughout the term. Alternates with Ge 147. Instructor: Saleeby. Given in alternate years; not offered 2006–07.

Ge 136 abc. Regional Field Geology of the Southwestern United States. *3 units (1-0-2); first, second, third terms. Prerequisite: Ge 11 ab or Ge 101, or instructor's permission.* Includes approximately three days of weekend field trips into areas displaying highly varied geology. Each student is assigned the major responsibility of being the resident expert on a pertinent subject for each trip. Graded pass/fail. Instructor: Kirschvink.

Ge/Ay 137. Planetary Physics. *9 units (3-0-6); first term. Prerequisites: Ph 106 abc, ACM 95/100 abc.* Solar-system dynamics, with emphasis on slow changes in the orbit and rotation rates of planets and satellites. Topics: tidal friction, resonant orbits and rotation rates, gravitational fields of planets and satellites, dynamics of polar wandering, continental drift, and planetary rings. Instructor: Sari.

Ge 140. Introduction to Isotope Geochemistry. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* An introduction to the physics and chemistry of isotopes and a broad overview of the principles and conceptual techniques used in the stable isotope geochemistry of the lighter elements (H, C, O, N, Si, S) and the origin and evolution of radiogenic parent-daughter systems in nature. Instructors: Eiler, Farley.

Ge/ESE 143. Organic Geochemistry. *9 units (3-0-6); second term. Prerequisite: Ch 41 a or equivalent.* Introduction to the properties and cycling of natural organic materials. The course follows the global cycle of organic matter, from production in living organisms to burial in sediments and preservation in the rock record. Specific topics include lipid biochemistry and stereochemistry, factors controlling preservation in sediments, methanogenesis, diagnetic alterations of carbon skeletons, fossil fuel production and degradation, life in the deep biosphere, and biomarkers for ancient life. Instructor: Sessions.

Ge 147. Tectonics of Western North America. *9 units (4-0-5); second term. Prerequisite: Ge 11 ab.* Major tectonic features of western North America, including adjacent craton and Pacific Ocean basin. Active plate junctures, igneous provinces, crustal uplift, and basin subsidence. Tectonic evolution from late Precambrian to recent time, and modern analogues for paleotectonic phenomena. Alternates with Ge 135. Instructor: Saleeby. Given in alternate years; offered 2006–07.

ESE/Ge 148 abc. Global Environmental Science. *9 units (3-0-6).* For course description, see Environmental Science and Engineering.

Ge/ESE 149. Marine Geochemistry. *9 units (3-0-6); second term.* Introduction to chemical oceanography and sediment geochemistry. We will address the question "Why is the ocean salty?" by examining the processes that determine the major, minor, and trace element distributions of seawater and ocean sediments. Topics include river and estuarine chemistry, air/sea exchange, nutrient uptake by the biota, radioactive tracers, redox processes in the water column and sediments, carbonate chemistry, and ventilation. Not offered 2006–07.

Ge 150. Planetary Atmospheres. *9 units (3-0-6); third term. Prerequisites: Ch 1, Ma 2, Ph 2, or equivalents.* Origin of planetary atmospheres, escape, and chemical evolution. Tenuous atmospheres: the moon, Mercury, and outer solar system satellites. Comets. Vapor-pressure atmospheres: Triton, Io, and Mars. Spectrum of dynamical regimes on Mars, Earth, Venus, Titan, and the gas giant planets. Instructor: Richardson.

Ge 151. Fundamentals of Planetary Surfaces. *9 units (3-3-3); third term.* Review of surface histories and processes responsible for the formation and modification of the surfaces of the terrestrial planets and the Jovian satellites. Topics: exogenic surface processes, including impact, gravitational degradation, atmospheric modification of surfaces by wind and water, and the direct interaction of surfaces with plasmas; endogenic modification of surfaces by tectonics and volcanism; surface histories of Mercury, Venus, the moon, and Mars; the surfaces of icy bodies. Instructor: Aharonson.

ESE/Ge 152. Atmospheric Radiation. *9 units (3-0-6).* For course description, see Environmental Science and Engineering.

ESE/Ge 153. Atmosphere and Ocean Dynamics. *9 units (3-0-6).* For course description, see Environmental Science and Engineering.

Ge/ESE 154. Readings in Paleoclimate. *3 units (1-0-2); second term. Prerequisite: instructor's permission.* Lectures and readings in areas of current interest in paleoceanography and paleoclimate. Not offered 2006–07.

Ge/ESE 155. Paleoceanography. *9 units (3-0-6); second term.* Evaluation of the data and models that make up our current understanding of past climates. Emphasis will be placed on a historical introduction to the study of the past ten thousand to a few hundred thousand years, with some consideration of longer timescales. Evidence from marine and terrestrial sediments, ice cores, corals, and speleothems will be used to address the mechanisms behind natural climate variability. Models of this variability will be evaluated in light of the data. Topics will include sea level and ice volume, surface temperature evolution, atmospheric composition, deep ocean circulation, tropical climate, ENSO variability, and terrestrial/ocean linkages. Instructor: Adkins. Not offered 2006–07.

Ge 156. Topics in Planetary Surfaces. *6 units (3-0-3); second term.* Reading about and discussion of current understanding of the surface of a selected terrestrial planet, major satellite, or asteroid. Important "classic" papers will be reviewed, relative to the data that are being returned from recent and current missions. May be repeated for credit. Instructor: Aharonson.

EE/Ge 157 abc. Introduction to the Physics of Remote Sensing. *9 units (3-0-6).* For course description, see Electrical Engineering.

EE/Ge 158 ab. Application of Digital Images and Remote Sensing in the Field. *3 units (0-2-1); second term. 6 units (0-5-1); third term.* For course description, see Electrical Engineering.

Ge 159. Planetary Evolution and Habitability. *9 units (3-0-6); third term.* Photochemistry of planetary atmospheres, comparative planetology, atmospheric evolution. What makes Earth habitable? Remote sensing of extrasolar planets, biosignatures. Instructor: Yung.

Ae/Ge/ME 160 ab. Continuum Mechanics of Fluids and Solids. *9 units (3-0-6).* For course description, see Aeronautics.

Ge 161. Plate Tectonics. *9 units (3-0-6); first term. Prerequisite: Ge 11 ab or equivalent.* Geophysical and geological observations related to plate tectonic theory. Instantaneous and finite motion of rigid plates on a sphere; marine magnetic and paleomagnetic measurements; seismicity and tectonics of plate boundaries; reference frames and absolute plate motions. Interpretations of geologic data in the context of plate tectonics; plate tectonic evolution of the ocean basins. Instructor: Stock.

Ge 162. Seismology. *9 units (3-0-6); second term. Prerequisite: ACM 95/100 abc or equivalent.* Review of concepts in classical seismology. Topics to be covered: basic theories of wave propagation in the earth, instrumentation, Earth's structure and tomography, theory of the seismic source, physics of earthquakes, and seismic risk. Emphasis will be placed on how quantitative mathematical and physical methods are used to understand complex natural processes, such as earthquakes. Instructor: Tromp.

Ge 163. Geodynamics. *9 units (3-0-6); third term. Prerequisite: Ae/Ge/ME 160 ab.* Quantitative introduction to the dynamics of the earth, including core, mantle, lithosphere, and crust. Mechanical models are developed for each of these regions and compared to a variety of data sets. Potential theory applied to the gravitational and geomagnetic fields. Special attention is given to the dynamics of plate tectonics and the earthquake cycle. Instructors: Gurnis, Simons.

Ge 165. Geophysical Data Analysis. *9 units (3-0-6); first term. Prerequisites: basic linear algebra and Fourier transforms.* Introduction to modern digital analysis: discrete Fourier transforms, Z-transforms, filters, deconvolution, auto-regressive models, spectral estimation, basic statistics, 1-D wavelets, model fitting via singular valued decomposition. Not offered 2006–07.

Ge 166. Radar Imaging of the Earth for Geoscience Applications. *9 units (3-0-6); second term. Prerequisite: Ge 165 or instructor's permission.* Basics of wave propagation and backscattering from surfaces, synthetic aperture radar imaging theory, radar signal processing, image interpretation, methods of interferometry and polarimetry. Practical experience in forming radar images from signal data, interfering them for measuring topography and surface change. Computer laboratory based on interferometric radar processing package applied to data from modern spaceborne radar sensors. Emphasis on understanding the characteristics of the images, including geophysical signals, random error sources, and signal processing artifacts. Given in alternate years; not offered 2006–07.

Ge 168. Crustal Geophysics. *9 units (3-0-6); third term. Prerequisite: ACM 95/100 or equivalent, or instructor's permission.* The analysis of geophysical data related to crust processes. Topics include reflection and refraction seismology, tomography, gravity, magnetics, and geodesy. Not offered 2006–07.

Ge 169 ab. Readings in Geophysics. *6 units (3-0-3); second, third terms.* Reading courses are offered to teach students to read critically the work of others and to broaden their knowledge about specific topics. Each student will be required to write a short summary of each paper that summarizes the main goals of the paper, to give an assessment of how well the author achieved those goals, and to point out related issues not discussed in the paper. Each student will be expected to lead the discussion on one or more papers. The leader will summarize the discussion on the paper(s) in writing. A list of topics offered each year will be posted on the Web. Individual terms may be taken for credit multiple times without regard to sequence. Instructor: Staff.

Ge/ESE 170. Microbial Ecology. *9 units (3-2-4); third term. Prerequisite: ESE/Bi 166.* Structural, phylogenetic, and metabolic diversity of microorganisms in nature. The course explores microbial interactions, relationships between diversity and physiology in modern and ancient environments, and influence of microbial community structure on biogeochemical cycles. Introduction to ecological principles and molecular approaches used in microbial ecology and geobiological investigations. Instructor: Orphan.

ESE/Ge/Ch 171. Atmospheric Chemistry I. *9 units (3-0-6).* For course description, see Environmental Science and Engineering.

ESE/Ge/Ch 172. Atmospheric Chemistry II. *3 units (3-0-0).* For course description, see Environmental Science and Engineering.

ESE/Ge 173. Topics in Atmosphere and Ocean Dynamics. *9 units (3-0-6).* For course description, see Environmental Science and Engineering.

Ge 174. Geobiological Constraints on Earth History. *9 units (3-1-5); second term. Prerequisite: Ge 104 or equivalent.* Systematic analysis of the origin and evolution of life in the solar system as read through the geological record. Effects of global glaciations, volcanism, and impact processes on the atmosphere, hydrosphere, and climate of Earth. Magnetofossils, genes as fossils, banded iron stones, algal mats, stromatolites, global glaciation, mass extinction events, the Cambrian Explosion, human and molecular evolution. The course usually includes one or two major field trips, in which each student is assigned the responsibility of being the resident expert on a pertinent subject for each trip. Instructor: Kirschvink.

ESE/Ch/Ge 175 ab. Environmental Organic Chemistry. *9 units (3-0-6).* For course description, see Environmental Science and Engineering.

Ge 177 ab. Geology of Earthquakes. *12 units (3-3-6); second, third terms. Prerequisites: Ge 112 and Ge 106 or equivalent.* Geologic manifestations of recent crustal deformation. Geomorphology, stratigraphy, structural geology, and mechanics applied to the study of active faults and folds in a variety of tectonic settings. Relation of seismicity and geodetic measurements to geologic structure and active tectonics processes, including case studies of selected earthquakes. Instructors: Sieh, Avouac. Given in alternate years; not offered 2006–07.

Ge 179 abc. Seismological Laboratory Seminar. *1 unit (1-0-0); first, second, third terms.* Presentation of current research in geophysics by students, staff, and visitors. Graded pass/fail. Instructor: Helmberger.

CE/Ge 181. Engineering Seismology. *9 units (3-0-6).* For course description, see Civil Engineering.

Ge 190. The Nature and Evolution of the Earth. *Units to be arranged. Offered by announcement only.* Advanced-level discussions of problems of current interest in the earth sciences. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Staff.

Ge 191. Special Topics in Geochemistry. *Units to be arranged. Offered by announcement only.* Advanced-level discussions of problems of current interest in geochemistry. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Staff.

Ge 192. Special Topics in the Geological Sciences. *Units to be arranged. Offered by announcement only.* Advanced-level discussions of problems of current interest in the geological sciences. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Staff.

Ge 193. Special Topics in Geophysics. *Units to be arranged. Offered by announcement only.* Advanced-level discussions of problems of current interest in geophysics. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Staff.

Ge 194. Special Topics in the Planetary Sciences. *Units to be arranged. Offered by announcement only.* Advanced-level discussions of problems of current interest in the planetary sciences. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Staff.

Ge 195. Special Opportunities in Field Geology. *Units to be arranged. Offered by announcement only.* Field experiences in different geological settings. Supporting lectures will usually occur before and during the field experience. This course will be scheduled only when special opportunities arise. Class may be taken more than once. Instructor: Staff.

Ge 196. Special Topics in Atmospheres and Oceans. *Units to be arranged. Offered by announcement only.* Advanced-level discussions of problems of current interest in atmospheric and ocean sciences. Instructor: Staff.

Ge 211. Applied Geophysics II. *Units to be arranged. Prerequisite: instructor's permission.* Intensive geophysical field experience in either marine or continental settings. Marine option will include participation in a student training cruise, with several weeks aboard a geophysical research vessel, conducting geophysical measurements (multibeam bathymetry, gravity, magnetics, and seismics), and processing and interpreting the data. Supporting lectures and problem sets on the theoretical basis of the relevant geophysical techniques and the tectonic background of the survey area will occur before and during the training cruise. The course might be offered in a similar format in other isolated situations. The course will be scheduled only when opportunities arise and this usually means that only six months' notice can be given. Auditing not permitted. Class may be taken more than once. Instructors: Stock, Clayton, Gurnis.

Ge 212. Thermodynamics of Geological Systems. *9 units (3-0-6); second term. Prerequisites: Ch 21 abc, Ge 115 a, or equivalents.* Chemical thermodynamics as applied to geological and geochemical problems. Classical thermodynamics, including stability criteria, homogeneous and heterogeneous equilibria, equilibria subject to generalized constraints, equations of state, ideal and nonideal solutions, redox systems, and electrolyte conventions. Brief discussion of statistical foundations and an introduction to the thermodynamics of irreversible processes. Instructor: Asimow. Given in alternate years; offered 2006–07.

Ge 214. Spectroscopy of Minerals. *9 units (3-0-6); third term. Prerequisites: Ge 114 a, Ch 21 ab, or instructor's permission.* An overview of the interaction of minerals with electromagnetic radiation from gamma rays to microwaves. Particular emphasis is placed on visible, infrared, Raman, and Mössbauer spectroscopies as applied to mineralogical problems such as phase identification, chemical analysis, site populations, and origin of color and pleochroism. Instructor: Rossman. Given in alternate years; offered 2006–07.

Ge 215. Topics in Advanced Petrology. *12 units (4-0-8); second term. Prerequisite: Ge 115 ab or instructor's permission.* Lectures, readings, seminars, and/or laboratory studies in igneous or metamorphic petrology, paragenesis, and petrogenesis. The course may cover experimental, computational, or analytical methods. Format and content are flexible according to the needs of the students. Instructor: Asimow. Given in alternate years; not offered 2006–07.

Ge 225 abc. Planetary Sciences Seminar. *1 unit (1-0-0); first, second, third terms.* Required of all planetary-science graduate students; others welcome. First term: current research by staff and students. Second and third terms: planetary research with spacecraft and current developments in planetary science. Instructor: Staff.

Ge 232. Chemistry of the Solar System. *9 units (3-0-6); second term. Prerequisite: Ge 140 or instructor's permission.* Advanced course using both chemical and isotopic data to evaluate the current state of knowledge concerning the composition of major segments of the solar system, viz., solar and meteoritic abundance data to infer the average solar-system composition; chemistry of meteorites as a clue to initial conditions in the solar nebula; bulk composition of the earth and moon; constraints on the bulk composition of the other planets, emphasizing data on atmospheric constituents. Instructor: Burnett. Given in alternate years; offered 2006–07.

Ge 236. Applications of Rare Gases to Earth Science Problems. *9 units (3-0-6); offered by announcement; third term. Prerequisite: instructor's permission.* Discussion of the principles, applications, and limitations of rare gases as records of terrestrial processes. Origin and behavior of rare gases in natural systems. Specific areas to be considered include K/Ar and $^{40}Ar/^{39}Ar$ dating; Ar thermochronology; surface-exposure dating; rare-gas constraints on mantle evolution and models of atmosphere formation; additional applications in geology, hydrology, paleoclimatology, and oceanography. Instructor: Farley.

Ge/Bi 244. Paleobiology Seminar. *5 units; third term.* Critical reviews and discussion of classic investigations and current research in paleoecology, evolution, and biogeochemistry. Instructor: Kirschvink.

Ge/Bi 246. Molecular Geobiology Seminar. *6 units (2-0-4); second term. Recommended prerequisite: ESE/Bi 166.* Critical reviews and discussion of classic papers and current research in microbiology and geomicrobiology. As the topics will vary from year to year, it may be taken multiple times. Instructor: Newman.

Ge 260. Physics of Earth Materials. *9 units (3-2-4); second term. Prerequisite: familiarity with basic concepts of thermodynamics and mineralogy; instructor's permission.* Application of high-pressure physics to geologic problems. Topics: concepts of elastic and shock propagation in single and polycrystalline solids and in fluids, and their relation to various thermodynamic processes; phase changes, dynamic yielding, shock metamorphism, high-pressure electrical properties of minerals, and application of shock and ultrasonic equation-of-state data to Earth and planetary interiors. Instructors: Ahrens and Stock. Given in alternate years; not offered 2006–07.

Ge 261. Advanced Seismology. *9 units (3-0-6); third term.* Continuation of Ge 162 with special emphasis on particular complex problems; includes generalizations of analytical methods to handle nonplanar structures and methods of interfacing numerical-analytical codes in two and three dimensions; construction of Earth models using tomographic methods and synthetics. Requires a class project. Instructor: Helmberger.

Ge 262. Long-Period Seismology. *9 units (3-0-6); third term.* Free oscillations and surface waves. Equations of motion that govern the vibrations of the prestressed, rotating, self-gravitating Earth model. Normal modes of a spherically symmetric Earth model: toroidal and spheroidal modes, Love and Rayleigh surface waves, and mode-ray duality. Effects of rotation, hydrostatic ellipticity, and lateral heterogeneity on free oscillations. Description of an earthquake in terms of the centroid-moment tensor. Free oscillations of an anelastic Earth model: attenuation, physical dispersion, and the Kramers-Kronig relations. Instructor: Tromp. Given in alternate years; offered 2006–07.

Ge 263. Computational Geophysics. *9 units (3-0-6); second term. Prerequisite: introductory class in geophysics, class in partial differential equations, some programming experience.* Finite-difference, pseudospectral, finite-element, and spectral-element methods will be presented and applied to a number of geophysical problems including heat flow, deformation, and wave propagation. Students will program simple versions of methods. Instructors: Tromp, Gurnis, Clayton. Given in alternate years; offered 2006–07.

Ae/Ge/ME 266 ab. Dynamic Fracture and Frictional Faulting. *9 units (3-0-6).* For course description, see Aeronautics.

Ge 268. Mantle Dynamics. *9 units (3-0-6); first term. Prerequisites: Ge 163 and Ge 263.* Analysis of mantle dynamics and connection with surface processes, especially plate tectonics. Selected problems will be examined, including the mechanics of subduction, mantle plumes, mantle convection, convective mixing, thermal evolution, and interpretation of seismic tomography. Term project using numerical models required. Instructor: Gurnis. Given in alternate years; not offered 2006–07.

Ge 270. Continental Tectonics. *9 units (3-0-6); first term. Prerequisites: ACM 95/100 or ACM 113; Ge 11 ab, Ge 106, Ge 162, Ge 166, or Ge 161.* The nature of nonplate, finite deformation processes in the evolution of the continental lithosphere, using the Alpine orogen as an example. Rheological stratification; isostatic and flexural response to near-vertical loads; rifting and associated basin development; collision and strike-slip tectonics; deep crustal processes. Instructor: Wernicke. Given in alternate years; offered 2006–07.

Ge 277. Active Tectonics Seminar. *6 units (1-3-2); second term.* Discussion of key issues in active tectonics based on a review of the literature. The topic of the seminar is adjusted every year based on students' interest and recent literature. Instructor: Avouac. For more information, see http://www.gps.caltech.edu/~avouac.

Ge 282 abc. Division Seminar. *1 unit; first, second, third terms.* Presentation of papers by invited investigators. Graded pass/fail.

Ge 297. Advanced Study. *Units to be arranged.*

Ge 299. Thesis Research. Original investigation, designed to give training in methods of research, to serve as theses for higher degrees, and to yield contributions to scientific knowledge.

HISTORY

Hum/H 1 ab. East Asian History. *9 units (3-0-6).* For course description, see Humanities.

Hum/H 2. American History. *9 units (3-0-6).* For course description, see Humanities.

Hum/H 3 abc. European Civilization. *9 units (3-0-6).* For course description, see Humanities.

Hum/H 4 abc. Civilization, Science, and Archaeology. *9 units (3-0-6).* For course description, see Humanities.

Hum/H/HPS 10. Introduction to the History of Science. *9 units (3-0-6).* For course description, see Humanities.

H 40. Reading in History. *Units to be determined for the individual by the division. Elective, in any term.* Reading in history and related subjects, done either in connection with the regular courses or independently, but under the direction of members of the department. A brief written report will usually be required. Graded pass/fail. *Not available for credit toward humanities–social science requirement.*

H 41. Prehistoric Peoples of the Southwest. *9 units (3-0-6); second term.* This course offers a comprehensive overview of the rich and varied archaeological record of the American Southwest, beginning with the colonization of the New World at the end of the last ice age and ending with the arrival of Spanish explorers in the 16th century. The course will review the major prehistoric culture that inhabited this region, stretching from coastal Southern California to the edge of the Great Plains in New Mexico and Colorado. Archaeological method and theory, the history of research in the region, and contemporary issues and debates in the field will also be discussed. Instructor: Van Keuren.

H 98. Reading in History. *9 units (1-0-8). Prerequisite: instructor's permission.* An individual program of directed reading in history, in areas not covered by regular courses. Instructor: Staff.

H 99 abc. Research Tutorial. *9 units (1-0-8). Prerequisite: instructor's permission.* Students will work with the instructor in the preparation of a research paper, which will form the basis of an oral examination. Instructor: Staff.

H 108 a. The Early Middle Ages. *9 units (3-0-6); first term.* This course is designed to introduce students to the formative period of Western medieval history, roughly from the fourth through the tenth centuries. It will emphasize the development of a new civilization from the fusion of Roman, Germanic, and Christian traditions, with a focus on the Frankish world. The course focuses on the reading, analysis, and discussion of primary sources. Instructor: Brown. Not offered 2006–07.

H 108 b. The High Middle Ages. *9 units (3-0-6); second term.* This course is designed to introduce students to European history between 1000 and 1400. It will provide a topical as well as chronological examination of the economic, social, political, and religious evolution of western Europe during this period, with a focus on France, Italy, England, and Germany. The course emphasizes the reading, analysis, and discussion of primary sources. Instructor: Brown. Not offered 2006–07.

H 109. Medieval Knighthood. *9 units (3-0-6); second term.* This course tells the story of the knight from his beginnings in the early Middle Ages, through his zenith in the 11th, 12th, and 13th centuries, to his decline and transformation in the late medieval and early modern periods. The course treats the knight not simply as a military phenomenon but also as a social, political, religious, and cultural figure who personified many of the elements that set the Middle Ages apart. Not offered 2006–07.

H 110. The World of Charlemagne. *9 units (3-0-6); offered by announcement.* The emperor Charlemagne looms large in the European consciousness as the warrior-king who created Europe. This course looks at Charlemagne's career in order to see how this late 8th- and early 9th-century Frankish ruler might have earned his reputation as the maker of a Christian Europe. At the same time, it explores the period dominated by his family, the Carolingians, as one in which the world of late antiquity was transformed into the civilization we call the Middle Ages. Not offered 2006–07.

H 111. The Medieval Church. *9 units (3-0-6); offered by announcement.* This course takes students through the history of the medieval Christian Church in Europe, from its roots in Roman Palestine, through the zenith of its power in the high Middle Ages, to its decline on the eve of the Reformation. The course focuses on the church less as a religion (although it will by necessity deal with some basic theology) than as an institution that came to have an enormous political, social, cultural, and economic impact on medieval life, and for a brief time made Rome once more the mistress of Europe. Instructor: Brown.

H 112. The Vikings. *9 units (3-0-6); third term.* This course will take on the Scandinavian seafaring warriors of the 8th–11th centuries as a historical problem. What were the Vikings, where did they come from, and how they did they differ from the Scandinavian and north German pirates and raiders who preceded them? Were they really the horned-helmeted, bloodthirsty barbarians depicted by modern popular media and by many medieval chronicles? What effect did they have in their roughly two centuries of raiding and colonization on the civilizations of medieval and ultimately modern Europe? Not offered 2006–07.

H 113. Hispanic Frontiers in North America. *9 units (3-0-6); second term.* This course explores the legacy of Spain in what later became the United States, focusing on what is today the American Southwest (from California to Texas) and American South (from Louisiana to Florida). The course will start with the Spanish exploration and settlement of North America, move through 300 years of cultural exchange and conflict on the northern frontiers of New Spain, and end with early Mexican rule (1821–1848). It will focus on Spanish expansion, native communities, the rise of new European-American cultures, and the transformation of imperial frontiers into national borderlands after 1821. Not offered 2006–07.

H 115 abc. British History. *9 units (3-0-6); first, second, third terms.* The political and cultural development of Great Britain from the early modern period to the 20th century. H 115 a covers the Reformation and the making of a Protestant state (1500–1700). H 115 b examines the Enlightenment and British responses to revolutions in France and America (1700–1830). H 115 c is devoted to the Victorian and Edwardian eras (1830–1918). H 115 a is not a prerequisite for H 115 b; neither it nor H 115 b is a prerequisite for H 115 c. Not offered 2006–07.

H 116. Studies in Narrative: History, Fiction, and Storytelling. *9 units (3-0-6); second term.* This course examines the fraught relationship between historical and literary narratives, two interdependent but often opposed forms of storytelling. It will look at works that raise the issue of veracity and storytelling, including fictions like Graham Swift's *Waterland*, films such as Kurosawa's *Rashomon*, and the "historical novellas" in Simon Schama's book *Dead Certainties*. It will also investigate in some detail the works of American, French, and Italian historians who have tried to solve this problem by turning to so-called microhistory. Instructor: Brewer. Not offered 2006–07.

H 117. Consumer Society: The Debate 1950–2000. *9 units (3-0-6); third term.* This course examines the debates about the nature, virtues, and vices of "consumer society" from its inception in the 1950s to the end of the 20th century. It will examine works of history, economics, sociology, and criticism, including such works as Galbraith's *The Affluent Society*, Rostow's *The Stages of Economic Growth*, Debord's *The Society of the Spectacle*, and Frank's *Luxury Fever.* Not offered 2006–07.

H 118. Histories of Collecting. *9 units (3-0-6); third term.* This course examines the history and theory of collecting, concentrating on collectors, collections, and collecting in the West since the Renaissance. It will include field trips to collections around Los Angeles, including the Huntington Art Gallery and the Museum of Jurassic Technology, and the examination of issues such as forgery and the workings of art markets. Instructor: Brewer. Not offered 2006–07.

H 120. The History of Christianity. *9 units (3-0-6); second term.* The course will introduce students to some of the most important ideas, individuals, institutions, and controversies that proved crucial to the development of Christianity in the past two millennia. Central to the course will be a comparative framework for the evaluation of such themes as the evolution of doctrine, the interplay between religious and political institutions, patterns of crisis and reform, the Protestant and Catholic Reformations, heresy and persecution, secularization, and the place of religion in the modern world. The course will emphasize the reading and analysis of primary sources. Instructor: Crosignani.

H 121. American Radicalism. *9 units (3-0-6); offered by announcement.* The course will cover a number of radical social, political, and artistic movements in 20th-century America. A focus on the first two decades of the century will center around the poet, journalist, and revolutionary John Reed and his circle in Greenwich Village. Topics will include their involvement with artistic experimentation, the Industrial Workers of the World, the Mexican Revolution, the Russian Revolution, and the movements for birth control and against American involvement in World War I. Other areas of concentration will be the Great Depression of the '30s, with its leftist political and labor actions, and the freewheeling radicalism of the '60s, including the anti-Vietnam protests, Students for a Democratic Society, and the ethnic struggles for social and political equality. Some reference will be made to the anti-globalization movements of today. Instructor: Rosenstone.

H 122. Household and Family Forms over Time. *9 units (3-0-6); offered by announcement.* This course examines the wide variety of family forms and household structures in past societies, as well as the social, cultural, institutional, and economic variables that influenced them. The course focuses mainly on Europe from about 1600 to the present, as this is the area for which most research has been done, but there will be some discussion of other parts of the world, including Asia, Africa, and North and South America. Special attention is given to comparisons among different societies. Instructor: Dennison.

H 123. Urban Politics and the Local State from the Progressive Era to the Present. *9 units (3-0-6); first term.* Cities and metropolitan areas have been arenas for some of the most intense conflict in American history and the target of nationwide reform and reconstruction efforts for over a century. This course will cover traditional topics in urban history with an emphasis on their political implications, including immigration and machine politics, social reform, labor relations, racial conflict, and suburbanization. In addition, it will examine the changing governmental institutions that plan, regulate, provide services, and build infrastructure, emphasizing the dialectical relationship between local government and urban society. Instructor: Dyble.

H/F 131. History on Film. *9 units (2-2-5); offered by announcement.* An investigation into the variety of ways history has been and can be represented on the screen. Some terms the focus will be a specific historical period or nation; other terms the focus will be the nature of film as a medium for history and biography. The class will include weekly screenings of films as well as weekly discussion sections. Instructor: Rosenstone.

H/F 133. Topics in Film History. *9 units (2-2-5); offered by announcement.* The course will focus each term on one kind of motion picture—either a film genre, or films made by an individual director, or from a single nation or region of the world or particular historical era. Included are weekly screenings, readings on film, a weekly discussion meeting, and a term paper. Instructor: Rosenstone.

H/F 134. The Science Fiction Film. *9 units (2-2-5); offered by announcement.* This course will introduce students to some of the classic works of the science fiction film from the earliest days of cinema until the present. It will analyze aesthetic, historical, and social documents, and will show that such films, while describing alternative, hypothetical, and futurist worlds, also serve as a commentary upon and/or a critique of contemporary (to the film) historical, social, political, and ideological systems and attitudes. Instructor: Rosenstone.

H 135. War, Conquest, and Empires. *9 units (3-0-6); offered by announcement.* This course will use historical examples of war and conquest and ask why some periods of history were times of warfare and why certain countries developed a comparative advantage in violence. The examples will come from the history of Europe and Asia, from ancient times up until World War I, and the emphasis throughout will be on the interplay between politics, military technology, and social conditions. Instructor: Hoffman. Not offered 2006–07.

H/F 136. Ethnic Visions. *9 units (2-2-5); offered by announcement.* In recent decades, directors from ethnic minorities that are often un- or misrepresented in mainstream Hollywood films have been making dramatic features depicting the history, problems, and prospects of their own communities. This course will feature a selection of such films by directors from African, Latino, Asian, Muslim, and European American ethnic groups, with an eye toward assessing the similarities and differences in the processes of immigration, acculturation, and Americanization. Instructor: Rosenstone.

H 137. Encounters in Early America, 1607–1814. *9 units (3-0-6); third term.* This course offers an exploration of early American history through the study of the multifaceted encounters between the indigenous inhabitants, the European settlers, and the Africans who were forcefully brought over. Early America was a melting pot of diverse ambitions, and understanding such diversity, as well as the tension between competing cultures and ideals, is crucial to comprehending both early American history and the nature of American society today. Instructor: O'Malley.

H 144. Topics in the History of American Immigration. *9 units (3-0-6).* A course that examines the history of American immigration from the 18th through the 20th centuries. This course will explore the impact of immigration upon American politics, culture, and law. Instructor: Feldblum.

Law/PS/H 148 ab. The Supreme Court in U.S. History. *9 units (3-0-6).* For course description, see Law.

HPS/H 156. The History of Modern Science. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 158. The Scientific Revolution. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 160 ab. Einstein and His Generation: The History of Modern Physical Sciences. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

H 161. Selected Topics in History. *9 units (3-0-6)*; offered by announcement. Instructors: Staff, visiting lecturers.

HPS/H 162. Social Studies of Science. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 166. Historical Perspectives on the Relations between Science and Religion. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 167. Experimenting with History/Historic Experiment. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 168. History of Electromagnetism and Heat Science. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 169. Selected Topics in the History of Science and Technology. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 170. History of Light from Antiquity to the 20th Century. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 171. History of Mechanics from Galileo through Euler. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 172. History of Mathematics: A Global View with Close-ups. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H/Pl 173. History of Chemistry. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H/Pl 174. Celestial and Terrestrial Mechanisms: Landmarks in the Development of Greek Astronomy. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 175. Matter, Motion, and Force: Physical Astronomy from Ptolemy to Newton. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 176. Useful Knowledge. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 177. Bacon, Boyle, and Locke. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H 178. Geometry, Mechanics, and Natural Philosophy in 17th–18th Centuries. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H/Pl 179. The Politics of Nature in Early Modern Europe. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H/Pl 180. The Philosophy of Scientific Argument and Evidence, 1550–1750. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

H 201. Reading and Research for Graduate Students. *Units to be determined for the individual by the division.*

HISTORY AND PHILOSOPHY OF SCIENCE

Hum/H/HPS 10. Introduction to the History of Science. *9 units (3-0-6); offered by announcement.* For course description, see Humanities.

HPS 98. Reading in History and Philosophy of Science. *9 units (1-0-8). Prerequisite: instructor's permission.* An individual program of directed reading in history and philosophy of science, in areas not covered by regular courses. Instructor: Staff.

HPS 102 ab. Senior Research Seminar. *12 units (2-0-10).* Offered in any two consecutive terms, by arrangement with HPS faculty. Under the guidance of an HPS faculty member, students will research and write a focused research paper of 15,000 words (approximately 50 pages). Work in the first term will comprise intensive reading in the relevant literature and/or archival or other primary source research. In the second term, students will draft and revise their paper. Open to seniors in the HPS option and to others by special permission of an HPS faculty member. Instructor: Staff.

HPS 103. Public Lecture Series. *1 unit (1-0-0); first, second, third terms.* Student attend four lectures, featuring speakers from outside Caltech, on topics in the history and philosophy of science. Students may choose from a variety of regularly scheduled HPS lectures, including HPS seminars, Harris lectures, and Munroe seminars (history or philosophy of science only). Graded on attendance. *Not available for credit toward the humanities–social science requirement.* Graded pass/fail. Instructors: Guest lecturers.

HPS/Pl 120. Introduction to Philosophy of Science. *9 units (3-0-6); offered by announcement.* An introduction to fundamental philosophical problems concerning the nature of science. Topics may include the character of scientific explanation, criteria for the conformation and falsification of scientific theories, the relationship between theory and observation, philosophical accounts of the concept of "law of nature," causation, chance, realism about unobservable entities, the objectivity of science, and issues having to do with the ways in which scientific knowledge changes over time. Instructor: Hitchcock. Given in alternate years; offered 2006–07.

HPS/Pl 121. Causation and Explanation. *9 units (3-0-6); first term.* An examination of theories of causation and explanation in philosophy and neighboring disciplines. Topics discussed may include probabilistic and counterfactual treatments of causation, the role of statistical evidence and experimentation in causal inference, and the deductive-nomological model of explanation. The treatment of these topics by important figures from the history of philosophy such as Aristotle, Descartes, and Hume may also be considered. Instructors: Woodward, Hitchcock, Zhang.

HPS/Pl 122. Confirmation and Induction. *9 units (3-0-6); offered by announcement.* Philosophical and conceptual issues arising from theories of confirmation and induction. Topics include Hume's "old" problem of induction; Goodman's "new" riddle of induction and various notions of "projectability"; inductive logic; Bayesian confirmation theory; and other theories of confirmation. Instructor: Huber.

HPS/Pl 124. Philosophy of Space and Time. *9 units (3-0-6); offered by announcement.* This course will focus on questions about the nature of space and time, particularly as they arise in connection with physical theory. Topics may include the nature and existence of space, time, and motion; the relationship between geometry and physical space (or space-time); entropy and the direction of time; the nature of simultaneity; and the possibility of time travel. Instructor: Hitchcock.

HPS/Pl 125. Philosophical Issues in Quantum Physics. *9 units (3-0-6); offered by announcement.* This course will focus on conceptual issues that arise within quantum physics. Topics may include determinism and indeterminism; Einstein's critiques of quantum theory; the interpretation of quantum measurement; and quantum logic. Instructor: Hitchcock.

HPS/Pl 126. Foundations of Probability and Inductive Inference. *9 units (3-0-6); offered by announcement*. Philosophical and conceptual issues arising from probability theory. Topics covered may include the psychological literature on common fallacies in probabilistic reasoning; comparative probability; Kolmogorov's axiomatization of probability, and an exploration of both defenses and criticisms thereof; the classical, analogical, logical, frequentist, propensity, and various subjectivist interpretations of probability; calibration; conditional probability as the primitive of probability theory; proposals for supplementing the probability calculus with certain further principles. Instructor: Staff.

HPS/Pl 129. Introduction to Philosophy of Biology. *9 units (3-0-6).* Philosophical and conceptual issues relating to the biological sciences. Topics covered may include the logical structure of evolutionary theory, units of selection, optimization theory, the nature of species, reductionism, teleological and functional reasoning, and ethical issues arising from contemporary biological research. Not offered 2006–07.

HPS/Pl 130. Philosophy and Biology. *9 units (3-0-6); offered by announcement*. This course will examine the impact of recent advances in biological sciences for studies of the mind, behavior, and society. Topics may include evolutionary psychology, the relation between evolution and development, the impact of molecular genetics on the theory of evolution, mathematical modeling of evolution and artificial evolution, philosophical and social issues raised by modern molecular biology. Instructor: Cowie. Not offered 2006–07.

HPS/Pl 132. Introduction to Philosophy of Mind and Psychology. *9 units (3-0-6); offered by announcement.* An introduction to the mind-body problem. The course attempts, from the time of Descartes to the present, to understand the nature of the mind and its relation to the body and brain. Topics to be addressed may include dualism, behaviorism, functionalism, computationalism, neurophilosophy, consciousness and qualia, scientific psychology vs. "folk" psychology, the nature of emotion, knowledge of other minds. Not offered 2006–07.

HPS/Pl 133. Philosophy and Neuroscience. *9 units (3-0-6); offered by announcement.* This course will examine the impact of recent advances in neuroscience on traditional philosophical problems. Topics may include the nature of free will in light of work on the neural basis of decision making; the nature of consciousness, knowledge, or learning; the mind/brain from the perspective of neural computation; and the neural foundations of cognitive science. Instructor: Quartz.

HPS/Pl 134. Current Issues in Philosophical Psychology. *9 units (3-0-6); offered by announcement*. An in-depth examination of one or more issues at the intersection of contemporary philosophy and the brain and behavioral sciences. Topics may include the development of a theory of mind and self-representation, theories of representation and neural coding, the nature of rationality, the nature and causes of psychopathology, learning and innateness, the modularity of mind. Instructor: Murphy.

HPS/Pl 136. Ethics in Research. *4 units (2-0-2) or 9 units (2-0-7); third term.* Course will address a number of ethical and philosophical issues arising in scientific research. Among the topics discussed will be the following: fraud and misconduct in science; various theories of the scientific method; the realities of science as practiced in laboratories and the pressures facing scientists in the real world; ethical issues raised by collaborative research; reward and credit in science; responsibilities of mentors, referees, and editors in the conduct of research; the role of government regulation and supervision in dealing with scientific misconduct; the role of the university; and changes in ethical standards due to advancing technology. Undergraduates wishing to take the course for advanced humanities credit should register for 9 units (a term paper will be required). Students who register for 4 units may do so on a pass/fail basis only. Instructors: Woodward, D. Goodstein. Not offered 2006–07.

HPS/H 156. The History of Modern Science. *9 units (3-0-6); third term.* Selected topics in the development of the physical and biological sciences since the 17th century. Instructor: Kormos-Buchwald.

HPS/H 158. The Scientific Revolution. *9 units (3-0-6); second term.* The birth of modern Western science from 1400 to 1700. The course examines the intellectual revolution brought about by the contributions of Copernicus, Galileo, Descartes, Kepler, Newton, and Harvey, and their relation to major political, social, and economic developments. Not offered 2006–07.

HPS/H 160 ab. Einstein and His Generation: The History of Modern Physical Sciences. *9 units (3-0-6); first, third terms.* An exploration of the most significant scientific developments in the physical sciences, structured around the life and work of Albert Einstein (1879–1955), with particular emphasis on the new theories of radiation, the structure of matter, relativity, and quantum mechanics. While using original Einstein manuscripts, notebooks, scientific papers, and personal correspondence, we shall also study how experimental and theoretical work in the sciences was carried out; scientific education and career patterns; personal, political, cultural, and sociological dimensions of science. Not offered 2006–07.

HPS/H 162. Social Studies of Science. *9 units (3-0-6).* A comparative, multidisciplinary course that examines the practice of science in a variety of locales, using methods from the history, sociology, and anthropology of scientific knowledge. Topics covered include the high-energy particle laboratory as compared with a biological one; Western as compared to non-Western scientific reasoning; the use of visualization techniques in science from their inception to virtual reality; gender in science; and other topics. Instructor: Feingold.

HPS/H 166. Historical Perspectives on the Relations between Science and Religion. *9 units (3-0-6); offered by announcement.* The course develops a framework for understanding the changing relations between science and religion in Western culture since antiquity. Focus will be on the ways in which the conceptual, personal, and social boundaries between the two domains have been reshaped over the centuries. Questions to be addressed include the extent to which a particular religious doctrine was more or less amenable to scientific work in a given period, how scientific activity carved an autonomous domain, and the roles played by scientific activity in the overall process of secularization. Instructor: Feingold.

HPS/H 167. Experimenting with History/Historic Experiment. *9 units (3-0-6); offered by announcement.* This course uses a combination of lectures with hands-on laboratory work to bring out the methods, techniques, and knowledge that were involved in building and conducting historical experiments. We will connect our laboratory work with the debates and claims made by the original discoverers, asking such questions as how experimental facts have been connected to theories, how anomalies arise and are handled, and what sorts of conditions make historically for good data. Typical experiments might include investigations of refraction, laws of electric force, interference of polarized light, electromagnetic induction, or resonating circuits and electric waves. We will reconstruct instrumentation and experimental apparatus based on a close reading of original sources. Instructor: Buchwald. Not offered 2006–07.

HPS/H 168. History of Electromagnetism and Heat Science. *9 units (3-0-6); offered by announcement*. This course covers the development of electromagnetism and thermal science from its beginnings in the early 18th century through the early 20th century. Topics covered include electrostatics, magnetostatics, electrodynamics, Maxwell's field theory, the first and second laws of thermodynamics, and statistical mechanics as well as related experimental discoveries. Instructor: Buchwald.

HPS/H 169. Selected Topics in the History of Science and Technology. *9 units (3-0-6); offered by announcement.* Instructors: Staff, visiting lecturers.

HPS/Pl 169. Selected Topics in Philosophy of Science. *9 units (3-0-6); offered by announcement*. Instructors: Staff, visiting lecturers.

HPS/H 170. History of Light from Antiquity to the 20th Century. *9 units (3-0-6); offered by announcement.* A study of the experimental, mathematical, and theoretical developments concerning light, from the time of Ptolemy in the 2nd century A.D. to the production of electromagnetic optics in the 20th century. Instructor: Buchwald.

HPS/H 171. History of Mechanics from Galileo through Euler. *9 units (3-0-6); second term. Prerequisite: basic Caltech physics course.* This course covers developments in mechanics, as well as related aspects of mathematics and models of nature, from just before the time of Galileo through the middle of the 18th century, which saw the creation of fluid and rotational dynamics in the hands of Euler and others. Instructor: Buchwald.

HPS/H 172. History of Mathematics: A Global View with Close-ups. *9 units (3-0-6); offered by announcement.* The course will provide students with a brief yet adequate survey of the history of mathematics, characterizing the main developments and placing these in their chronological, cultural, and scientific contexts. A more detailed study of a few themes, such as Archimedes' approach to infinite processes, the changing meanings of "analysis" in mathematics, Descartes' analytic geometry, and the axiomatization of geometry c. 1900; students' input in the choice of these themes will be welcomed. Instructor: Staff.

HPS/H/Pl 173. History of Chemistry. *9 units (3-0-6); first term.* This course examines developments in chemistry from medieval alchemy to the time of Lavoisier. It will examine the real content of alchemy and its contributions to modern science, as well as how to decode its bizarre language; chemistry's long quest for respect and academic status; the relations of chemistry with metallurgy, medicine, and other fields; and the content and development of the chemical theories and the chemical laboratory and its methods. Not offered 2006–07.

HPS/H/Pl 174. Celestial and Terrestrial Mechanisms: Landmarks in the Development of Greek Astronomy. *9 units (3-0-6); first term.* The course will highlight the background and some of the landmarks in the evolution of Greek astronomy from its tentative beginnings in the 5th century B.C., to its culmination in the work of Ptolemy in the 2nd century A.D. Not offered 2006–07.

HPS/H 175. Matter, Motion, and Force: Physical Astronomy from Ptolemy to Newton. *9 units (3-0-6); second term.* The course will examine how elements of knowledge that evolved against significantly different cultural and religious backgrounds motivated the great scientific revolution of the 17th century. Not offered 2006–07.

HPS/H 176. Useful Knowledge. *9 units (3-0-6).* This course will first examine the original arguments in favor of useful knowledge in all areas of study, including the civic, humanistic, and religious influences on the idea that knowledge must be pursued "for the common good"; gradual transformations that took place in the 18th and 19th centuries that culminated in the rise of positivism and utilitarianism; and a critical examination of the ways in which the 19th-century conception of utility has remained influential throughout the 20th century and into the 21st. Instructor: Sargent.

HPS/H 177. Bacon, Boyle, and Locke. *9 units (3-0-6).* The course will trace the development of English philosophy during the 17th century by examining the contributions made in natural philosophy, methodology, and epistemology by Francis Bacon, Robert Boyle, and John Locke. A primary focus will be upon their defense of experimental reasoning and will include a close reading of their texts as well as some short criticisms of their project by philosophers such as Baruch Spinoza and Thomas Hobbes. In addition to the intellectual context, elements from the social context (such as the legal, mechanical, political, and theological traditions) will be examined to see how these philosophers used them in the development and justification of their ideas. Instructor: Sargent.

HPS/H 178. Geometry, Mechanics, and Natural Philosophy in 17th–18th Centuries. *9 units (3-0-6); first term.* The complex developments during these centuries concern conflicts between a purely mechanistic view of nature, such as the one developed by Descartes and his followers, and the views of others, such as those of Newton and Leibniz. We will examine the several tensions that arose out of this conflict in order to understand the divisions during this period that inflamed academic rivalries and priority disputes among major and minor figures alike, for even the less well-known contributed to the deep transformation of "physico-mathematics" that resulted, forming much of the basis for modern physics. Instructor: Guicciardini.

HPS/H/Pl 179. The Politics of Nature in Early Modern Europe. *9 units (3-0-6); second term.* This course will consider some of the ways in which "nature" was invoked as a basis for moral and political philosophy in the 16–18th centuries. We will study the origins and development of so-called "natural law" theory from the writings of Spanish philosophers of the "second scholastic" through some of the classics of early modern political philosophy: Hobbes's *Leviathan*, Locke's *Two Treatises*, and David Hume's early masterpiece, *A Treatise of Human Nature*. At the heart of the course lies a deep question with lasting implications: to what extent should modern political liberalism be regarded as a consequence of the scientific revolution? Instructor: Serjeantson.

HPS/H/Pl 180. The Philosophy of Scientific Argument and Evidence, 1550–1750. *9 units (3-0-6); third term.* Historians and philosophers of science have long debated whether the "scientific revolution" of the early modern period should fundamentally be regarded as decisive change in metaphysical views of the world or as a change in the social practices and functions of natural investigation. This course will endeavor to reconcile these two approaches by considering how the conceptual developments in the treatment of evidence both shaped theories and affected practices in the study of the natural world. We will consider the transformation from Aristotelian conceptions of nature to the "experimental philosophy" of the later 17th century; the role of the evidential disciplines of logic and rhetoric; and the incursion of legal notions of "matter of fact" into the philosophy of science in the same period. Instructor: Serjeantson.

Pl/HPS 184. Science, Ethics, and Public Policy. *9 units (3-0-6).* For course description, see Philosophy.

HUMANITIES

Hum/H 1 ab. East Asian History. *9 units (3-0-6); offered by announcement.* Late imperial values, institutions, and behaviors and their evolution in the 19th and 20th centuries. Hum/H 1 a will deal largely with China, and Hum/H 1 b with Japan. The readings will consist of selected thematic texts as well as a chronological textbook. Each term is independent of the other, and students will normally take only one of the two terms. Instructor: Staff.

Hum/H 2. American History. *9 units (3-0-6); offered by announcement.* Among the major events, trends, and problems of our country's history are the American Revolution, the framing and development of the Constitution, wars, slavery and emancipation, ethnic and gender relations, immigration, urbanization, westward conquest, economic fluctuations, changes in the sizes and functions of governments, foreign relations, class conflicts, domestic violence, and social and political movements. Although no one course can treat all of these themes, each freshman American history course will deal with two or more of them. How have American historians approached them? What arguments and evidence have scholars offered for their interpretations and how can we choose between them? In a word, what can we know about our heritage? Instructor: Kousser.

Hum/H 3 abc. European Civilization. *9 units (3-0-6); offered by announcement.* This course will be divided into three terms, each of which will focus on a coherent period in the history of European civilization. Each term is independent of the others, and students will normally take only one of the three terms.

a. The Classical and Medieval Worlds. Will survey the evolution of Mediterranean and European civilization from antiquity through the end of the Middle Ages. It will emphasize the reading and discussion of primary sources, especially but not exclusively literary works, against the backdrop of the broad historical narrative of the periods. The readings will present students with the essential characteristics of various ancient and medieval societies and give students access to those societies' cultural assumptions and perceptions of change. Instructors: Brown, Hoffman, Pigman.

b. Early Modern Europe. Will survey the evolution of European civilization from the 14th century to the early 19th century. The topics covered will depend on the individual instructor, but they will include some of the major changes that transformed Western civilization in the early modern period, such as the Renaissance, the Reformation, the rise of sovereign states and the concomitant military revolution, the Scientific Revolution and the Enlightenment, and the French and industrial revolutions. Readings will include major works from the period, as well as studies by modern historians. Instructors: Brown, Hoffman, Pigman, Crosignani, Dennison.

c. Modern Europe. Will introduce students to major aspects of the politics and culture of modernity that have profoundly transformed Western society and consciousness from the French Revolution to the contemporary era. A variety of historical, literary, and artistic works will be used to illuminate major social, intellectual, and cultural movements. The focus will be on significant and wide-ranging historical change (e.g., the industrial revolution, imperialism, socialism, fascism); on cultural innovation (e.g., modernism, impressionism, cubism); and on the work of significant thinkers. Instructors: Kormos-Buchwald, Rosenstone.

Hum/H 4 abc. Civilization, Science, and Archaeology. *9 units (3-0-6); offered by announcement.* This course will be divided into three terms, each of which will focus on a particular aspect of pre-classical antiquity or premodern science. Each term is independent of the others, and students will normally take only one of the three terms. Instructor: Buchwald.

a. Before Greece: The Origins of Civilization in Mesopotamia. This course will introduce students to the early development of civilization in Mesopotamia and Egypt from 4000 B.C.E. through 1000 B.C.E. Origins of agriculture and writing, the evolution of the city, and the structures of the Mesopotamian economy and social order will be discussed. Comparison with contemporary developments in Egypt during the Old and Middle Kingdoms may include a reading of *Gilgamesh* from 3000 B.C.E. and of the Egyptian *Tale of Sinuhe*. The course concludes with a discussion of life during the late Bronze Age. Focus will be on life as it was lived and experienced by many groups in pre-classical antiquity rather than on kings and dynasties.

b. Before Copernicus: Exploration of the Development of Science from Babylon through the Renaissance. Connections in antiquity between astrology and astronomy, the first comprehensive accounts of vision and light by al-Kindi in 9th-century Baghdad, the emergence of new concepts of knowledge about nature during the Middle Ages in Europe, alchemy in the early laboratory, and the development of linear perspective during the Renaissance.

c. The Origins of Polytheism and Monotheism in Ancient Egypt, Mesopotamia, and Israel. The civilizations of Egypt and Mesopotamia gave rise to complex forms of religious belief and cult practices that were tightly connected to views concerning the social order, moral behavior, and the afterlife. Development of the concept of a moral death—that judgment of good and evil in life determines fate—in early Egypt, and the emergence there and in Mesopotamia of "sin" as a violation of cosmic order. The emergence of monotheism, which was born and shaped within this polytheistic matrix.

Hum/En 5. Major British Authors. *9 units (3-0-6); offered by announcement.* This course will introduce students to some of the genres of English literature, including poetry, drama, and prose fiction, by studying major authors from different periods. Sometimes the course will cover a wide range of authors, while at others it will concentrate on a few. Authors might include Chaucer, Shakespeare, Milton, Austen, George Eliot, or Joyce. Instructors: Gilmartin, Haugen, La Belle, Mandel, Pigman.

Hum/En 6. American Literature and Culture. *9 units (3-0-6); offered by announcement.* Studies of American aesthetics, genres, and ideas from the birth of the nation to the present. Students will be introduced to the techniques of formal analysis. We will consider what constitutes evidence in relation to texts and how to develop a persuasive interpretation. Topics may include *Nature's Nation*, slavery and its aftermath, individualism and the marketplace, the "New Woman," and the relation between word and image. Instructors: Jurca, Weinstein.

Hum/En 7. Modern European Literature. *9 units (3-0-6); offered by announcement.* An introduction to literary analysis through a sustained exploration of the rise and aftermath of modernism. What was the modernist revolt of the early 20th century, how did it challenge literary tradition and existing social forms, and to what extent have we inherited a world remade by modernism? While the course will focus on British and Continental literature, writers from other parts of the world whose work closely engages the European tradition may also be considered. Authors may include Flaubert, James, Conrad, Joyce, Woolf, Kafka, Borges, Yeats, and Eliot. Instructors: Gilmartin, Haugen, Pigman.

Hum/Pl 8. Right and Wrong. *9 units (3-0-6); offered by announcement.* This course addresses the question "Where do moral ideas come from and how should they guide our conduct?" by exploring selections from the great works of moral and political philosophy—Aristotle's *Nichomachean Ethics*, Plato's *Republic*, Hobbes's *Leviathan*, Locke's *Second Treatise on Government*, Mill's *Utilitarianism*, Rousseau's *The Social Contract*, Kant's *Groundings for a Metaphysics of Morals*, Rawls's *A Theory of Justice*—as well as a variety of more modern texts and commentaries. Throughout, an attempt will be made to acquaint students with the basic elements of Western moral and political tradition: notions about human rights, democracy, and the fundamental moral equality of all human beings. This historical approach will then provide a background for the issues that frame contemporary discussions of moral and political ideas. Instructor: Philosophy staff.

Hum/Pl 9. Knowledge and Reality. *9 units (3-0-6); offered by announcement.* The theme of this course is the scope and limitations of rational belief and knowledge. Students will examine the nature of reality, the nature of the self, the nature of knowledge, and how we learn about the natural world. Students will be introduced to these issues through selections from some of the world's greatest philosophical works, including Descartes's *Meditations*, Pascal's *Pensées*, Hume's *Enquiry Concerning Human Understanding*, Berkeley's *Principles of Human Knowledge*, and Kant's *Prolegomena to any Future Metaphysics*. A variety of more contemporary readings will also be assigned. Instructor: Philosophy staff.

Hum/H/HPS 10. Introduction to the History of Science. *9 units (3-0-6); offered by announcement.* Major topics include the following: What are the origins of modern Western science, when did it emerge as distinct from philosophy and other cultural and intellectual productions, and what are its distinguishing features? When and how did observation, experiment, quantification, and precision enter the practice of science? What were some of the major turning points in the history of science? What is the changing role of science and technology? Using primary and secondary sources, students will take up significant topics in the history of science, from ancient Greek science to the 20th-century revolution in physics, biology, and technology. Hum/H/HPS 10 may be taken for credit toward the additional 36-unit HSS requirement by HPS majors and minors who have already fulfilled their freshman humanities requirement and counts as a history course in satisfying the freshman humanities breadth requirement. Instructor: History staff.

Hum 119. Selected Topics in Humanities. *9 units (3-0-6); offered by announcement.* Instructors: Staff, visitors.

INDEPENDENT STUDIES PROGRAM

Students who have chosen to enter the Independent Studies Program (ISP) instead of a formulated undergraduate option may enroll in special ISP courses. These courses are designed to accommodate individual programs of study or special research that fall outside ordinary course offerings. The student and the instructor first prepare a written course contract specifying the work to be accomplished and the time schedule for reports on progress and for work completed. The units of credit and form of grading are decided by mutual agreement between the instructor, the student, and his or her advisory committee. See page 217 for complete details.

INFORMATION SCIENCE AND TECHNOLOGY

IST 1. Introduction to Information. *9 units (3-0-6); third term.* This course offers an introduction to the modern study of information, addressing fundamental questions about information representation, transmission, and learning. Questions considered include: What is information, and how should we represent it for storage and transmission? What does it mean to represent information efficiently? Is there a "shortest possible" description? Can we hope to communicate reliably in a noisy world? How much information can be transmitted, and what are the strategies by which we can improve reliability? What does it mean for a machine to learn? How much data must be observed to achieve reliable learning? Not offered on a pass/ fail basis. *Satisfies the menu requirement of the Caltech core curriculum.* Instructor: Effros.

IST 4. Information and Logic. *9 units (3-0-6); third term.* The course explains the key concepts at the foundations of computing with physical substrates, including representations of numbers, Boolean algebra as an axiomatic system, Boolean functions and their representations, composition of functions and relations, implementing functions with circuits, circuit complexity, representation of computational processes with state diagrams, state diagrams as a composition of Boolean functions and memory, and the implementation of computational processes with finite state machines. The basic concepts covered in the course are connected to advanced topics like programming, computability, logic, complexity theory, information theory, and biochemical systems. Not offered on a pass/fail basis. *Satisfies the menu requirement of the Caltech core curriculum.* Instructor: Bruck.

LANGUAGES

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Additional information about these courses can be found at http://languages.caltech.edu.

L 101. Selected Topics in Language. *Units to be determined by arrangement with the instructor.* Graded pass/fail. Instructors: Staff, visiting lecturers.

L 102 abc. Elementary French. *10 units (3-1-6); first, second, third terms.* The course uses French in Action, a multimedia program, and emphasizes the acquisition of fundamental skills: oral ability, comprehension, writing, and reading. Students are evaluated on the basis of quizzes and compositions (1/3), midterm and final (1/3), and class participation (1/3). The course is mainly designed for students with no previous knowledge of French. Students who have had French in secondary school or college must consult with the instructor before registering. Instructors: Orcel, de Bedts.

L 103 abc. Intermediate French. *9 units (3-0-6); first, second, third terms. Prerequisite: L 102 abc or equivalent.* The first two terms feature an extensive grammar review and group activities that promote self-expression. Op-Ed articles and a series of literary texts provide a basis for classroom discussion and vocabulary expansion. Several short written compositions are required. The third term is designed to further develop an active command of the language. A variety of 19th- and 20th-century short stories are discussed in class to improve comprehension and oral proficiency. Students are expected to do an oral presentation, to write four short compositions, and a final paper. Second and third terms are offered for advanced humanities credit. Instructors: de Bedts, Orcel.

L/F 104. French Cinema. *9 units (3-0-6); first term. Prerequisite: L 103 abc or equivalent.* A critical survey of major directors, genres, and movements in French cinema. Particular attention is devoted to the development of film theory and criticism in France and their relation to film production. The course may also focus on problems of transposition from literature to cinema. The course includes screenings of films by Melies, Dulac, Clair, Renoir, Carné, Pagnol, Cocteau, Bresson, Tati, Truffaut, Godard, Resnais, Lelouch, Malle, Pialat, Rohmer, and Varda. Students are expected to write three 5-page critical papers. Conducted in French. Instructor: Orcel.

L 105 ab. French Literature. *9 units (3-0-6); second, third terms. Prerequisite: L 103 abc or equivalent.* Close critical analysis of representative works from 19th- and 20th-century authors. The texts are examined in relation to the artistic, intellectual, and political context. Designed for the nonspecialist with little or no background in French literary history. Autobiography in 20th-century France, the modern French novel, the French avant-garde, the modern French theater and its aesthetic, and women's voices: 20th-century French narrative prose, are some of the topics offered previously. Film versions of the texts studied may be included. Conducted in French. Three 5-page critical papers on topics chosen by the student are required. L 105 a may be repeated for credit. Instructor: Orcel.

L 106 abc. Elementary Japanese. *10 units (5-1-4); first, second, third terms.* Emphasis on oral-aural skills, and understanding of basic grammar. Immediate introduction of the native script—*hiragana*, *katakana*—and gradual introduction to 300 to 500 characters. Not offered on a pass/fail basis. Instructor: Hirai.

L 107 abc. Intermediate Japanese. *10 units (5-1-4); first, second, third terms. Prerequisite: L 106 abc or equivalent.* Continued instruction and practice in conversation, building up vocabulary, and understanding complex sentence patterns. The emphasis, however, will be on developing reading skills. Recognition of approximately 1,000 characters. Not offered on a pass/fail basis. Instructor: Hirata.

L 108 abc. Advanced Japanese. *10 units (3-1-6); first, second, third terms. Prerequisite: L 107 abc or equivalent.* Developing overall language skills. Literary and newspaper readings. Technical and scientific translation. Improvement of listening and speaking ability so as to communicate with Japanese people in real situations. Recognition of the 1,850 "general-use characters." Not offered on a pass/fail basis. Instructor: Hirata.

L 110 abc. Elementary Spanish. *10 units (3-1-6); first, second, third terms.* Grammar fundamentals and their use in understanding, speaking, reading, and writing Spanish. Exclusively for students with no previous knowledge of Spanish. Instructors: Garcia, Arjona.

L 112 abc. Intermediate Spanish. *9 units (3-0-6); first, second, third terms. Prerequisite: L 110 abc or equivalent.* Grammar review, vocabulary building, practice in conversation, and introduction to relevant history, literature, and culture. Literary reading and writing are emphasized in the second and third terms. Students who have studied Spanish elsewhere must consult with the instructor before registering. Instructors: Garcia, Arjona.

L 114 abc. Spanish and Latin American Literature. *9 units (3-0-6); offered by announcement. Prerequisite: L 112 abc or equivalent.* First and second terms: study of literary texts from the Spanish American and Spanish traditions, their cultural and historical relevance, covering all periods, with emphasis on contemporary authors. Third term: contemporary topics in literature and/or film of the Hispanic world. Conducted in Spanish. Instructors: Garcia, Arjona.

L 130 abc. Elementary German. *10 units (3-1-6); first, second, third terms.* Grammar fundamentals and their use in aural comprehension, speaking, reading, and writing. Students who have had German in secondary school or college must consult with the instructor before registering. Instructor: Aebi.

L 132 abc. Intermediate German. *9 units (3-0-6); first, second, third terms. Prerequisite: L 130 abc or equivalent.* Reading of short stories and plays, grammar review, aural and oral drills and exercises, expansion of vocabulary, and practice in reading, writing, and conversational skills. Second and third terms will emphasize written expression, technical/scientific translation, and literary readings. Students who have studied German elsewhere must consult with the instructor before registering. Instructor: Aebi.

L 140 abc. German Literature. *9 units (3-0-6). Prerequisite: L 132 c or equivalent (two years of college German), or instructor's permission.* Reading and discussion of works by selected 12th–21st-century authors, current events on Internet/TV, exposure to scientific and technical writing, business communication. Viewing and discussion of German-language films. Conducted in German. Not offered 2006–07.

L 152 ab. French Literature in Translation: Classical and Modern. *9 units* (3-0-6); first, second terms. First term: French classical literature of the 17th and 18th centuries; second term: reading and discussion of works by selected 19th- and 20th-century authors. The approach is both historical and critical. Conducted in English, but students may read the French originals. Film versions of the texts studied may be included. Instructors: de Bedts, Orcel.

L 160 ab. German Literature in Translation. *9 units (3-0-6).* First term: "Tales of Hollywood," German exile literature 1933–45; second term: German literature of the 19th century—Biedermeier, young Germany, realism, and naturalism. Not offered 2006–07.

L 162. Spanish and Latin American Literature in Translation. *9 units (3-0-6); offered by announcement.* This class is an introduction to the literary masterworks of the Hispanic tradition from the 16th to the 20th centuries. Readings and discussions are in English, but students may read Spanish originals. Instructor: Staff.

L 167 abc. Latin Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: three years of high-school Latin.* Major works of Latin literature, usually one per term. No work will be studied more than once in four years, and students may repeat the course for credit. Not offered 2006–07.

L 170 abc. Introduction to Chinese. *10 units (4-1-5); first, second, third terms.* An introductory course in standard Chinese (Mandarin) designed for students with no previous knowledge of the language. The course introduces the fundamentals of Chinese, including pronunciation, grammar, and Chinese characters, emphasizing the four basic language skills: listening, speaking, reading, and writing. By the end of the three-term sequence, students will have acquired knowledge of basic rules of grammar and the ability to converse, read, and write on simple topics of daily life, and will have command of more than 800 Chinese compounds and 700 characters. Instructor: Wang.

L 171 abc. Elementary Chinese. *10 units (4-1-5); first, second, third terms. Prerequisite: placement exam results or instructor's permission.* A fast-paced course for students who have had prior exposure to the language. Students are introduced to the basic principles of written and oral communication. Emphasis will be placed on consolidating basic grammar, and developing the ability to use the language creatively in talking about oneself and in dealing with daily situations within a Chinese cultural context. Instructor: Wang.

L 172 abc. Intermediate Chinese. *10 units (4-1-5); first, second, third terms. Prerequisite: L 170 abc or L 171 abc or equivalent.* A course designed to meet the personal interests and future professional goals of students who have had one year of elementary modern Chinese. Students will learn new vocabulary, sentence patterns, idiomatic expressions, and proverbs, as well as insights into Chinese society, culture, and customs. Instructor: Ming.

L 173 ab. Advanced Chinese. *10 units (3-1-6); first, second terms. Prerequisite: L 172 abc or equivalent.* A course designed to further develop overall language proficiency through extensive reading of selected texts representing a wide variety of styles and genres, including newspapers and magazines, visual materials, and a selection of works of major modern writers. Classes are conducted primarily in Chinese. Instructor: Ming.

L 174. Topics in Chinese Literature. *9 units (3-0-6); offered by announcement. Prerequisite: instructor's permission.* Reading and discussion of representative Chinese works from the 16th century to the present, including contemporary works from China, Taiwan, and Hong Kong. Conducted in Chinese. Students are expected to examine literary works in light of their socio-political and historical contexts. Instructor: Ming.

LAW

Law 33. Introduction to the Law. *9 units (3-0-6); first term.* An introduction to Anglo-American law from both the legal and the social-scientific points of view. Subject can vary from year to year. Available for introductory social science credit. Instructor: Spitzer.

Law 134. Law and Technology. *9 units (3-0-6); second term.* A sophisticated introduction to and exploration of the intersection of science and the law, focusing on the intellectual property system and the various means by which the conduct and products of scientific research are regulated. The course will analyze and compare American, international, and theoretical alternative systems, in part by means of economics modeling. The latter portion of the course will explore a particular scientific area in depth, typically using guest lecturers or coteachers to convey the science element (examples include the human genome project; the Internet and cyberspace; the law of the sea; and outer-space exploration). Some background in law and economics would be helpful. Not offered 2006–07.

Law 135. History of Anglo-American Law. *9 units (3-0-6); second term.* An introductory survey of English law from medieval to modern times, with discussion of parallel and divergent developments in the United States. Topics include the constitution: constraints on the king, Magna Carta, the rise of parliamentary democracy, the role of courts, written versus unwritten constitutions, the U.S. Constitution; law making: statutes and the doctrine of precedent; fact finding: trial by battle and by ordeal, the development of the jury trial; civil justice: common law, equity, contract, and property law; criminal justice: private and public prosecution, star chamber, defendants' rights, criminal sanctions; family law and the changing legal status of women. Instructor: Klerman.

Law/PS/H 148 ab. The Supreme Court in U.S. History. *9 units (3-0-6); second, third terms.* The development of the Supreme Court, its doctrines, personalities, and role in U.S. history through analyses of selected cases. The first half of the course, which is a prerequisite for the second half but may also be taken by itself, will deal with such topics as federalism, economic regulation, political rights, and free speech. The second half will cover such issues as the rights of the accused, equal protection, and privacy. Instructor: Kousser.

MATERIALS SCIENCE

Additional information concerning these courses can be found at http://www.matsci.caltech.edu/courses.html.

MS 78 abc. Senior Thesis. *9 units; first, second, third terms. Prerequisite: instructor's permission.* Supervised research experience, open only to senior-class materials-science majors. Starting with an open-ended topic, students will plan and execute a project in materials science and engineering that includes written and oral reports based upon actual results, synthesizing topics from their coursework. Only the first term may be taken pass/fail. Instructor: Staff.

MS 90. Materials Science Laboratory. *9 units (1-6-2); third term.* An introductory laboratory in relationships between the structure and properties of materials. Experiments involve materials processing and characterization by X-ray diffraction, scanning electron microscopy, and optical microscopy. Students will learn techniques for measuring mechanical and electrical properties of materials, as well as how to optimize these properties through microstructural and chemical control. Independent projects may be performed depending on the student's interests and abilities. Instructor: Staff.

MS 100. Advanced Work in Materials Science. The staff in materials science will arrange special courses or problems to meet the needs of students working toward the M.S. degree or of qualified undergraduate students. Graded pass/fail for research and reading. Instructor: Staff.

MS 105. Phase Transformations. *9 units (3-0-6); third term. Prerequisites: APh 105 b or ChE/Ch 164, or instructor's permission.* Thermodynamics and kinetics of phase transformations. Phase diagrams for decomposition and ordering. Nucleation, spinodal decomposition, microstructural morphologies. Role of strain energy in solid-solid phase transformations. Thermomechanical processing of selected materials. Instructor: Haile.

MS 110 abc. Materials Research Lectures. *1 unit (1-0-0); first, second, third terms.* A seminar course designed to introduce advanced undergraduates and graduate students to modern research in materials science. Not offered 2006–07.

MS 115 ab. Fundamentals of Materials Science. *9 units (3-0-6); first, second terms. Prerequisite: Ph 2.* An introduction to the structure and properties of materials and the processing routes utilized to optimize properties. All major classes of materials are covered, including metals, ceramics, electronic materials, composites, and polymers. In the first term, emphasis is on the relationships between chemical bonding, crystal structure, thermodynamics, phase equilibria, microstructure, and properties. In the second term, generic processing and manufacturing methods are presented for each class of materials with particular focus on the influence of these processes on mechanical properties. Emphasis is placed on the basic materials science behind each processing method, covering such topics as thermodynamics, diffusion, kinetics of phase transformations, and microstructure development. Instructors: Haile, staff.

MS 125. Advanced Transmission Electron Microscopy. *9 units (1-6-2); third term. Prerequisite: MS 132.* Diffraction contrast analysis of crystalline defects. Phase contrast imaging. Physical optics approach to dynamical electron diffraction and imaging. Microbeam methods for diffraction and imaging. Chemical analysis by energy dispersive X-ray spectrometry and electron energy loss spectrometry. Instructor: Ahn.

MS 130. Diffraction and Structure. *9 units (3-0-6); second term. Prerequisite: graduate standing or instructor's permission.* Content is identical to MS 132 but without the laboratory exercises. Instructor: Fultz.

MS 131. Structure and Bonding in Materials. *9 units (3-0-6); second term. Prerequisite: graduate standing or introductory quantum mechanics.* Atomic structure, hybridization, molecular orbital theory, dependence of chemical bonding on atom configurations. Covalency, ionicity, electronegativity. Madelung energy. Effects of translational periodicity on electron states in solids. Band structures of group IV semiconductors; transition metals and ferromagnetism. Structural features of materials such as point defects, dislocations, disclinations, and surfaces. Structures of defects calculated with the embedded atom method. Instructor: van de Walle.

MS 132. Diffraction and Structure of Materials. *12 units (3-3-6); first term.* Principles of electron and X-ray diffraction, with applications for characterizing materials. Topics include scattering and absorption of electrons and X rays by atoms. The transmission electron microscope (TEM) and the X-ray diffractometer. Kinematical theory of diffraction: effects of strain, size, disorder, and temperature. Crystal defects and their characterization. A weekly laboratory will complement the lectures. Instructors: Fultz, Ahn.

MS 133. Kinetic Processes in Materials. *9 units (3-0-6); third term. Prerequisites: APh 105 b or ChE/Ch 164, or instructor's permission.* Kinetic master equation, uncorrelated and correlated random walk, diffusion. Mechanisms of diffusion and atom transport in solids, liquids, and gases. Coarsening of microstructures. Nonequilibrium processing of materials. Instructors: Fultz and Kornfield.

MS 142. Application of Diffraction Techniques in Materials Science. *9 units (2-3-4); third term. Prerequisites: MS 132 or instructor's permission.* Applications of X-ray and neutron diffraction methods to the structural characterization of materials. Emphasis is on the analysis of polycrystalline materials but some discussion of single crystal methods is also presented. Techniques include quantitative phase analysis, crystalline size measurement, lattice parameter refinement, internal stress measurement, quantification of preferred orientation (texture) in materials, Rietveld refinement, and determination of structural features from small angle scattering. Homework assignments will focus on analysis of diffraction data. Samples of interest to students for their thesis research may be examined where appropriate. Not offered 2006–07.

MS 143. Electrochemical Energy Storage and Conversion. *9 units (3-0-6); first term.* Electrochemical thermodynamics and kinetics, with emphasis on processes in electrode materials and electrolytes used in batteries, fuel cells, and supercapacitors. Electroanalytical characterization techniques. Electrode materials for energy storage: mixed (ion and electron) conductors, intercalation materials. Theoretical and practical energy density, rate capability and energy vs. power characteristics. Factors affecting electrode performance, diagnostic techniques, and failure mechanisms. Applications include batteries (primary, secondary, and advanced), fuel cells (ceramic, molten salts, and polymer electro-lytes systems), supercapacitors (aqueous, organic, and solid-state systems). Safety and environmental issues. Not offered 2006–07.

MS 200. Advanced Work in Materials Science. The staff in materials science will arrange special courses or problems to meet the needs of advanced graduate students.

Ae/AM/MS/ME 213. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6).* For course description, see Aeronautics.

ME/MS 260 abc. Micromechanics. *12 units (3-0-9).* For course description, see Mechanical Engineering.

MS 300. Thesis Research.

MATHEMATICS

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Ma 1 abc. Calculus of One and Several Variables and Linear Algebra. *9 units (4-0-5); first, second, third terms. Prerequisites: high-school algebra, trigonometry, and calculus. Special section of Ma 1 a, 12 units (5-0-7).* Review of calculus. Complex numbers, Taylor polynomials, infinite series. Comprehensive presentation of linear algebra. Derivatives of vector functions, multiple integrals, line and path integrals, theorems of Green and Stokes. Ma 1 b, c is divided into two tracks: analytic and practical. Students will be given information helping them to choose a track at the end of the fall term. There will be a special section or sections of Ma 1 a for those students who, because of their background, require more calculus than is provided in the regular Ma 1 a sequence. These students will not learn series in Ma 1 a and will be required to take Ma 1 d. Instructors: Groves, Borodin, Aschbacher, Wales, Ramakrishnan, Dunfield.

Ma 1 d. Series. *5 units (2-0-3); second term only. Prerequisite: special section of Ma 1 a.* This is a course intended for those students in the special calculus-intensive sections of Ma 1 a who did not have complex numbers, Taylor polynomials, and infinite series during Ma 1 a. It may not be taken by students who have passed the regular Ma 1 a. Instructor: Staff.

Ma 2 ab. Differential Equations, Probability and Statistics. *9 units (4-0-5); first, second terms. Prerequisite: Ma 1 abc.* Ordinary differential equations, probability, statistics. Instructors: Makarov, Calegari, Lorden.

Ma 3. Number Theory for Beginners. *9 units (3-0-6); third term.* Some of the fundamental ideas, techniques, and open problems of basic number theory will be introduced. Examples will be stressed. Topics include Euclidean algorithm, primes, Diophantine equations, including $a^n + b^n = c^n$ and $a^2 - db^2 = \pm 1$, constructible numbers, composition of binary quadratic forms, and congruences. Instructor: Keevash.

Ma 4. Introduction to Mathematical Chaos. *9 units (3-0-6); third term.* An introduction to the mathematics of "chaos." Period doubling universality, and related topics; interval maps, symbolic itineraries, stable/unstable manifold theorem, strange attractors, iteration of complex analytic maps, applications to multidimensional dynamics systems and real-world problems. Possibly some additional topics, such as Sarkovski's theorem, absolutely continuous invariant measures, sensitivity to initial conditions, and the horseshoe map. Instructor: Gorodetski.

Ma 5 abc. Introduction to Abstract Algebra. *9 units (3-0-6); first, second, third terms. Freshmen must have instructor's permission to register.* Introduction to groups, rings, fields, and modules. The first term is devoted to groups and includes treatments of semidirect products and Sylow's theorem. The second term discusses rings and modules and includes a proof that principal ideal domains have unique factorization and the classification of finitely generated modules over principal ideal domains. The third term covers field theory and Galois theory, plus some special topics if time permits. Instructors: Wambach, Wales, Flach.

Ma/CS 6 abc. Introduction to Discrete Mathematics. *9 units (3-0-6); first, second, third terms. Prerequisite: for Ma/CS 6 c, Ma/CS 6 a or Ma 5 a or instructor's permission.* First term: a survey emphasizing graph theory, algorithms, and applications of algebraic structures. Graphs: paths, trees, circuits, breadth-first and depth-first searches, colorings, matchings. Enumeration techniques; formal power series; combinatorial interpretations. Topics from coding and cryptography, including Hamming codes and RSA. Second term: directed graphs; networks; combinatorial optimization; linear programming. Permutation groups; counting nonisomorphic structures. Topics from extremal graph and set theory, and partially ordered sets. Third term: elements of computability theory and computational complexity. Discussion of the P=NP problem, syntax and semantics of propositional and first-order logic. Introduction to the Gödel completeness and incompleteness theorems. Instructors: Wilson, Ku, Kechris.

Ma 8. Problem Solving in Calculus. *3 units (3-0-0); first term. Prerequisite: simultaneous registration in Ma 1 a.* A three-hour per week hands-on class for those students in Ma 1 needing extra practice in problem solving in calculus. Instructor: Vuletic.

Ma 10. Oral Presentation. *3 units (2-0-1); first term. Open for credit to anyone. Freshmen must have instructor's permission to enroll.* In this course, students will receive training and practice in presenting mathematical material before an audience. In particular, students will present material of their own choosing to other members of the class. There will also be elementary lectures from members of the mathematics faculty on topics of their own research interest. Instructor: Borodin.

Ma 11. Mathematical Writing. *3 units (0-0-3); third term.* Students will work with the instructor and a mentor to write and revise a self-contained paper dealing with a topic in mathematics. In the first week, an introduction to some matters of style and format will be given. Some help with typesetting in TeX may be available. Students are encouraged to take advantage of the Hixon Writing Center. The mentor and the topic are selected in consultation with the instructor. It is expected that in most cases the paper will be in the style of a textbook or journal article, at the level of the student's peers. *Fulfills the Institute scientific writing requirement.* Graded pass/fail. Instructor: Wilson.

Ma 12. Chance. *9 units (4-0-5); second term.* This course will explore the use and misuse of notions of probability and statistics in popular culture and in science. The course will be structured around case studies chosen from mass media and from the scientific literature. Not offered 2006–07.

Ma 17. How to Solve It. *4 units (2-0-2); first term.* There are many problems in elementary mathematics that require ingenuity for their solution. This is a seminar-type course on problem solving in areas of mathematics where little theoretical knowledge is required. Students will work on problems taken from diverse areas of mathematics; there is no prerequisite and the course is open to freshmen. May be repeated for credit. Graded pass/fail. Instructor: Tsankov.

Ma 92 abc. Senior Thesis. *9 units (0-0-9); first, second, third terms. Prerequisite: To register, the student must obtain permission of the mathematics undergraduate representative, Richard Wilson.* Open only to senior mathematics majors who are qualified to pursue independent reading and research. This research must be supervised by a faculty member. The research must begin in the first term of the senior year and will normally follow up on an earlier SURF or independent reading project. Two short presentations to a thesis committee are required: the first at the end of the first term and the second at the midterm week of the third term. A draft of the written thesis must be completed and distributed to the committee one week before the second presentation. Graded pass/fail in the first and second terms; a letter grade will be given in the third term.

Ma 98. Independent Reading. *3–6 units by arrangement.* Occasionally a reading course will be offered after student consultation with a potential supervisor. Topics, hours, and units by arrangement. Graded pass/fail.

Ma 105. Elliptic Curves. *9 units (3-0-6); first term. Prerequisite: Ma 5, Ma 3, or equivalents.* The ubiquitous elliptic curves will be analyzed from elementary, geometric, and arithmetic points of view. Possible topics are the group structure via the chord-and-tangent method, the Nagel-Lutz procedure for finding division points, Mordell's theorem on the finite generation of rational points, points over finite fields through a special case treated by Gauss, Lenstra's factoring algorithm, integral points. Other topics may include diophantine approximation and complex multiplication. Not offered 2006–07.

Ma 108 abc. Classical Analysis. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 2 or equivalent, or instructor's permission. May be taken concurrently with Ma 109.* First term: structure of the real numbers, topology of metric spaces, a rigorous approach to differentiation in R^n. Second term: brief introduction to ordinary differential equations; Lebesgue integration and an introduction to Fourier analysis. Third term: the theory of functions of one complex variable. Instructors: Zinchenko, Christiansen.

Ma 109 abc. Introduction to Geometry and Topology. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 or equivalent, and Ma 108 must be taken previously or concurrently.* First term: aspects of point set topology, and an introduction to geometric and algebraic methods in topology. Second term: the differential geometry of curves and surfaces in two- and three-dimensional Euclidean space. Third term: an introduction to differentiable manifolds. Transversality, differential forms, and further related topics. Instructors: Gorodnik, McReynolds, Graber.

Ma 110 abc. Analysis, I. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 or previous exposure to metric space topology, Lebesgue measure.* First term: integration theory and basic functional analysis: measure spaces, integral, L^p-spaces, Fejer's theorem, measures as functionals, product measures, Baire category, Hahn-Banach theorem, Alaoglu's theorem, differential theory including maximal functions. Second term: basic complex analysis: analytic functions, conformal maps, idea of Riemann surfaces, elementary and some special functions, residue calculus, infinite sums and products, entire and meromorphic functions, asymptotic analysis. Third term: real and harmonic analysis. Real analysis: convexity, Hausdorff measures, arc length and surface measures, integral and convolution operators, L^p-estimates, interpolation theorems, singular integrals, generalized functions, Sobolev spaces. Harmonic analysis: Fourier analysis of periodic functions, harmonic functions in the unit disk and Fourier series, harmonic analysis in R^d, Fourier integral, boundary behavior of harmonic functions, convergence of Fourier series and integrals, applications to analysis of convolution operators. Instructor: Simon.

Ma 111 ab. Analysis, II. *9 units (3-0-6); second, third terms. Prerequisite: Ma 110 or instructor's permission.* This course will discuss advanced topics in analysis, including zeros of analytic functions and functions on the unit disk, Riemann surfaces, probabilistic methods in analysis, combinatorial methods in analysis, operator theory, C*-algebras. First term: advanced topics in the theory of a complex variable, including elliptic functions, Picard's theorems, zeros, properties of bounded analytic functions on the disk. Second term: potential theory. Part a not offered 2006–07. Instructor: Makarov.

Ma 112 ab. Statistics. *9 units (3-0-6); first, second terms. Prerequisite: Ma 2 a probability and statistics or equivalent.* The first term covers general methods of testing hypotheses and constructing confidence sets, including regression analysis, analysis of variance, and nonparametric methods. The second term covers permutation methods and the bootstrap, point estimation, Bayes methods, and multistage sampling. Instructor: Lorden.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 or equivalent, or instructor's permission.* Propositional logic, predicate logic, formal proofs, Gödel completeness theorem, the method of resolution, elements of model theory. Computability, undecidability, Gödel incompleteness theorems. Axiomatic set theory, ordinals, transfinite induction and recursion, iterations and fixed points, cardinals, axiom of choice. Not offered 2006–07.

Ma/CS 117 abc. Computability Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 or equivalent, or instructor's permission.* Various approaches to computability theory, e.g., Turing machines, recursive functions, Markov algorithms; proof of their equivalence. Church's thesis. Theory of computable functions and effectively enumerable sets. Decision problems. Undecidable problems: word problems for groups, solvability of Diophantine equations (Hilbert's 10th problem). Relations with mathematical logic and the Gödel incompleteness theorems. Decidable problems, from number theory, algebra, combinatorics, and logic. Complexity of decision procedures. Inherently complex problems of exponential and superexponential difficulty. Feasible (polynomial time) computations. Polynomial deterministic vs. nondeterministic algorithms, NP-complete problems and the P = NP question. Instructors: Kechris, Caicedo.

Ma 118. Topics in Mathematical Logic. *9 units (3-0-6); first term. Prerequisite: Ma 116 or Ma 117 or equivalent.* Consistency and independence in set theory: Goedel's constructible universe L, and consistency of the axiom of choice and the continuum hypothesis CH with the other axioms of set theory. Cohen's method of forcing and independence of CH and the axiom of choice. Solovay's theorem on the consistency of "all sets of reals are Lebesgue measurable." Additional topics in set theory depending on the audience. Contents vary from year to year so that students may take the course in successive years. Instructor: Caicedo.

Ma 120 abc. Abstract Algebra. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 or equivalent. Undergraduates who have not taken Ma 5 must have instructor's permission.* Basic theory of groups, rings, modules, and fields, including free groups; Sylow's theorem; solvable and nilpotent groups; factorization in commutative rings; integral extensions; Wedderburn theorems; Jacobson radical; semisimple, projective, and injective modules; tensor products; chain conditions; Galois theory;

cyclotomic extensions; separability; transcendental extensions. Instructors: Aschbacher, Dimitrov.

Ma 121 abc. Combinatorial Analysis. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5.* A survey of modern combinatorial mathematics, starting with an introduction to graph theory and extremal problems. Flows in networks with combinatorial applications. Counting, recursion, and generating functions. Theory of partitions. (0, 1)-matrices. Partially ordered sets. Latin squares, finite geometries, combinatorial designs, and codes. Algebraic graph theory, graph embedding, and coloring. Instructors: Keevash, Wilson, Ku.

Ma 122 ab. Topics in Group Theory. *9 units (3-0-6); first, second terms. Prerequisite: Ma 5 abc or instructor's permission.* Groups of Lie type: classical groups, Coxeter groups, root systems, Chevalley groups, weight theory, linear algebraic groups, buildings. Not offered 2006–07.

Ma 123. Classification of Simple Lie Algebras. *9 units (3-0-6); third term. Prerequisite: Ma 5 or equivalent.* This course is an introduction to Lie algebras and the classification of the simple Lie algebras over the complex numbers. This will include Lie's theorem, Engel's theorem, the solvable radical, and the Cartan Killing trace form. The classification of simple Lie algebras proceeds in terms of the associated reflection groups and a classification of them in terms of their Dynkin diagrams. Instructor: Wales.

EE/Ma 126 ab. Information Theory. *9 units (3-0-6).* For course description, see Electrical Engineering.

EE/Ma 127 ab. Error-Correcting Codes. *9 units (3-0-6).* For course description, see Electrical Engineering.

CS/EE/Ma 129 abc. Information and Complexity. *9 units (3-0-6) first, second terms; (1-4-4) third term.* For course description, see Computer Science.

Ma 130 abc. Algebraic Geometry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 120 (or Ma 5 plus additional reading).* Plane curves, rational functions, affine and projective varieties, products, local properties, birational maps, divisors, differentials, intersection numbers, schemes, sheaves, general varieties, vector bundles, coherent sheaves, curves and surfaces. Instructors: Arinkin, Graber.

Ma 131. Algebraic Geometry of Curves. *9 units (3-0-6); second term. Prerequisites: Ma 5, Ma 108, and Ma 109, or equivalent.* The theory of algebraic curves is a central branch of mathematics, having relations to fields as diverse as complex analysis, number theory, combinatorics, codes, topology, representation theory, and physics. The aim of the course is to give a substantial introduction to this subject. The topics will include affine and projective plane curves, mappings, differentials, divisors and line bundles, Jacobians, sheaves, cohomology, and moduli. Important results such as Riemann-Roch theorem, Hurwitz's theorem, and Abel's theorem will be discussed. Not offered 2006–07.

Ma 135 ab. Arithmetic Geometry. *9 units (3-0-6); first, third terms. Prerequisite: Ma 130.* The course deals with aspects of algebraic geometry that have been found useful for number theoretic applications. Topics will be chosen from the following: general cohomology theories (étale cohomology, flat cohomology, motivic cohomology, or p-adic Hodge theory), curves and Abelian varieties over arithmetic schemes, moduli spaces, Diophantine geometry, algebraic cycles. Not offered 2006–07.

Ma 140 abc. Functional Analysis. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 110.* First term: theory of operators. Second term: symmetric and self-adjoint operators, spectral analysis of differential operators. Third term: theory of trace ideals on a Hilbert space, moment problems, and orthogonal polynomials. Not offered 2006–07.

Ma/ACM 142 abc. Ordinary and Partial Differential Equations. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108. Ma 109 is desirable.* The mathematical theory of ordinary and partial differential equations, including a discussion of elliptic regularity, maximal principles, solubility of equations. The method of characteristics. Part c not offered 2006–07. Instructor: Christiansen.

Ma/ACM 144 ab. Probability. *9 units (3-0-6); first, second terms.* Overview of measure theory. Random walks and the Strong law of large numbers via the theory of martingales and Markov chains. Characteristic functions and the central limit theorem. Poisson process and Brownian motion. Not offered 2006–07.

Ma 145 abc. Introduction to Unitary Group Representations. *9 units (3-0-6); first, second, third terms.* The study of representations of a group by unitary operators on a Hilbert space, including finite and compact groups, and, to the extent that time allows, other groups. First term: general representation theory of finite groups. Frobenius's theory of representations of semidirect products. The Young tableaux and the representations of symmetric groups. Second term: the Peter-Weyl theorem. The classical compact groups and their representation theory. Weyl character formula. Third term: introduction to the representation theory of big groups (injective limits of finite and compact groups). Classification of irreducible characters for the infinite symmetric group and the infinite-dimensional unitary group. Generalized regular representations and their decomposition on irreducible components. Parts a, b not offered 2006–07. Instructor: Borodin.

Ma 147 abc. Dynamical Systems. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 108, Ma 109, or equivalent.* First term: real dynamics and ergodic theory. Second term: Hamiltonian dynamics. Third term: complex dynamics. Instructors: Gorodetski, Makarov.

Ma 148. Topics in Mathematical Physics. *9 units (3-0-6); third term.* The course will discuss the moment problem, inverse spectral theory for one-dimensional Schrödinger operators, and the connections between them. May be taken for credit in multiple years. Not offered 2006–07.

Ma 151 abc. Algebraic and Differential Topology. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 ab or equivalent.* A basic graduate core course. Fundamental groups and covering spaces, homology and calculation of homology groups, exact sequences. Fibrations, higher homotopy groups, and exact sequences of fibrations. Bundles, Eilenberg-Maclane spaces, classifying spaces. Structure of differentiable manifolds, transversality, degree theory, De Rham cohomology, spectral sequences. Instructors: Dunfield, Calegari, Groves.

Ma 157 ab. Riemannian Geometry. *9 units (3-0-6); second, third terms. Prerequisite: Ma 151 or equivalent, or instructor's permission.* Part a: basic Riemannian geometry: geometry of Riemannian manifolds, connections, curvature, Bianchi identities, completeness, geodesics, exponential map, Gauss's lemma, Jacobi fields, Lie groups, principal bundles, and characteristic classes. Part b: basic topics may vary from year to year and may include elements of Morse theory and the calculus of variations, locally symmetric spaces, special geometry, comparison theorems, relation between curvature and topology, metric functionals and flows, geometry in low dimensions. Instructors: Dunfield, Gorodnik.

Ma 160 abc. Number Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5.* In this course, the basic structures and results of algebraic number theory will be systematically introduced. Topics covered will include the theory of ideals/divisors in Dedekind domains, Dirichlet unit theorem and the class group, p-adic fields, ramification, Abelian extensions of local and global fields. Instructors: Dimitrov, Mantovan.

Ma 162 abc. Topics in Number Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 160.* The course will discuss in detail some advanced topics in number theory, selected from the following: Galois representations, elliptic curves, modular forms, L-functions, special values, automorphic representations, p-adic theories, theta functions, regulators. Instructors: Wambach, Ramakrishnan.

Note: The courses labeled Ma 191, Ma 192, etc., are topics courses. Different courses are offered each year, reflecting the interests of faculty, visiting faculty, and students. Those offered in the fall term have an "a" designation, and "b" and "c" denote winter and spring. None of these courses is a prerequisite for any other.

Ma 191 a. Combinatorics of Finite Sets. *9 units (3-0-6); first term.* Properties of subsets of finite sets. Topics include LYM inequality, AZ identity, shadows, shifting operation, the Erdos-Ko-Rado theorem, Katona's intersection theorem, the complete intersection theorem of Ahlswede and Khachatrian, Hilton-Milner theorem, Turan's problems for cancellative hypergraphs, Turan's density for triple systems. Instructor: Ku.

Ma 191 b. Topics in Logic, Ergodic Theory, and Topological Dynamics. *9 units (3-0-6); second term.* Some possible topics include the descriptive set theory of Borel equivalence relations and group actions, a theory of complexity of classification problems in mathematics, countable equivalence relations and ergodic theory, topological dynamics of the infinite symmetric group and automorphism groups of countable structures with applications to model theory and combinatorics, the Urysohn space and its group of isometries. Instructor: Kechris.

Ma 191 c. Topics in Spectral and Inverse Spectral Theory. *9 units (3-0-6); third term.* Study of spectral and inverse spectral problems that arise in mathematical physics. Continuous (Schrödinger operators) and discrete models (Jacobi operators) will be discussed. Possible topics: spectral theorem, Weyl-Titchmarsh theory, eigenfunction expansion, Borg's inverse theorems, Gel'fand-Levitan and Marchenko methods in inverse problems. Instructor: Zinchenko.

Ma 192 a. Riemann-Hilbert Problems, Their Asymptotics and Applications. *9 units (3-0-6); first term. Prerequisites: basic probability theory, complex variables, functional analysis.* Basic theory of Riemann-Hilbert problems. Applications to problems in PDEs, orthogonal polynomials, random matrix theory, and combinatorics. Steepest descent method for Riemann-Hilbert problems. Solution of various asymptotic problems such as the longtime behavior of integrable systems, the asymptotics of orthogonal polynomials, and universality for random matrix ensembles, and the solution of Ulam's problem in combinatorics. Instructor: Deift.

Ma 193 a. Discrete Groups and Geometry. *9 units (3-0-6); first term.* This course will focus on groups that arise in geometry. Topics will include discrete subgroups of Lie groups, arithmetic groups, automorphism groups of geometric objects like manifolds and varieties, and properties of these groups. The production of interesting examples will pull ideas from many areas of mathematics. However, the primary focus will be on the interaction of groups with geometry, and in particular, on building geometric objects with interesting properties. Instructor: McReynolds.

SS/Ma 214. Mathematical Finance. *9 units (3-0-6).* For course description, see Social Science.

Ma 290. Reading. *Hours and units by arrangement.* Occasionally, advanced work is given through a reading course under the direction of an instructor.

Note: The following research courses and seminars, intended for advanced graduate students, are offered according to demand. They cover selected topics of current interest. The courses offered, and the topics covered, will be announced at the beginning of each term.

Ma 316 abc. Seminar in Mathematical Logic. Instructor: Kechris.

Ma 324 abc. Seminar in Combinatorics. Instructor: Wilson.

Ma 325 abc. Seminar in Algebra. Instructors: Aschbacher, Wales.

Ma 345 abc. Seminar in Analysis and Dynamics. Instructors: Borodin, Makarov.

Ma 348 abc. Seminar in Mathematical Physics. Instructor: Simon.

Ma 351 abc. Seminar in Geometry and Topology. Instructors: Calegari, Dunfield.

Ma 360 abc. Seminar in Number Theory. Instructors: Flach, Graber, Mantovan, Ramakrishnan.

Ma 390. Research. *Units by arrangement.*

Ma 392. Research Conference. *Three terms.*

See also the list of courses in Applied and Computational Mathematics.

MECHANICAL ENGINEERING

Additional advanced courses in the field of mechanical engineering may be found listed in other engineering options such as aeronautics, applied mechanics, applied physics, control and dynamical systems, and materials science.

ME 18 ab. Thermodynamics. *9 units (3-0-6); second, third terms.* An introduction to classical thermodynamics with engineering applications. First term includes the first and second laws; closed and open systems; properties of a pure substance; availability and irreversibility; generalized thermodynamic relations. Second term emphasizes applications: gas and vapor power cycles; propulsion; mixtures; combustion and thermochemistry; chemical equilibrium. Instructor: Hunt.

ME 19 ab. Fluid Mechanics. *9 units (3-0-6); first, second terms. Prerequisites: Ma 2, Ph 1 abc.* Properties of fluids, basic equations of fluid mechanics, theorems of energy, linear and angular momentum. Euler's equations, inviscid potential flow, surface waves, airfoil theory. Navier-Stokes equations, vorticity and vorticity transport. Flow of real fluids, similarity parameters, flow in ducts. Boundary layer theory for laminar and turbulent flow, transition to turbulence. Drag, lift, and propulsion. Instructor: Brennen.

ME 20. Heat Transfer. *9 units (3-0-6); third term. Prerequisites: ME 18 ab, ME 19 ab.* An introduction to heat transfer. Steady-state and transient conduction, including numerical solutions. Forced and natural convective-heat transfer. Heat exchangers. Radiative heat transfer and solar energy. Not offered 2006–07.

ME 35 abc. Statics and Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Introduction to statics and dynamics of rigid and deformable bodies. Equilibrium of force systems, principle of virtual work, distributed force systems, friction, static analysis of rigid and deformable structures, kinematics, particle dynamics, rigid-body dynamics, dynamics of deformable systems, and vibrating systems. Instructor: Staff.

ME 65. Mechanics of Materials. *9 units (3-0-6); first term. Prerequisites: ME 35 abc, Ma 2 ab.* Introduction to continuum mechanics, principles of elasticity, plane stress, plane strain, axisymmetric problems, stress concentrations, thin films, fracture mechanics, variational principles, frame structures, finite element methods, composites, and plasticity. Taught concurrently with Ae/AM/CE/ME 102. Instructor: Ravichandran.

ME 66. Vibration. *9 units (3-0-6); second term. Prerequisites: ME 35 abc, Ma 2 ab.* Introduction to vibration and wave propagation in continuous and discrete multi-degree-of-freedom systems. Strings, mass-spring systems, mechanical devices, elastic continua. Equations of motion, Lagrange's equations, Hamilton's principle, and time-integration schemes. Instructor: Heaton.

ME 71. Introduction to Engineering Design. *9 units (3-5-1); third term. Prerequisite: ME 35 ab recommended. Enrollment is limited and will be based on responses to a questionnaire available in the Registrar's Office during registration. Not offered on a pass/fail basis.* Introduction to mechanical engineering design, fabrication, and visual communication. Concepts are taught through a series of short design projects and design competitions emphasizing physical concepts. Many class projects will involve substantial use of the shop facilities, and construction of working prototypes. Instructor: Staff.

ME 72 ab. Engineering Design Laboratory. *9 units (3-4-2), first term; (1-8-0), second term. Prerequisites: ME 35 abc, ME 71, Me 18 ab, CS 1 or equivalent, and instructor's permission. Enrollment is limited.* A project-based course in which teams of students design, fabricate, analyze, test, and operate an electromechanical device to compete against devices designed by other student teams. The class lectures and the projects stress the integration of mechanical design, sensing, engineering analysis, and computation to solve problems in engineering system design. The laboratory units of ME 72 can be used to fulfill a portion of the laboratory requirement for the ME or EAS option. Not offered on a pass/fail basis. Instructor: Antonsson.

ME 73. Machine Component Design. *9 units (3-4-2); second term. Prerequisites: ME 35 abc, ME 72, or instructor's permission.* Basic machine components, including bearings, seals, shafts, gears, belts, chains, couplings, linkages, and cams. Analysis and synthesis of these devices, as well as their use in the design of larger engineering systems, will be examined. The laboratory section makes use of contemporary mechanical hardware to provide students with "hands-on" experience with the components discussed in class. Not offered 2006–07.

CS/EE/ME 75 abc. Introduction to Multidisciplinary Systems Engineering. *3 units (2-0-1) first term; 3–6 units second term; 12 units (2-9-1) or 18 units (2-15-1) third term.* For course description, see Computer Science.

ME 90 abc. Senior Thesis, Experimental. *9 units; (0-0-9) first term; (0-9-0) second, third terms. Prerequisite: senior status; instructor's permission.* Experimental research supervised by an engineering faculty member. The topic selection is determined by the adviser and the student and is subject to approval by the Mechanical Engineering Undergraduate Committee. First and second terms: midterm progress report and oral presentation during finals week. Third term: completion of thesis and final presentation. The second and third terms may be used to fulfill laboratory credit for EAS. Not offered on a pass/fail basis. Instructor: Hunt.

ME 91 abc. Senior Thesis, Analytical. *9 units (0-0-9); first, second, third terms. Prerequisite: senior status; instructor's permission.* Undergraduate research supervised by an engineering faculty member. The topic selection is determined by the adviser and the student and is subject to approval by the Mechanical Engineering Undergraduate Committee. First and second terms: midterm progress report and oral presentation during finals week. Third term: completion of thesis and final presentation. Not offered on a pass/fail basis. Instructor: Hunt.

ME/CE 96. Mechanical Engineering Laboratory. *6 or 9 units as arranged with instructor; third term. Prerequisites: ME 18 ab, ME 19 ab, ME 35 ab.* A laboratory course in the experimental techniques for heat transfer, fluid mechanics, solid mechanics, and dynamics. Students usually select approximately three regular experiments, but they may propose special investigations of brief research projects on their own. Instructor: Goodwin.

ME 100. Advanced Work in Mechanical Engineering. The faculty in mechanical engineering will arrange special courses on problems to meet the needs of qualified undergraduate students. Graded pass/fail for research and reading. A written report is required for each term.

Ae/APh/CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/CE/ME 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6).* For course description, see Aeronautics.

E/ME 103. Management of Technology. *9 units (3-0-6).* For course description, see Engineering.

E/ME 105. Product Design for the Developing World. *9 units (3-0-6).* For course description, see Engineering.

ME 110. Special Laboratory Work in Mechanical Engineering. *3–9 units per term; maximum two terms.* Special laboratory work or experimental research projects may be arranged by members of the faculty to meet the needs of individual students as appropriate. A written report is required for each term of work. Instructor: Staff.

ME 115 ab. Introduction to Kinematics and Robotics. *9 units (3-0-6); second, third terms. Prerequisites: Ma 2, ACM 95/100 ab recommended.* Introduction to the study of planar, rotational, and spatial motions with applications to robotics, computers, computer graphics, and mechanics. Topics in kinematic analysis will include screw theory, rotational representations, matrix groups, and Lie algebras. Applications include robot kinematics, mobility in mechanisms, and kinematics of open and closed chain mechanisms. Additional topics in robotics include path planning for robot manipulators, dynamics and control, and assembly. Course work will include laboratory demonstrations using simple robot manipulators. Not offered 2006–07.

ME 118. Thermodynamics. *9 units (3-0-6); first term. Prerequisites: ME 18 ab, ME 19 ab.* Fundamentals of classical and statistical thermodynamics. Basic postulates, thermodynamic potentials, chemical and phase equilibrium, phase transitions, and thermodynamic properties of solids, liquids, and gases. Instructor: Goodwin.

ME 119 ab. Heat and Mass Transfer. *9 units (3-0-6); second, third terms. Prerequisites: ME 18 ab, ME 19 ab, ACM 95/100 (may be taken concurrently).* Transport properties, conservation equations, conduction heat transfer, convective heat and mass transport in laminar and turbulent flows, phase change processes, thermal radiation. Not offered 2006–07.

Ae/ME 120 ab. Combustion Fundamentals. *9 units (3-0-6).* For course description, see Aeronautics.

ME 131. Advanced Robotics: Manipulation and Sensing. *9 units (3-6-0); third term. Prerequisite: ME 115 ab.* The course focuses on current topics in robotics research in the area of robotic manipulation and sensing. Past topics have included advanced manipulator kinematics, grasping and dextrous manipulation using multifingered hands, and advanced obstacle avoidance and motion planning algorithms. The lectures will be divided between a review of the appropriate analytical techniques and a survey of the current research literature. Course work will focus on an independent research project chosen by the student. Not offered 2006–07.

ME/CS 132. Advanced Robotics: Navigation and Vision. *9 units (3-6-0); second term. Prerequisite: ME 115 ab.* The course focuses on current topics in robotics research in the area of autonomous navigation and vision. Topics will include mobile robots, multilegged walking machines, use of vision in navigation systems. The lectures will be divided between a review of the appropriate analytical techniques and a survey of the current research literature. Course work will focus on an independent research project chosen by the student. Instructor: Burdick.

Ae/Ge/ME 160 ab. Continuum Mechanics of Fluids and Solids. *9 units (3-0-6).* For course description, see Aeronautics.

AM/ME 165 ab. Elasticity. *9 units (3-0-6).* For course description, see Applied Mechanics.

ME 170. Introduction to Mechanical CAD. *4 units (1-0-3); third term.* An introduction to the use of one or more mechanical computer-aided design (CAD) packages via a series of weekly instructional exercises. Instructor: Staff.

ME 171. Computer-Aided Engineering Design. *9 units (3-0-6); second term. Prerequisites: ACM 95/100 abc, ME 35 abc, ME 72, CS 1, or equivalent, working knowledge of the C computer programming language.* Methods and algorithms for design of engineering systems using computer techniques. Topics include the design process; interactive computer graphics; curves and surfaces (including cubic and B-splines); solid modeling (including constructive solid geometry and boundary models); kinematic and dynamic mechanism simulation; single and multivariable optimization; optimal design, and symbolic manipulation. Assessment of CAD as an aid to the design process. Not offered 2006–07.

ME 175. Fuzzy Sets in Engineering. *9 units (3-0-6); second term. Prerequisites: ACM 95/100 abc, working knowledge of the C computer programming language.* The relatively new mathematics of fuzzy sets has recently been used to represent and manipulate vague and imprecise information in engineering. This course will present the basics of fuzzy sets and fuzzy mathematics and explore applications in the areas of data representation; function representation; filters and triggers; engineering design and optimization, including (fuzzy) set-based concurrent engineering. Not offered 2006–07.

ME 200. Advanced Work in Mechanical Engineering. The faculty in mechanical engineering will arrange special courses on problems to meet the needs of graduate students. Graded pass/fail; a written report is required for each term of work.

ME 202 abc. Engineering Two-Phase Flows. *9 units (3-0-6). Prerequisites: ACM 95/100 abc, Ae/APh/CE/ME 101 abc, or equivalents.* Selected topics in engineering two-phase flows with emphasis on practical problems in modern hydro-systems. Fundamental fluid mechanics and heat, mass, and energy transport in multiphase flows. Liquid/vapor/gas (LVG) flows, nucleation, bubble dynamics, cavitating and boiling flows, models of LVG flows; instabilities, dynamics, and wave propagation; fluid/structure interactions. Discussion of two-phase flow problems in conventional, nuclear, and geothermal power plants, marine hydrofoils, and other hydraulic systems. Not offered 2006–07.

Ae/AM/MS/ME 213. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/CE/ME 214 abc. Computational Solid Mechanics. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/ME 215. Dynamic Behavior of Materials. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/ME 223. Plasticity. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM/ME 225. Special Topics in Solid Mechanics. *Units to be arranged.* For course description, see Aeronautics.

ME/MS 260 abc. Micromechanics. *12 units (3-0-9). Prerequisites: ACM 95/100 or equivalent, and Ae/AM/CE/ME 102 abc or Ae 160 abc or instructor's permission.* The course gives a broad overview of micromechanics, emphasizing the microstructure of materials, its connection to molecular structure, and its consequences on macroscopic properties. Topics include phase transformations in crystalline solids, including martensitic, ferroelectric, and diffusional phase transformations, twinning and domain patterns, active materials; effective properties of composites and polycrystals, linear and nonlinear homogenization; defects, including dislocations, surface steps, and domain walls; thin films, asymptotic methods, morphological instabilities, self-organization; selected applications to microactuation, thin-film processing, composite materials, mechanical properties, and materials design. Open to undergraduates with instructor's permission. Instructor: Bhattacharya.

Ae/Ge/ME 266 ab. Dynamic Fracture and Frictional Faulting. *9 units (3-0-6).* For course description, see Aeronautics.

ME 300. Research in Mechanical Engineering. *Hours and units by arrangement.* Research in the field of mechanical engineering. By arrangement with members of the faculty, properly qualified graduate students are directed in research.

MUSIC

Mu 10. Selected Topics in Music; *offered by announcement. Units to be determined by arrangement with instructor.* Instructors: Staff, visiting lecturers.

Mu 21. Understanding Music. *9 units (3-0-6); first term.* The Listening Experience I. How to listen to and what to listen for in classical and other musical expressions. Listening, analysis, and discussion of musical forms, genres, and styles. Course is intended for musicians as well as nonmusicians and is strongly recommended as an introduction to other music courses. Instructor: Neenan.

Mu 22. Life and Music of Mozart. *9 units (3-0-6); second term.* This course will explore Mozart's music within the context of his life and times, including the early works composed as a child prodigy and touring artist; the first masterpieces he composed, and finally the masterworks written during his meteoric rise and his equally amazing fall from grace. Not offered 2006–07.

Mu 23. Life and Music of Beethoven. *9 units (3-0-6); third term.* The course will examine the exuberant works of Beethoven's youth, the series of grand, heroic masterpieces of the early 1800s, and the puzzling and mysterious works of his final decade. Not offered 2006–07.

Mu 24. Introduction to Opera. *9 units (3-0-6); second term.* Opera exploded onto the cultural scene around the year 1600 and quickly became the most popular, expensive, and lavish spectacle in all of Europe. The course will trace the history of the genre examining masterpieces by Monteverdi, Handel, Mozart, Rossini, Verdi, Wagner, Strauss, Berg, and Britten, and will sample a host of newer works, including *Einstein on the Beach*, *The Death of Klinghoffer*, and *The Ghosts of Versailles.* Not offered 2006–07.

Mu 25. History of Chamber Music. *9 units (3-0-6); third term.*To be coordinated with Caltech's spring chamber music performances; enrollment limited to students preparing performances of chamber music during the term. The course will survey the history of chamber music and will offer more in-depth exploration of works in preparation for performance. Instructor: Neenan.

Mu 26. Jazz History. *9 units (3-0-6); third term.* This course will examine the history of jazz in America from its roots in the unique confluence of racial and ethnic groups in New Orleans around 1900 to the present. The lives and music of major figures such as Robert Johnson, Jelly Roll Morton, Louis Armstrong, Benny Goodman, Duke Ellington, Count Basie, Charlie Parker, Dizzy Gillespie, Thelonius Monk, Miles Davis and others will be explored. Instructor: Neenan.

Mu 27. Fundamentals of Music Theory and Elementary Ear Training. *9 units (3-0-6); first term.* Basic vocabulary and concepts of music theory (rhythm and pitch notation, intervals, scales, function of key signatures, etc.); development of aural perception via elementary rhythmic and melodic dictation, and sight-singing exercises. Instructor: Neenan.

Mu 28. Harmony I. *9 units (3-0-6). Prerequisite: Mu 27 or entrance exam.* Study of tonal harmony and intermediate music theory; techniques of chord progression, modulation, and melody writing according to common practice; ear training, continued. Instructor: Neenan.

Mu 29. Harmony II. *9 units (3-0-6). Prerequisite: Mu 28 or entrance exam.* More advanced concepts of music theory, including chromatic harmony, and 20th-century procedures relating to selected popular music styles; ear training, continued. Instructor: Neenan.

Mu 31. Music of Courts and Cathedrals. *9 units (3-0-6).* Explores the music of the Middle Ages and Renaissance, including that of the great medieval monasteries, cathedrals, and chapels. The course will include study of the music and dances from courts, towns, and countryside by trouvères, troubadours, and other entertainers. Not offered 2006–07.

Mu 32. Monteverdi to Bach: Music of the Baroque. *9 units (3-0-6); second term.* Survey of musical forms and composers during the period 1600–1750. The course will include masterworks of Monteverdi, Purcell, Vivaldi, Handel, Bach, and others. Not offered 2006–07.

Mu 33. Music of the Age of Enlightenment. *9 units (3-0-6); third term.* Music of the so-called pre-Classic and Classic periods (ca. 1750–1825), with emphasis on C. P. E. Bach, Gluck, Haydn, Mozart, and the early works of Beethoven. Not offered 2006–07.

Mu 37. History I: Music History to 1750. *9 units (3-0-6); first term.* The course traces the history of music from ancient Greece to the time of Bach and Handel. A survey of the contributions by composers such as Machaut, Josquin, and Palestrina will lead to a more in-depth look at the music of Monteverdi, Purcell, Corelli, Vivaldi, and the two most important composers of the high baroque, Bach and Handel. Given in alternate years; not offered 2006–07. Instructor: Neenan.

Mu 38. History II: Music History from 1750 to 1850. *9 units (3-0-6); second term.* Music composed between 1750 and 1850 is among the most popular concert music of today and the most recorded music in the classical tradition. This course will focus on developments in European music during this critical period. An in-depth look at the music of Haydn, Mozart, and Beethoven along with the cultural and societal influences that shaped their lives will be the primary focus. Music of composers immediately preceding and following them (the Bach sons, Schubert, Chopin, and others) will also be surveyed. Given in alternate years; not offered 2006–07. Instructor: Neenan.

Mu 39. History III: Music History from 1850 to the Present. *9 units (3-0-6); third term.* From the end of the 19th century to the present day, classical music has undergone the fastest and most radical changes in its history. The course explores these changes, tracing the development of various musical styles, compositional methods, and music technologies while examining acknowledged masterpieces from throughout the period. Given in alternate years; not offered 2006–07. Instructor: Neenan.

PERFORMANCE AND ACTIVITIES

Courses under this heading cover the instructional content of a range of extracurricular activities and work in the fine arts and elsewhere. These courses will appear on the student's transcript, and will be graded pass/fail only. The units count toward the total unit requirement for graduation, but they do not count toward the 108-unit requirement in humanities and social sciences.

PA 15 abc. Student Publications. *3 units (1-0-2); first, second, third terms.* The elementary principles of newspaper writing and editing, with special attention to student publications at the Institute. Instructor: Staff.

PA 16. Cooking Basics. *3 units (0-3-0).* The class will survey different cooking styles, techniques, and cuisines from around the world. Topics covered may include knives and tools; tastes and flavors; sauces and reductions; legumes, grains, and beans; meat; dessert. The emphasis will be on presentation and creativity. Instructor: Mannion.

PA 20 abc. Debate. *3 units (1-0-2); first, second, third terms.* Study and discussion of the annual intercollegiate debate topic. Instructor: Staff.

PA 30 abc. Women's Glee Club. *3 units (0-3-0); first, second, third terms.* Performance of women's choral repertoire in all style periods, from the Renaissance to the present. Includes performances with orchestra and with the Men's Glee Club (singing mixed-voice repertoire). Includes opportunities for individual instruction. No previous experience required. Three hours a week. Instructor: LaVertu.

PA 31 abc. Chamber Music. *3 units (0-3-0); first, second, third terms.* Study and performance of music for mixed ensembles of three to seven members and for piano four-hands. Literature ranges from the baroque to contemporary eras. Open to students who play string, woodwind, brass instruments, or piano. After auditioning, pianists will be placed in either section by the instructors.

Section 1: Mixed ensembles. Instructor: D. Bing.
Section 2: Piano four-hands. Instructor: Gross.

PA 32 abc. Symphony Orchestra. *3 units (0-3-0); first, second, third terms.* Study and performance of music written for full symphony orchestra and chamber orchestra. The orchestra performs both the standard symphonic repertoire and contemporary music. Two and a half hours of rehearsal per week. Instructor: Gross.

PA 33 abc. Concert Band. *3 units (0-3-0); first, second, third terms.* Study and performance of music written for the classical wind ensemble. Emphasis is placed on the traditional literature, but the study of contemporary music is an important part of the curriculum. Instructor: W. Bing.

PA 34 abc. Jazz Band. *3 units (0-3-0); first, second, third terms.* Study and performance of all styles of jazz, from Duke Ellington to Pat Metheny. Jazz improvisation is also stressed. Instructor: W. Bing.

PA 35 abc. Guitar. *3 units (0-3-0); first, second, third terms.* Offered on three levels: beginning (no previous experience required), intermediate, and advanced. Instruction emphasizes a strong classical technique, including an exploration of various styles of guitar—classical, flamenco, folk, and popular. Instructor: Denning.

PA 36 abc. Men's Glee Club. *3 units (0-3-0); first, second, third terms.* Performance of repertoire from the Renaissance to the present day for men's voices in all styles. Opportunity for performance with orchestra and for mixed voices. No prerequisite or previous experience necessary. Three hours of rehearsal a week. Individual instruction. Instructor: Caldwell.

PA 37 abc. Chamber Singers. *3 units (0-3-0); first, second, third terms.* A sixteen-voice SATB-auditioned ensemble, the Chamber Singers provide costumed entertainments for the Athenaeum and community in December, participate with orchestra in the annual All-Mozart Concert in April, and present a musical theater review in June. One and a half hours of rehearsal per week. Instructor: Caldwell.

PA 40 abc. Theater Arts. *3 units (2-0-1); first, second, third terms.* Instruction in all phases of theatrical production, culminating in multiple performances for the public. A hands-on, practical approach includes workshops in stage combat, costume construction, scenic arts, occasional informal encounters with professional actors, designers, and directors, as well as a few relevant field trips offered as possible. Understanding of dramatic structure, respect for production values, and problem solving are stressed. Material of academic value is drawn from 3,000 years of worldwide dramatic literature. Instructor: Marneus.

PA 61 abc. Silkscreen and Airbrush. *3 units (0-3-0); first, second, third terms.* Instruction in silkscreen and airbrush techniques, using a variety of media including T-shirts. Instructor: Barry.

PA 62 abc. Drawing and Painting. *3 units (0-3-0); first, second, third terms.* Instruction in techniques of drawing and painting, utilizing models, architecture, and still lifes as subjects. Instructor: Barry.

PA 63 abc. Ceramics. *3 units (0-3-0); first, second, third terms.* Instruction in the techniques of creating ceramics, including the slab roller and potter's wheel, and glazing methods. Instructor: Freed.

PHILOSOPHY

Hum/Pl 8. Right and Wrong. *9 units (3-0-6).* For course description, see Humanities.

Hum/Pl 9. Knowledge and Reality. *9 units (3-0-6).* For course description, see Humanities.

Pl 90 ab. Senior Thesis. *9 units (1-0-8).* Required of students taking the philosophy option. To be taken in any two consecutive terms of the senior year. Students will research and write a thesis of 10,000–12,000 words on a philosophical topic to be determined in consultation with their thesis adviser. Instructor: Staff.

Pl 98. Reading in Philosophy. *9 units (1-0-8). Prerequisite: Instructor's permission.* An individual program of directed reading in philosophy, in areas not covered by regular courses. Instructor: Staff.

Pl 102. Selected Topics in Philosophy. *9 units (3-0-6); offered by announcement*. Prerequisite: Hum/Pl 8 or Hum/Pl 9 or instructor's permission.

HPS/Pl 120. Introduction to Philosophy of Science. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 121. Causation and Explanation. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 122. Confirmation and Induction. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 124. Philosophy of Space and Time. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 125. Philosophical Issues in Quantum Physics. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 126. Foundations of Probability and Inductive Inference. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 129. Introduction to Philosophy of Biology. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 130. Philosophy and Biology. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 132. Introduction to Philosophy of Mind and Psychology. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 133. Philosophy and Neuroscience. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 134. Current Issues in Philosophical Psychology. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/Pl 136. Ethics in Research. *4 units (2-0-2) or 9 units (2-0-7).* For course description, see History and Philosophy of Science.

Pl 150. History of Early Modern Philosophy. *9 units (3-0-6); first term. Prerequisite: Hum/Pl 8 or Hum/Pl 9 or instructor's permission.* A study of important figures and ideas in the empiricist and rationalist traditions in the period from Descartes through Kant. Material covered will vary depending on the decision of the instructor, but will include readings from some of the following: Descartes, Spinoza, Leibniz, Kant, Hobbes, Locke, Berkeley, and Hume. Not offered 2006–07.

HPS/Pl 169. Selected Topics in Philosophy of Science. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H/Pl 173. History of Chemistry. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H/Pl 174. Celestial and Terrestrial Mechanisms: Landmarks in the Development of Greek Astronomy. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H/Pl 179. The Politics of Nature in Early Modern Europe. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

HPS/H/Pl 180. The Philosophy of Scientific Argument and Evidence, 1550–1750. *9 units (3-0-6).* For course description, see History and Philosophy of Science.

Pl/HPS 184. Science, Ethics, and Public Policy. *9 units (3-0-6); offered by announcement.* This course discusses some moral and social issues concerning research in the sciences (chiefly, biomedicine, with special attention to stem-cell research.) We will begin by discussing attempts to find a framework within which the issues can be addressed, and then we will discuss some specific topics. In most cases we will not so much seek answers to moral questions as attempt to identify helpful questions, clarify the issues involved, and analyze the moral status of the protagonists. We will also pay special attention to issues of public policy, and ask how scientific research should be organized and funded in a democracy. Instructor: Murphy.

Pl 185. Moral Philosophy. *9 units (3-0-6); third term.* A survey of topics in moral philosophy. The emphasis will be on metaethical issues, although some normative questions may be addressed. Metaethical topics that may be covered include the fact/value distinction; the nature of right and wrong (consequentialism, deontological theories, rights-based ethical theories, virtue ethics); the status of moral judgments (cognitivism vs. noncognitivism, realism vs. irrealism); morality and psychology; moral relativism; moral skepticism; morality and self-interest; the nature of justice. The implications of these theories for various practical moral problems may also be considered. Not offered 2006–07.

Pl 186. Political Philosophy. *9 units (3-0-6); offered by announcement.* This course will address one or more issues in contemporary political theory and/or the history of political thought. Topics may include the nature of democracy; liberalism; distributive justice; human rights; the moral and legal regulation of warfare; the status of positive law; social choice theory; the relations between the market and the state. The work of figures such as Plato, Aristotle, Locke, Hobbes, Mill, Machiavelli, and Rawls will be discussed. Instructors: Murphy, Woodward.

Pl 187. Natural Justice. *9 units (3-0-6); first term.* This course examines the unorthodox view that morality is a natural phenomenon—the product of a combination of biological and cultural evolution. It reviews and criticizes the traditional arguments used to deny both moral naturalism and moral relativism, notably the Naturalistic Fallacy. It assesses the success of the approach advocated by evolutionary biologists and psychologists. It examines the evidence from laboratory experiments on fairness and justice. Finally, it attempts to synthesize all these strands using the theory of games as a unifying framework. Not offered 2006–07.

PHYSICAL EDUCATION

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PE 1 abc. Student Designed Fitness. *3 units.* Independent fitness program as arranged with instructor, three times a week. Detailed proposals must be submitted in writing during first week of each term. Instructor: Staff.

PE 2 abc. Skin Diving. *3 units.* Fundamentals of skin diving and oceanography. Instructor: Dodd.

PE 4 abc. Introduction to Power Walking. *3 units.* Introduction to walking for fitness. Emphasis on cardiovascular benefits for a healthy lifestyle. The program is progressive and suitable for walkers of all levels. Instructor: Staff.

PE 6 abc. Core Training, Beginning/Intermediate. *3 units.* Learn to develop functional fitness using core stability training techniques that focus on working the deep muscles of the entire torso at once. The course is taught using exercises that develop core strength, including exercises on a stability ball, medicine ball, wobble boards as well as with Pilates exercise programs. Instructor: Staff.

PE 7 abc. Speed and Agility Training, Intermediate/Advanced. *3 units.* Instruction to increase foot speed and agility with targeted exercises designed to help the student increase these areas for use in competitive situations. Instruction will focus on increasing foot speed, leg turnover, sprint endurance, and competitive balance. Proper technique and specific exercises as well as the development of an individual or sport-specific training workout will be taught. Instructor: Staff.

PE 8 abc. Fitness Training, Beginning. *3 units.* An introductory class for students who are new to physical fitness. Students will be introduced to different areas of fitness such as weight training, core training, walking, aerobics, yoga, swimming, and cycling. Students will then be able to design an exercise program for lifelong fitness. Instructor: Staff.

PE 9 abc. Soccer. *3 units.* Fundamental instruction on shooting, passing, trapping, dribbling, penalty kicks, offensive plays, defensive strategies, and goal keeping. Class includes competitive play using small field and full field scrimmages. Instructor: Uribe.

PE 10 abc. Aerobic Dance. *3 units.* Each class includes a thorough warm-up, a cardiovascular workout phase that also includes a variety of conditioning exercises designed to tone and strengthen various muscle groups, and a relaxation cool-down and stretch, all done to music. Instructor: Staff.

PE 12 abc. Baseball Skills, Intermediate/Advanced. *3 units.* Baseball skills—including infield/outfield, pitcher/catcher, and batting drills—taught, leading to competitive play. Students must have experience in hard ball. Instructor reserves the right to exclude students who do not fit criteria. Instructor: D'Auria.

PE 14 abc. Basketball Skills, Beginning and Beginning/Intermediate. *3 units.* Features fundamental instruction on shooting, dribbling, passing, defensive positioning, and running an offense. Class includes competitive play and free-throw shooting. Instructors: Dow, Marbut.

PE 20 abc. Fencing, Beginning and Intermediate/Advanced. *3 units.* Beginning fencing includes basic techniques of attack, defense, and counter-offense. Lecture topics include fencing history, strategy, scouting and analysis of opponents, and gamesmanship. Intermediate/Advanced covers foil theory and techniques, group drillwork, and video analysis. Instructor: Staff.

PE 23 abc. Track and Field, Beginning. *3 units.* Features instruction on 10 different track events, allowing the student an opportunity to attempt a variety of skills: shot put, discus, javelin, sprints, hurdles, long jump, high jump, middle- and long-distance running, and the relays. Class emphasis placed on learning new skills safely with time devoted to warm-up and stretching, as well as weight training for specific events. Instructor: Levesque.

PE 24 abc. Yoga, Beginning. *3 units.* Hatha Yoga is a system of physical postures designed to stretch and strengthen the body, calm the nervous system, and center the mind. It is a noncompetitive activity designed to reduce stress for improved health of body and mind while increasing flexibility, strength, and stamina, and reducing the chance of athletic injury. Instructor: Staff.

PE 27 abc. Ultimate Frisbee. *3 units.* Instruction will center on developing students' knowledge of techniques, rules, strategy, etiquette, and safety regulations of the game. Students will develop the ability to perform all the skills necessary to play the game confidently on a recreational basis. Instructor: Staff.

PE 30 abc. Golf, Beginning, Intermediate, and Advanced. *3 units.* Beginning class covers fundamentals of the game, including rules, terminology, etiquette, basic grip, set-up, swing, and club selection for each shot. The following shots will be covered: full swing (irons and woods), chip, pitch, sand, and putting. Intermediate class will focus on swing development of specialty shots and on course play management. Advanced instruction covers course management and mental aspects of performance. Instructor: Staff.

PE 35 abc. Diving, Beginning/Intermediate. *3 units.* Teaches the fundamentals of springboard diving to include basic approach, and five standard dives. Intermediate class includes instruction in the back somersault, forward somersault, forward somersault full twist, and reverse somersault. Instructor: Dodd.

PE 36 abc. Swimming, Beginning/Intermediate and Advanced. *3 units.* Instruction in all basic swimming strokes, including freestyle, elementary backstroke, racing backstroke, breaststroke, sidestroke, and butterfly. Advanced class focuses on proper technique of the four competitive strokes using video and drills along with instruction on training methods and proper workout patterns. Instructor: Dodd.

PE 38 abc. Water Polo. *3 units.* Basic recreational water polo with instruction of individual skills and team strategies. A background in swimming is encouraged. Instructor: Dodd.

PE 44 abc. Karate (Shotokan), Beginning and Intermediate/Advanced. *3 units.* Fundamental self-defense techniques including form practice and realistic sparring. Emphasis on improving muscle tone, stamina, balance, and coordination, with the additional requirement of memorizing one or more simple kata (forms). Instructor: Staff.

PE 46 abc. Karate (Tang Soo Do), Beginning and Intermediate/Advanced. *3 units.* Korean martial art focusing on self-defense and enhancement of physical and mental health. Practical and traditional techniques such as kicks, blocks, hyungs (forms) are taught. Intermediate/Advanced level incorporates technique combinations, sparring skills, jumping and spinning kicks, and history and philosophy. Instructor: Staff.

PE 48 abc. T'ai-Chi Ch'uan, Beginning and Intermediate/Advanced. *3 units.* Chinese movement art emphasizing relaxation and calm awareness through slow, flowing, meditative movement using only the minimum of strength needed to accomplish the action. Instructor: Staff.

PE 50 abc. Badminton, Beginning/Intermediate. *3 units.* Basic skills will be taught, including grips, services, overhead and underhand strokes, and footwork. Rules, terminology, and etiquette are covered. Intermediate skills such as drives, service returns, forehand and backhand smash returns, attacking clears, and sliced drop shots are taught. Singles and doubles play along with drill work throughout the term. Instructor: Staff.

PE 54 abc. Racquetball, Beginning and Intermediate/Advanced. *3 units.* Fundamentals of the game will be emphasized, including rules, scoring, strategy, and winning shots. All types of serves will be covered, as well as a variety of shots to include kill, pinch-off, passing, ceiling, and off-the-backwall. Singles and doubles games will be played. Intermediate/Advanced course will review all fundamentals with a refinement of winning shots and serves and daily games. Instructor: Staff.

PE 56 abc. Squash, Beginning, Intermediate, Advanced. *3 units.* Learn by playing as the basic rules and strokes are taught. Fundamentals to include proper grip, stroke, stance, and positioning, along with serve and return of serve. Intermediate and Advanced classes will concentrate on skill development with the inclusion of forehand and backhand drives, lobs, volleys, and drops, with an emphasis on court movement, shot selection, and tactics. Instructor: Staff.

PE 60 abc. Tennis, Beginning, Intermediate, and Advanced. *3 units.* Stroke fundamentals, singles and doubles play, plus rules, terminology, and etiquette are covered in all classes. Beginning class emphasizes groundstrokes, volleys, serve, and grips. Beginning/Intermediate class is for those players caught between levels and will concentrate on strategy, drills, and match play. Intermediate level focuses on improving technique, footwork, and court positioning, with instruction on approach shots, volleys, overheads, and lobs. Advanced course fine tunes each individual's skills while targeting weaknesses. Instructors: D'Auria, Gamble, Uribe.

PE 70 abc. Weight Training, Beginning/Intermediate. *3 units.* Active participation in a strength and conditioning program designed for individual skill level and desired effect. Course will enlighten students on various methods, terminology, and techniques in the areas of isokinetic strength and cardiovascular fitness training. Instructor: Staff.

PE 77 abc. Volleyball, Beginning, Intermediate, and Advanced. *3 units.* Fundamental instruction on drills, strategies, and rules, with game-playing opportunity. Basics of serve, pass, set, spike, defense, and court position will be taught. Intermediate level focuses on skill development to a more competitive standard and features multiple offenses and understanding officiating. Advanced class emphasizes specialization of all skills, court position, and multiple offenses and defenses. Instructor: Staff.

PE 80 abc. Health Advocates. *3 units (1-1-1); first, second, third terms.* A course designed to involve students with health care and education, develop familiarity with common college health problems, and provide peer health services on and off campus. First term: CPR and first aid certification and basic anatomy and physiology. Second and third terms: lectures and discussions on current student and community health problems, symptoms, and treatment. Each student will be expected to devote one hour per week to a supervised clinical internship at the Health Center. *Does not satisfy the Institute physical education requirement.* Instructor: Staff.

PE 82 abc. Rock Climbing, Beginning and Intermediate. *3 units.* Basic skills will be covered to utilize each student's strength and endurance while learning to climb safely. Use of climbing rope and other equipment for belaying, rappelling, and emergency ascent will be taught. Skills will be demonstrated and practiced on a climbing wall and then later at an off-campus climbing site. Intermediate level will include ascents on prussiks or jumars, with more off-campus climbing. Instructor: Staff.

PE 84 abc. Table Tennis, Beginning, Intermediate, and Advanced. *3 units.* Introductory course to provide general knowledge of equipment, rules, and basic strokes, including topspin drive, backspin chop, and simple block in both forehand and backhand. Multiball exercise utilizing robot machines and video. Intermediate class covers regulations for international competition and fundamentals of winning table tennis, including footwork drills, smash, serve, and attack. Instructor: Staff.

Intercollegiate Teams

PE 83 abc. Intercollegiate Basketball Team (Women). *3 units.* Coach: Marbut.

PE 85 abc. Intercollegiate Track and Field Team (Men and Women). *3 units.* Coach: Levesque.

PE 87 abc. Intercollegiate Swimming Team (Men and Women). *3 units.* Coach: Dodd.

PE 89 abc. Intercollegiate Fencing Team (Men and Women). *3 units.* Coach: Staff.

PE 90 abc. Intercollegiate Water Polo Team (Men and Women). *3 units.* Coach: Dodd.

PE 91 abc. Intercollegiate Basketball Team (Men). *3 units.* Coach: Dow.

PE 92 abc. Intercollegiate Soccer Team (Men). *3 units.* Coach: Uribe.

PE 93 abc. Intercollegiate Baseball Team (Men). *3 units.* Coach: D'Auria.

PE 95 abc. Intercollegiate Tennis Team (Men). *3 units.* Coach: Gamble.

PE 96 abc. Intercollegiate Tennis Team (Women). *3 units.* Coach: Gamble.

PE 97 abc. Intercollegiate Cross-Country Team (Men and Women). *3 units.* Coach: Jung.

PE 99 abc. Intercollegiate Volleyball Team (Women). *3 units.* Coach: Burl.

PHYSICS

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Ph 1 abc. Classical Mechanics and Electromagnetism. *9 units (4-0-5); first, second, third terms.* The first year of a two-year course in introductory classical and modern physics. Topics: Newtonian mechanics in Ph 1 a; electricity and magnetism, and special relativity, in Ph 1 b, c. Emphasis on physical insight and problem solving. Ph 1 b, c is divided into two tracks: the Practical Track emphasizing practical electricity with take-home lab kits, and the Analytic Track, which has no lab component but teaches and uses methods of multivariable calculus.

Students will be given information helping them to choose a track at the end of fall term. Lecturers: Goodstein, McKeown, Soifer, Politzer.

Ph 2 ab. Statistical Physics, Waves, and Quantum Mechanics. *9 units (4-0-5); first, second terms. Prerequisites: Ph 1 abc, Ma 1 abc, or equivalents.* The second year of a five-term introductory course in classical and modern physics. Topics to be covered include statistical physics and classical waves first term, introductory quantum mechanics second term. *Students may transfer from Ph 12 b to Ph 2 b any time during the term, before the last day for dropping courses. The final grade will be based on the combined record in the two courses.* Lecturers: Lange, Harrison.

Ph 3. Physics Laboratory. *6 units; first, second, third terms. Prerequisite: Ph 1 a or instructor's permission.* An introduction to experimental technique, commonly used in the physical sciences. A variety of topics is presented, including the Maxwell top, electrical and mechanical resonant systems, and radioactivity. Special emphasis is given to data analysis techniques based on modern statistical methods. The course consists of one three-hour laboratory session a week, conferences with the instructor, prelaboratory preparation, and analysis of experimental results. Graded pass/fail; seniors receive letter grades. Only one term may be taken for credit. Instructors: Sannibale, Zmuidzinas.

Ph 5. Physics Laboratory. *9 units; first term. Prerequisites: Ph 1 abc, Ph 3, or equivalents.* A laboratory course dealing with "operational" electronics with emphasis on analog electronics. The following topics are studied: RC circuits, electrical oscillations, operational amplifiers, diodes, and transistors. Combining diodes, transistors, and operational amplifiers; computer data acquisitions. The course culminates in a two-week project of the student's choosing. Instructors: Rice, Sannibale, Zmuidzinas.

Ph 6. Physics Laboratory. *9 units; second term. Prerequisites: Ph 1 abc, Ph 2 b or Ph 12 b (or taken concurrently), and Ph 3 or equivalent.* Experiments in electromagnetic phenomena such as electromagnetic induction, properties of magnetic materials, and high-frequency circuits. Mobility of ions in gases; precise measurement of the value of e/m of the electron. Instructors: Rice, Sannibale, Zmuidzinas.

Ph 7. Physics Laboratory. *9 units; third term. Prerequisite: Ph 6 or equivalent.* Experiments in atomic and nuclear physics, including studies of the Balmer series of hydrogen and deuterium, the decay of radioactive nuclei, absorption of X rays and gamma rays, ratios of abundances of isotopes, and the Stern-Gerlach experiment. Instructors: Rice, Sannibale, Zmuidzinas.

Ph 10. Frontiers in Physics. *3 units (2-0-1); first term. Open for credit to freshmen and sophomores.* Weekly seminar by a member of the physics department or a visitor, to discuss his or her research at an introductory level; the other class meetings will be used to explore background material related to seminar topics and to answer questions that arise. The course will also help students find faculty sponsors for individual research projects. Graded pass/fail. Instructor: Soifer.

Ph 11 abc. Research Tutorial. *6 units (2-0-4); second and third terms of freshman year and first term of sophomore year.* A small number of students will be offered the opportunity to enroll in this tutorial, the purpose of which is to demonstrate how research ideas arise, and are evaluated and tested, and how those ideas that survive are developed. This is accomplished by doing individual, original projects. There will be weekly group meetings and individual tutorial meetings with the instructor. Support for summer research at Caltech between the freshman and sophomore years will be automatic for those students making satisfactory progress. Graded pass/fail. Instructor: Tombrello.

Ph 12 abc. Waves, Quantum Physics, and Statistical Mechanics. *9 units (4-0-5); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or equivalents.* A one-year course primarily for students intending further work in the physics option. Topics include classical waves; wave mechanics, interpretation of the quantum wave-function, one-dimensional bound states, scattering, and tunneling; thermodynamics, introductory kinetic theory, and quantum statistics. May be taken to fulfill the Institute Ph 2 requirement. *Students may transfer from Ph 12 b to Ph 2 b any time during the term, before the last day for dropping courses. The final grade will be based on the combined record in the two courses.* Instructors: Kimble, Filippone, Preskill.

Ph 20, 21, 22. Freshman/Sophomore Computational Physics Laboratory. A series of courses on the application of computational techniques to simulate or solve simple physical systems, with the intent of aiding both physics understanding and programming ability. Instructors: Mach, Prince.

20. *6 units (0-6-0); first, second, third terms. Prerequisite: CS 1 or equivalent experience in programming.* Introduction to scientific computing with applications to physics. Use of simple numerical algorithms and symbolic manipulation packages for solution of physical problems. Numerical integration and numerical solution of differential equations of motion. Simulation of orbital mechanics.

21. *6 units (0-6-0); second, third terms. Prerequisite: Ph 20 or equivalent experience with programming and simple numerical techniques.* Introduction to numerical algorithms for scientific computing. Root-finding, Runge-Kutta methods, Monte Carlo techniques, numerical solution of partial differential equations, minimization techniques such as neural networks. Applications to problems in classical mechanics and discrete-element electromagnetism.

22. *6 units (0-6-0); third term. Prerequisite: Ph 20 or equivalent experience with programming and simple numerical techniques.* Introduction to scientific computing on parallel computers. Introduction to parallel computing and multiprocessing. Message passing on networked workstations. Algorithm decomposition and parallelization. Numerical solution of N-body systems on multiprocessor computers. Additional information concerning this course can be found at http://www.pma.caltech.edu/~physlab.

Ph 70. Oral and Written Communication. *6 units (2-0-4); first, third terms.* Provides practice and guidance in oral and written communication of material related to contemporary physics research. Students will choose a topic of interest, make presentations of this material in a variety of formats, and, through a guided process, draft and revise a technical or review article on the topic. The course is intended for senior physics majors. *Fulfills the Institute scientific writing requirement.* Instructor: Hitlin.

Ph 77 abc. Advanced Physics Laboratory. *9 units (0-5-4); first, second, third terms. Prerequisite: Ph 7 or instructor's permission.* A three-term laboratory course to familiarize students with equipment and procedures used in the research laboratory. Experiments illustrate fundamental physical phenomena in atomic, optical, condensed-matter, nuclear, and particle physics, including NMR, laser-based atomic spectroscopy, gamma and X-ray spectroscopy, muon decay, weak localization, superconductivity, positron annihilation, and others. Instructors: Black, Libbrecht.

Ph 78 abc. Senior Thesis, Experimental. *9 units; first, second, third terms. Prerequisite: To register for this course the student must obtain approval of the chair of the Physics Undergraduate Committee (Ed Stone). Open only to senior physics majors.* This research must be supervised by a faculty member, the student's thesis adviser. Laboratory work is required for this course. Two 15-minute presentations to the Physics Undergraduate Committee are required, one at the end of the first term and the second at the midterm week of the third term. The written thesis must be completed and distributed to the committee one week before the second presentation. Not offered on a pass/fail basis. See Note, below.

Ph 79 abc. Senior Thesis, Theoretical. *9 units; first, second, third terms. Prerequisite: to register for this course the student must obtain approval of the chair of the Physics Undergraduate Committee (Ed Stone). Open only to senior physics majors.* This research must be supervised by a faculty member, your thesis adviser. Two 15-minute presentations to the Physics Undergraduate Committee are required, one at the end of the first term and the second at the midterm week of the third term. The written thesis must be completed and distributed to the committee one week before the second presentation. Not offered on a pass/fail basis. See Note, below.

Note: Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with the chair of the Physics Undergraduate Committee, or any other member of this committee. A grade will not be assigned in Ph 78 or Ph 79 until the end of the third term. P grades will be given the first two terms, and then changed at the end of the course to the appropriate letter grade.

Ph 101. Order-of-Magnitude Physics. *9 units (3-0-6); second term.* Emphasis will be on using basic physics to understand complicated systems. Examples will be selected from properties of materials, geophysics, weather, planetary science, astrophysics, cosmology, biomechanics, etc. Instructor: Phinney.

Ph 103 ab. Topics in Contemporary Physics. *9 units (3-0-6); first, second terms. Prerequisite: instructor's permission.* A series of introductory one-term, independent courses. Students may register for any particular term or terms.

a. Atomic and Molecular Spectroscopy. *Second term.* This course will review the basic spectroscopy of atoms and molecules, with applications to astrophysics, the terrestrial atmosphere, and the laboratory. Species to be discussed include hydrogen and simple multielectron atoms such as carbon, diatomic and polyatomic molecules, and some solids. Mechanisms and effects determining linewidths and lineshapes will be discussed for laboratory, atmospheric, and astrophysical conditions. Instructor: Phillips.

Ph/Bi 103 b. Neuroscience for Physicists and Engineers. *First term.* A reading and discussion course on topics ranging from the function of single neurons to methods for studying multineural activity in synapses; electrical recording; vision; positron and NMR topography; and neural modeling. Preference is given to physics seniors. Instructor: Pine.

Ph 105. Analog Electronics for Physicists. *9 units; first term. Prerequisites: Ph 1 abc, Ph 3, or equivalents (the take-home lab of Ph 1 bc may be substituted for Ph 3).* A laboratory course dealing with "operational" electronics with emphasis on analog electronics. The following topics are studied: RC circuits, electrical oscillations, operational amplifiers, diodes, and transistors. Combining diodes, transistors, and operational amplifiers; computer data acquisition. The course culminates in a two-week project of the student's choosing. Instructors: Rice, Sannibale, Zmuidzinas.

Ph 106 abc. Topics in Classical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 ab or Ph 12 abc, Ma 2.* An intermediate course in the application of basic principles of classical physics to a wide variety of subjects. Roughly half of the year will be devoted to mechanics, and half to electromagnetism. Topics include Lagrangian and Hamiltonian formulations of mechanics, small oscillations and normal modes, boundary-value problems, multipole expansions, and various applications of electromagnetic theory. Instructors: Golwala, Cross.

Ph/EE 118 ab. Low-Noise Electronic Measurement. *9 units (3-0-6); first, second terms. Prerequisite: Ph 105 or equivalent.* An introduction to ultralow-noise electrical measurements and sensor technology as applied to experimental research. Topics include physical noise processes, signal transduction, synchronous and lock-in detection, digital signal transforms, and other aspects of precision measurements. Specific sensor technologies will include SQUID sensors, single electron transistors, transition-edge sensors, tunnel junction detectors, micro- and nanomechanical detectors, and biosensors. Instructor: Roukes.

Ph 125 abc. Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 ab, Ph 12 abc or Ph 2 ab, or equivalents.* A one-year course in quantum mechanics and its applications, for students who have completed Ph 12 or Ph 2. Wave mechanics in 3-D, scattering theory, Hilbert spaces, matrix mechanics, angular momentum, symmetries, spin-$^1/_2$ systems, approximation methods, identical particles, and selected topics in atomic, solid-state, nuclear, and particle physics. Instructor: Mabuchi.

Ph 127 abc. Statistical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 12 c or equivalent, and a basic understanding of quantum and classical mechanics.* A course in the fundamental ideas and applications of classical and quantum statistical mechanics. Topics to be covered include the statistical basis of thermodynamics; ideal classical and quantum gases (Bose and Fermi); lattice vibrations and phonons; weak interaction expansions; phase transitions; and fluctuations and dynamics. Part c not offered 2006–07. Instructor: Refael.

Ph 129 abc. Mathematical Methods of Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 106 abc and ACM 95/100 abc or Ma 108 abc, or equivalents.* Mathematical methods and their application in physics. First term includes analytic and numerical methods for solving differential equations, integral equations, and transforms, and other applications of real analysis. Second term focuses on probability and statistics in physics. Third term covers group theoretic methods in physics. The three terms can be taken independently. Instructors: Porter, Gottschalk.

Ph 134. String Theory. *9 units (3-0-6); third term. Prerequisites: Ph 125 ab, Ph 106 ab.* A basic course in string theory designed to be accessible to a broad audience. The main topics include the motion of relativistic point particles and strings, actions, world-sheet symmetries and currents, light-cone quantization, and the spectra of relativistic open and closed strings. The course will conclude with an exploration of D-branes, T-duality, or string thermodynamics, depending on student interest. Not offered 2006–07.

Ph 135 abc. Applications of Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125 abc or equivalent.* Applications of quantum mechanics to topics in contemporary physics. Nuclear physics, condensed-matter physics, and nonaccelerator particle physics will be offered first, second, third terms, respectively. Terms may be taken independently. Instructors: McKeown, Motrunich, Golwala.

Ph 136 abc. Applications of Classical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* Applications of classical physics to topics of interest in contemporary "macroscopic" physics. Continuum physics and classical field theory; elasticity and hydrodynamics; plasma physics; magnetohydrodynamics; thermodynamics and statistical mechanics; gravitation theory, including general relativity and cosmology; modern optics. Content will vary from year to year, depending on the instructor. An attempt will be made to organize the material so that the terms may be taken independently. Instructors: Cross, Thorne.

Ph 171. Reading and Independent Study. *Units in accordance with work accomplished.* Occasionally, advanced work involving reading, special problems, or independent study is carried out under the supervision of an instructor. Approval of the instructor and of the student's departmental adviser must be obtained before registering. Graded pass/fail.

Ph 172. Research in Experimental Physics. *Units in accordance with work accomplished.* Approval of the student's research supervisor and department adviser must be obtained before registering. Graded pass/fail.

Ph 173. Research in Theoretical Physics. *Units in accordance with work accomplished.* Approval of the student's research supervisor and departmental adviser must be obtained before registering. Graded pass/fail.

CNS/Bi/BE/Ph 178. Evolution and Biocomplexity. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

CNS/Bi/Ph/CS 187. Neural Computation. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

Ph 199. Major Open Questions in Physics. *9 units (3-0-6); third term. Prerequisites: Ph 125 abc, Ph 106 abc.* This course will examine several open questions in modern physics. Topics will include the following: What is the expansion history of the universe? What are dark matter and dark energy? Where does mass come from? Why is the universe made of matter rather than antimatter? Is nature supersymmetric? Is there a quantum theory of gravity that can describe the universe? Why is there a spectrum of fermion masses? How heavy are neutrinos, and what was their role in the formation of the universe? Where do ultrahigh-energy cosmic rays come from? What can we learn from the detection of gravitational waves? Instructor: Weinstein.

Ph 205 abc. Relativistic Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125.* Topics: the Dirac equation, second quantization, quantum electrodynamics, scattering theory, Feynman diagrams, non-Abelian gauge theories, Higgs symmetry-breaking, the Weinberg-Salam model, and renormalization. Instructor: Wise.

Ph 210. Theoretical Quantum Chromodynamics. *9 units (3-0-6); third term. Prerequisite: Ph 205 ab.* Applications of quantum field theory to quantum chromodynamics, including operator product expansion, twist expansion and applications to deep inelastic scattering and Drell-

Yan; effective field theories, including chiral perturbation theory, heavy quark effective theory, and soft collinear effective theory; large Nc; introduction to lattice chromodynamics. Applications to strong interaction phenomenology and weak decays. Not offered 2006–07.

Ph/CS 219 abc. Quantum Computation. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 129 abc or equivalent.* The theory of quantum information and quantum computation. Overview of classical information theory, compression of quantum information, transmission of quantum information through noisy channels, quantum error-correcting codes, quantum cryptography and teleportation. Overview of classical complexity theory, quantum complexity, efficient quantum algorithms, fault-tolerant quantum computation, physical implementations of quantum computation. Part c not offered 2006–07. Instructors: Preskill, Kitaev.

Ph/APh 223 abc. Advanced Condensed-Matter Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125 or equivalent, or instructor's permission.* Advanced topics in condensed-matter physics, emphasizing the application of formal quantum field theory and group theory methods to many-body systems. Selected topics may include path integral and canonical formalisms, Green's function techniques and Feynman diagrams, Fermi liquid theory, symmetry breaking, Landau-Ginzburg theory of phase transitions, critical phenomena and renormalization group theory, group theory and its applications, field theory for interacting bosons and superfluidity, superconductivity, topological field theory, and strongly correlated electronic systems. Instructors: Yeh, Kitaev.

Ph 225 abc. Advanced Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125 or equivalent.* Advanced theory of quantum mechanics, focusing on formal methods and applications in different fields of physics. Topics will include selections from atomic and molecular physics, quantum optics, quantum information, condensed-matter physics, and nuclear and particle physics, with specific content depending on the instructors. Emphasis will be placed on subject matter directly relevant to research in condensed-matter physics, quantum optics, and atomic physics. Not offered 2006–07.

Ph 229 abc. Advanced Mathematical Methods of Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 129 abc or equivalent.* Advanced topics in geometry and topology that are widely used in modern theoretical physics. Emphasis will be on understanding and applications more than on rigor and proofs. First term will cover basic concepts in topology and manifold theory. Second term will include Riemannian geometry, fiber bundles, characteristic classes, and index theorems. Third term will include anomalies in gauge-field theories and the theory of Riemann surfaces, with emphasis on applications to string theory. Instructor: Schwarz.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205 abc or equivalent.* Advanced methods in quantum field theory. First term: introduction to supersymmetry, including the minimal supersymmetric extension of the standard model, supersymmetric grand unified theories, extended supersymmetry, supergravity, and supersymmetric theories in higher dimensions. Second and third terms: nonperturbative phenomena in non-Abelian gauge field theories, including quark confinement, chiral symmetry breaking, anomalies, instantons, the 1/N expansion, lattice gauge theories, and topological solitons. Instructors: Kapustin, Mikhailov, Gukov.

Ph 231 abc. Elementary Particle Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125 or equivalent.* An introduction to elementary particle physics, stressing experimental phenomena and their theoretical interpretations. The standard model and its confrontation with experiment will be covered. Current notions for particle physics beyond the standard model will be explored, along with possible experimental signatures. Experimental techniques will also be discussed, including an introduction to accelerator physics. Not offered 2006–07.

Ph 232. Introduction to Topological Field Theory. *9 units (3-0-6); second term. Prerequisite: Ph 205.* Topological field theories are the simplest examples of quantum field theories which, in a sense, are exactly solvable and generally covariant. During the past twenty years they have been the main source of interaction between physics and mathematics. Thus, ideas from gauge theory led to the discovery of new topological invariants for 3-manifolds and 4-manifolds. By now, topological quantum field theory (TQFT) has evolved into a vast subject, and the main goal of this course is to give an accessible introduction to this elegant subject. Instructor: Gukov.

Ph 235 abc. Introduction to Supersymmetry and String Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205.* First term: introduction to supersymmetry. After explaining the basic concepts of supersymmetry, the emphasis will be on formulating and analyzing the minimal supersymmetric extension of the standard model and supersymmetric grand unified theories. There will also be brief introductions to supersymmetric theories in higher dimensions, theories with extended supersymmetry, and supergravity. Second term: introduction to superstring theory. Topics to be discussed include relativistic strings and their quantization, perturbative string theory, low energy effective supergravity theories, p-brane solutions and p-brane world volume theories, compactification of extra dimensions, M theory and F theory, dualities relating various superstring and M theory configurations, problems and prospects. Not offered 2006–07.

Ph 236 abc. Relativity. *9 units (3-0-6); first, second, third terms. Prerequisite: a mastery of special relativity at the level of Goldstein's* Classical Mechanics, or of Jackson's Classical Electrodynamics. A systematic exposition of Einstein's general theory of relativity, with emphasis on applications to astrophysical and cosmological problems. Instructor: Kamionkowski.

Ph 237 ab. Gravitational Waves. *9 units (3-0-6); second, third terms. Prerequisite: Ph 106.* The theory of gravitational waves: their generation, propagation, and interaction with detectors. Astrophysical sources of gravitational waves: the Big Bang, early-universe phenomena, binary stars, black holes, supernovae, and neutron stars. Gravitational-wave detectors: their design, noise, data analysis, and underlying physics, with emphasis on LIGO and LISA but also detectors based on resonant masses, doppler tracking of spacecraft, pulsar timing, and the polarization of the cosmic microwave background. Not offered 2006–07.

Ph 242 ab. Physics Seminar. *3 units (2-0-1); first, second terms.* Topics in physics emphasizing current research at Caltech. One two-hour meeting per week. Speakers will be chosen from both faculty and students. Registration restricted to first-year graduate students in physics; exceptions only with permission of instructor. Graded pass/fail. Instructor: Stone.

Ph 250. Introduction to String Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205 or equivalent.* The first two terms will focus largely on the bosonic string. Topics covered will include conformal invariance and construction of string scattering amplitudes, the origins of gauge interactions and gravity from string theory, T-duality, and D-branes. The third term will cover perturbative aspects of superstrings, supergravity, various BPS branes, and string dualities. Not offered 2006–07.

Ph 300. Thesis Research. *Units in accordance with work accomplished.* Ph 300 is elected in place of Ph 172 or Ph 173 when the student has progressed to the point where research leads directly toward the thesis for the degree of Doctor of Philosophy. Approval of the student's research supervisor and department adviser or registration representative must be obtained before registering. Graded pass/fail.

POLITICAL SCIENCE

PS 12. Introduction to Political Science. *9 units (3-0-6); first, second, third terms.* Introduction to the tools and concepts of analytical political science. Subject matter is primarily American political processes and institutions. Topics: spatial models of voting, redistributive voting, games, presidential campaign strategy, Congress, congressional-bureaucratic relations, and coverage of political issues by the mass media. Instructors: Kiewiet, Ordeshook.

PS 99 ab. Political Science Research Seminar. *9 units (3-0-6). Prerequisite: political science major; completion of a required PS course for major.* Development and presentation of a major research paper on a topic of interest in political science or political economy. The project will be one that the student has initiated in a political science course he or she has already taken from the PS courses required for the PS option, numbered above 101. This course will be devoted to understanding research in political science, and basic political science methodology. Students will be exposed to current research journals, work to understand a research literature of interest, and work to formulate a research project. *Fulfills the Institute scientific writing requirement.*

PS 101. Selected Topics in Political Science. *Units to be determined by arrangement with the instructor; offered by announcement.* Instructor: Staff.

PS 120. American Electoral Behavior and Party Strategy. *9 units (3-0-6); first term.* A consideration of existing literature on the voting behavior of the citizen, and an examination of theoretical and empirical views of the strategies followed by the parties. Instructor: Alvarez.

PS 121. Congressional Policy Formation and Legislative Process. *9 units (3-0-6).* Decision making in legislative bodies, with emphasis on the United States Congress. An investigation into the impact of congressional structure and practices on the policies adopted by the federal government. Not offered 2006–07.

PS 122. Political Representation. *9 units (3-0-6); second term. Prerequisite: PS 12.* Theory, practice, and consequence of political representation in the electoral context. Topics include the concept of representation; how the degree of representation of various groups and interests (such as ethnic and racial) is affected by different electoral rules; and the impact of representation of minorities on public policies. The primary focus is on the empirical literature pertaining to the United States, but examples from other countries are also examined for comparative purposes. Instructor: Ueda.

PS 123. Regulation and Politics. *9 units (3-0-6); first term. Prerequisite: PS 12.* This course will examine the historical origins of several regulatory agencies and trace their development over the past century or so. It will also investigate a number of current issues in regulatory politics, including the great discrepancies that exist in the cost-effectiveness of different regulations, and the advent of more market-based approaches to regulations instead of traditional "command-and-control." Not offered on a pass/fail basis. Instructor: Kiewiet.

PS 124. Political Economy. *9 units (3-0-6); second term.* The aim of this course is to introduce students to theoretical and applied research in political economy. The focus will be on formal analysis of the strategic interaction between rational individuals, political institutions, and economic outcomes. Some of the questions will be: Why do people vote? What are the incentives of elected politicians, and what is the effect of these incentives on the policies they will implement? To what extent do differences in political institutions account for differences in redistributive policies? Topics may include the theory of voting, models of direct democracy, models of electoral competition, the political economy of redistribution, and comparative political institutions. Instructor: Mattozzi.

PS 126. Political Corruption. *9 units (3-0-6); third term.* This course explores fundamental questions related to the scientific study of corruption. Political corruption will first be defined and then how one might go about measuring it will be discussed. The following questions will be asked: What are the stylized facts about the common determinants of corruption across countries? Do certain political institutions constrain corruption, and if so, what are the constraining mechanisms? How is political corruption related to bureaucratic corruption? The course builds on the latest literature in economics and political science; hence, some background in economics and/or political science is desirable. Instructor: Kunicova.

PS 130. Introduction to Social Science Surveys: Methods and Practice. *9 units (3-0-6); third term.* In this course, students will learn the basic methodologies behind social science survey analysis: self-completion and interview-assisted surveying, sampling theory, questionnaire design, theories of survey response, and the basic analysis and presentation of survey results will be covered, as well as contemporary research in survey methodology and public opinion analysis. Students will be involved in the active collection and analysis of survey data and the presentation of survey results; students will be required to complete an independent project involving some aspect of survey methodology. Instructor: Alvarez.

PS 132. Formal Theories in Political Science. *9 units (3-0-6). Prerequisite: PS 12 or equivalent.* Axiomatic structure and behavioral interpretations of game theoretic and social choice models and models of political processes based on them. Instructor: Ordeshook.

PS 135. Analyzing Legislative Elections. *9 units (3-0-6); second term.* The purpose of this course is to understand legislative elections. The course will study, for example, what role money plays in elections and why incumbents do better at the polls. It will also examine how electoral rules impact the behavior both of candidates and voters, and will explore some of the consequences of legislative elections, such as divided government. Instructor: Katz.

PS/SS 139. Comparative Politics. *9 units (3-0-6). Prerequisite: PS 12 or SS 13.* The politics of non-American political systems. Areas of study: the politics of nondemocratic states, including the Communist nations; the politics of developing societies; the politics of the Western European democracies. Emphasis on the effect of distinctive institutions on the performance of government and the content of public policy. Not offered 2006–07.

PS 141. A History of Budgetary Politics in the United States. *9 units (3-0-6); offered by announcement.* This class will examine budgetary conflict at key junctures in U.S. history. Topics include the struggle to establish a viable fiscal system in the early days of the Republic, the *ante bellum* tariff, the “pension politics” of the post–Civil War era, the growth of the American welfare state, and the battle over tax and entitlement reform in the 1980s and 1990s. Instructor: Kiewiet.

Law/PS/H 148 ab. The Supreme Court in U.S. History. *9 units (3-0-6).* For course description, see Law.

Ec/PS 160 abc. Laboratory Experiments in the Social Sciences. *9 units (3-3-3).* For course description, see Economics.

PS/Ec 172. Noncooperative Games in the Social Sciences. *9 units (3-0-6); first term. Prerequisite: PS 12 or equivalent.* Axiomatic structure and behavioral interpretations of game theory models in social science. Axiomatic utility theory and general noncooperative games. Instructor: Echenique.

PS/Ec 173. Cooperation and Social Behavior. *9 units (3-0-6). Prerequisite: PS/Ec 172 or instructor’s permission.* Game theoretic and evolutionary approaches to modeling various types of cooperative, altruistic, and social behavior. Emphasis on economic and political applications. Not offered 2006–07.

Ec/PS 190. Undergraduate Research. *Units to be arranged.* For course description, see Economics.

PSYCHOLOGY

Psy 15. Social Psychology. *9 units (3-0-6); offered by announcement.* The study of how people think about other people and behave toward or around others. Topics include attribution, social cognition, motivation and incentive, social influence, liking, stereotyping, deception, fairness and altruism, and conformity. Instructor: Castelli.

Psy 16. Understanding Psychological Disorders. *9 units (3-0-6); first term.* A descriptive and theoretical survey of the major forms of psychopathology in children, adolescents, and adults. The course will examine current trends and research in the fields of mental health and psychopathology. Instructor: Castelli.

Psy 20. Introduction to Cognitive Psychology. *9 units (3-0-6); second term.* This course will develop basic concepts in how humans process different kinds of information such as visual, auditory, and symbolic. These concepts will then be used to explore topics such as visual perception, attention and automaticity, working and long-term memory, imagery, knowledge representation, language acquisition and comprehension, judgement and choice, reasoning and decision making, problem solving, and group differences. Instructor: Spezio.

Psy 25. Reading and Research in Psychology. *Units to be determined by the instructor.* Written report required. Graded pass/fail. *Not available for credit toward humanities–social science requirement.* Not offered 2006–07.

Psy 101. Selected Topics in Psychology. *Units to be determined by arrangement with the instructor; offered by announcement.* Instructor: Staff.

CNS/Bi/Psy 120. The Neuronal Basis of Consciousness. *9 units (4-0-5).* For course description, see Computation and Neural Systems.

Psy 125. Reading and Research in Psychology. Same as Psy 25, but for graduate credit. *Not available for credit toward humanities–social science requirement.*

Psy/CNS 130. Introduction to Human Memory. *9 units (3-0-6); second term.* The course offers an overview of experimental findings and theoretical issues in the study of human memory. Topics include iconic and echoic memory, working memory, spatial memory, implicit learning and memory; forgetting: facts vs. skills, memory for faces; retrieval: recall vs. recognition, context-dependent memory, semantic memory, spreading activation models and connectionist networks, memory and emotion, infantile amnesia, memory development, and amnesia. Not offered 2006–07.

CNS/Psy/Bi 131. The Psychology of Learning and Motivation. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

Bi/CNS/Psy 133. Neurobiology and Evolution of Emotion: Do Flies Have Feelings? *9 units (3-0-6).* For course description, see Biology.

SS/Psy/Bi/CNS 140. Social Neuroscience. *9 units (3-0-6).* For course description, see Social Science.

Psy/SS/CNS 254. Neural Foundations of Preference Formation and Consumer Choice. *9 units (3-0-6); third term.* This course explores the role of automatic and deliberative processes on consumer decision making from the perspectives of computational neuroscience, cognitive neuroscience, psychology, and behavioral economics. Instructor: Rangel.

SS/Psy/Bi/CNS 255. Topics in Emotion and Social Cognition. *9 units (3-0-6).* For course description, see Social Science.

SOCIAL SCIENCE

SS 13. The Application of Social Scientific Methods to Problems in History. *9 units (3-0-6); first term.* The application of theory from economics, political science, and demography to historical subjects, with an emphasis on questions of institutional change. The historical topics covered will depend upon the instructor. Not offered 2006–07.

BEM/Ec/SS 20. Scientific Writing and Oral Presentation in the Social Sciences. *6 units (2-0-4).* For course description, see Business Economics and Management.

SS 98. Reading in Social Science. *Units to be determined for the individual by the department. Elective, in any term.* Reading in social science and related subjects, done either in connection with the regular courses or independently of any course, but under the direction of members of the department. A brief written report will usually be required. Graded pass/fail. *Not available for credit toward humanities–social science requirement.*

SS 101. Selected Topics in Social Science. *9 units (3-0-6); offered by announcement.* Not available for social science credit unless specifically approved by social science faculty. Instructors: Staff, visiting lecturers.

Ec/SS 129. Economic History of the United States. *9 units (3-0-6).* For course description, see Economics.

Ec/SS 130. Economic History of Europe from the Middle Ages to the Industrial Revolution. *9 units (3-0-6).* For course description, see Economics.

PS/SS 139. Comparative Politics. *9 units (3-0-6).* For course description, see Political Science.

SS/Psy/Bi/CNS 140. Social Neuroscience. *9 units (3-0-6); third term. Prerequisite: Bi/CNS 150 recommended.* This course will survey the neural basis of social behavior, drawing on both theoretical and empirical approaches. Recent findings from cognitive neuroscience will be discussed, with an emphasis on data from humans. Topics will include motivation, emotion, theory of mind, social perception, and simulation. Not offered 2006–07.

The graduate courses listed below are not necessarily taught each year. They will be offered as need dictates.

SS 200. Selected Topics in Social Science. *Units to be determined by arrangement with instructors; offered by announcement.* Instructors: Staff, visiting lecturers.

SS 201 abc. Analytical Foundations of Social Science. *9 units (3-0-6).* This course covers the fundamentals of utility theory, game theory, and social choice theory. These basic theories are developed and illustrated with applications to electoral politics, market trading, bargaining, auctions, mechanism design and implementation, legislative and parliamentary voting and organization, public economics, industrial organization, and other topics in economics and political science. Instructors: Echenique, Chambers, Goeree.

SS 202 abc. Political Theory. *9 units (3-0-6).* Course will introduce the student to the central problems of political theory and analysis, beginning with the essential components of the democratic state and proceeding through a variety of empirical topics. These topics will include the analysis of electoral and legislative institutions, legislative agenda processes, voting behavior, comparative political economy, and cooperation and conflict in international politics. The student will be sensitized to the primary empirical problems of the discipline and trained in the most general applications of game theoretic reasoning to political science. Instructors: Alvarez, Ordeshook.

SS 205 abc. Foundations of Economics. *9 units (3-0-6). Prerequisite: Ec 121 ab or instructor's permission.* This is a graduate course in the fundamentals of economics. Topics include comparative statics and maximization techniques, the neoclassical theory of consumption and production, general equilibrium theory and welfare economics, public goods and externalities, the economic consequences of asymmetric information and incomplete markets, and recursive methods with applications to labor economics and financial economics. Instructors: Border, Echenique.

SS 209. Behavioral Economics. *9 units (3-0-6); offered by announcement. Prerequisite: SS 201 abc or instructor's permission.* This course explores how psychological facts and constructs can be used to inform models of limits on rationality, willpower and greed, to expand the scope of economic analysis. Topics include overconfidence, heuristics for statistical judgment, loss-aversion, hyperbolic discounting, optimal firm behavior when consumers are limited in rationality, behavioral game theory, behavioral finance, neuroeconomic dual-self models, and legal and welfare implications of rationality limits. Instructor: Camerer.

SS 210 abc. Foundations of Political Economy. *9 units (3-0-6). Prerequisites: SS 202 c, SS 205 b.* Mathematical theories of individual and social choice applied to problems of welfare economics and political decision making as well as to the construction of political economic processes consistent with stipulated ethical postulates, political platform formulation, the theory of political coalitions, and decision making in political organizations. Instructors: Mattozzi, Iaryczower, Yariv.

SS 211 abc. Advanced Economic Theory. *9 units (3-0-6). May be repeated for credit.* Advanced work in a specialized area of economic theory, with topics varying from year to year according to the interests of students. Instructors: Palfrey, Chambers.

SS 212. Application of Microeconomic Theory. *9 units (3-0-6). May be repeated for credit.* A working seminar in which the tools of microeconomic theory are applied to the explanation of events and the evaluation of policy. Not offered 2006–07.

SS 213 abc. Financial Economics. *9 units (3-2-4).* First term: asset pricing theory, statistical tests on historical data and evidence from financial markets experiments. Second term: financial econometrics, with emphasis on applications to risk management. Third term: general equilibrium foundations of asset and option pricing theory. Not offered 2006–07.

SS/Ma 214. Mathematical Finance. *9 units (3-0-6); second term.* A course on fundamentals of the mathematical modeling of stock prices and interest rates, the theory of option pricing, risk management, and optimal portfolio selection. Students will be introduced to the stochastic calculus of various continuous-time models, including diffusion models and models with jumps. Instructor: Cvitanic.

SS 216. Interdisciplinary Studies in Law and Social Policy. *9 units (3-0-6); second term.* A policy problem or problems involving the legal system will be studied, using concepts from at least one social science discipline. Each offering will be taught by a law professor, alone or in conjunction with a member of the social science faculty. The topic will differ from term to term, so the course may be taken more than once. Selected undergraduates may enroll in this course with the permission of the instructor. Instructor: Spitzer.

SS 222 abc. Econometrics. *9 units (3-0-6).* Introduction to the use of multivariate and nonlinear methods in the social sciences. Instructors: Sherman, Matzkin.

SS 223 abc. Advanced Topics in Econometric Theory. *9 units (3-0-6). Prerequisite: SS 222 abc; may be repeated for credit.* A course in quantitative methods for second- and third-year social science graduate students. Instructors: Sherman, Matzkin.

SS 227. Identification Problems in the Social Sciences. *9 units (3-0-6); second term. Prerequisite: SS 222 abc.* There is a tension in modeling social science phenomena between making strong assumptions, which lead to descriptive or normative conclusions that are precise when the assumptions hold but invalid when they do not hold, and making weak assumptions, which lead to less precise conclusions but hold more generally. The preponderance of social science research to date takes the former approach. This course studies recent advances in the latter approach. The course will review the work of Manski on bounds identification and estimation and trace some of the developments in this line of research to the present. Various applications of the methodology will be considered, including applications to Stanford-9 test-score data and data on organic pollutants in the Love Canal. Not offered 2006–07.

SS 228. Applied Data Analysis for the Social Sciences. *9 units (3-0-6); third term.* The course covers issues of management and computation in the statistical analysis of large social science databases. Maximum likelihood and Bayesian estimation will be the focus. This includes a study of Markov Chain Monte Carlo (MCMC) methods. Substantive social science problems will be addressed by integrating programming, numerical optimization, and statistical methodology. Instructor: Katz.

SS 229 abc. Theoretical and Quantitative Dimensions of Historical Development. *9 units (3-0-6). May be repeated for credit.* Introduction to modern quantitative history. The tools of economic and political theory applied to problems of economic, social, and political development in a historical context. Second and third terms will be graded together. A pass/fail will be assigned in the second term and then changed to the appropriate letter grade at the end of the third term. Instructor: Hoffman.

SS 231 abc. American Politics. *9 units (3-0-6).* A three-term course in American politics and political behavior. While drawing from contemporary materials, the course will emphasize the historical background of American political institutions. Instructor: Katz.

SS 232 abc. Historical and Comparative Perspectives in Political Analysis. *9 units (3-0-6).* Provides a knowledge and understanding of developments in both the American past and in other parts of the world. Instructor: Staff.

SS 240. Techniques of Policy Research. *9 units (3-0-6). Prerequisite: SS 205 ab.* The application of social science theory and methods to the formulation and evaluation of public policy. Not offered 2006–07.

SS/CS 241 ab. Introduction to Social and Information Sciences. *9 units (3-0-6); second, third terms. Undergraduates cannot use this course towards fulfilling the core Institute social science requirement.* Introduction to techniques and methods used in research at the intersection of social and information sciences: aggregation of dispersed information and optimal allocation of resources through markets, networks, and other social systems; formation and off-equilibrium behavior of these systems; distributed cognition; related computational issues; aggregation, allocation, formation, and equilibration enhancements through technology—hardware and software, economic theory applied to the design of communication networks and computational systems; distributed information systems supporting economic activity. Instructors: EAS and HSS faculty.

CNS/SS 251. Human Brain Mapping: Theory and Practice. *9 units (3-1-5).* For course description, see Computation and Neural Systems.

Psy/SS/CNS 254. Neural Foundations of Preference Formation and Consumer Choice. *9 units (3-0-6).* For course description, see Psychology.

SS/Psy/Bi/CNS 255. Topics in Emotion and Social Cognition. *9 units (3-0-6); third term. Prerequisite: SS/Psy/Bi/CNS 140 or instructor's permission.* This course will cover recent findings in the psychology and neurobiology of emotion and social behavior. What role does emotion play in other cognitive processes, such as memory, attention, and decision making? What are the component processes that guide social behavior? To what extent is the processing of social information domain-specific? Readings from the current literature will emphasize functional imaging, psychophysical, and lesion studies in humans. Instructor: Adolphs.

SS 260. Experimental Methods of Political Economy. *9 units (3-3-3).* Survey of laboratory experimental research related to the broad field of political economy. Topics: the behavior of markets, organizations, committee processes, and election processes. Emphasis on experimental methods and techniques. Students will design and conduct experiments. May be repeated for credit with instructor's permission. Instructor: Plott.

SS 280. Modern Topics in Social Science. *9 units (3-0-6); first term.* This course will teach students about the major modern contributions of social science in fields outside their areas of specialization. Students will cover a series of basic topics by reading and discussing the central papers or books that characterize what is known about each topic area. Different sections of the course will be offered in different social sciences (e.g., economics and political science). Instructor: Staff.

SS 281. Graduate Social Science Writing Seminar. *9 units (3-0-6); third term.* Only open to advanced graduate students in social science. How can social scientists write in a style that makes someone actually want to read their papers? This seminar combines writing exercises with help in planning a professional social science paper and with extensive comments on drafts. Instructor: Ledyard.

SS 300. Research in Social Science. *Units to be arranged.*