familiar territory. When in doubt, Freshmen should, after seeking advice, trust to their energies and choose the more challenging courses.

In deciding about the appropriate courses in which to place themselves, Freshmen should first read carefully the material in this chapter and in the *Academic Handbook for Freshmen,* and then examine the introductory information about particular fields in CHAPTER III of this bulletin. (The *Academic Handbook* is mailed to all Freshmen during the summer.) The introductory passages in CHAPTER III of this bulletin contain information concerning courses that are especially appropriate for Freshmen as well as explanations of the differences in level or approach among various introductory courses. After considering the descriptions of course offerings, Freshmen should consult their Freshman faculty advisers. Since advisers cannot know everything about every subject of instruction, the student should regard the faculty adviser not only as a source of information but also as a point of contact with other members of the faculty who have the more precise and specific information a particular Freshman may need. The faculty adviser may therefore refer a student with special qualifications or problems to the Director of Undergraduate Studies of a department or program, to a departmental placement officer, or to a departmental adviser in the student's Residential College. The names of these members of the faculty are given with the introductory information on each subject described in CHAPTER III, and no Freshman should hesitate to consult them at any point during the academic year, particularly during the first weeks of the term.

In deciding the most appropriate level of placement, a student may want to attend courses on a trial basis. Freshmen have ample time after Freshman registration in which to submit their course schedules, so that a student can resolve doubts about placement by attending courses at two levels (or on two different aspects) of the same subject. Discussions with the instructors of these courses will usually be helpful, because in that context the question of a student's placement can be explored in a concrete and exact way. Even after the term is under way, with the permission of the department a change of level in such subjects as foreign languages or mathematics may be arranged if the instructor and student agree that it is appropriate.

Departments offering instruction in subjects for which students may take Advanced Placement or Achievement tests have drawn up placement policies that are fully described in the *Academic Handbook for Freshmen.* Although these policies are intended to answer most of the questions that Freshmen may have, they cannot take into account everyone's individual situation. Freshmen with questions about placement that are not answered in the *Academic Handbook* or in this bulletin are invited to discuss their qualifications with the appropriate Director of Undergraduate Studies or departmental representative.

PLACEMENT IN ADVANCED COURSES AND ACCELERATION CREDIT

The term "placement" as it is used in this chapter simply means eligibility to enroll in an advanced course. Such eligibility is different from acceleration credit. Some students who are eligible to enroll in an advanced course may also be awarded acceleration credit in that subject on entrance to Yale; other eligible students may not be awarded such credit. However, those students without acceleration credit in a subject but eligible to enroll in an appropriate advanced course in that subject may subsequently earn acceleration credit in the subject by taking an advanced course during their freshman year and completing it with a satisfactory grade. Thus, students may receive acceleration credit either upon entrance or by conversion of advanced course work at Yale into acceleration credit during the freshman year.

ENROLLMENT IN AN ADVANCED COURSE is permitted students whose secondary school work, as verified usually by an Advanced Placement or Achievement test, shows that they have anticipated the main content of the introductory or intermediate level course or courses in that subject in Yale College. Some students—for example, native speakers of foreign languages or students who have studied languages or other subjects independently—enter Yale with sufficient preparation to enroll in advanced courses directly. Placement in an advanced course carries no quantitative value; that is, it does not count as the equivalent of any of the thirty-six course credits required for graduation. It merely allows the student to go into advanced work in a subject. Students may determine whether they are eligible to undertake advanced work in a subject by consulting the *Academic Handbook for Freshmen.*

An ACCELERATION CREDIT is the equivalent of one course credit which may be applied to the thirty-six-course-credit requirement for the bachelor's degree only by students who are permitted to accelerate their progress toward graduation, that is, to complete the requirements of the bachelor's degree in fewer than eight terms. Acceleration credits may be used to reduce the number of course credits required for the bachelor's degree only if they are employed in accordance with the policies governing acceleration given in the Academic Regulations.* Acceleration credits may *not* be employed to meet any of the distributional requirements, except for the foreign language requirement and the Distributional Requirement for the First Two Years. Acceleration credits may be acquired in two ways:

(a) *On entrance.* Freshmen who have scored 4 or 5 on an Advanced Placement test of the College Board will in most subjects be awarded two acceleration credits at matriculation. See below, CRITERIA FOR THE AWARD OF ACCELERATION CREDIT UPON ENTRANCE. Similarly, for subjects in which acceleration credits are awarded for specified scores on Advanced Placement tests, Freshmen may be awarded two acceleration credits for scores of 6 or 7 on higher-level International Baccalaureate examinations, or for scores of A or B on the General Certificate of Education (GCE) A-level examinations in subjects in which acceleration credits are granted. Students who have taken such examinations should bring them to the attention of their Residential College Deans.

For a score on an Advanced Placement test to result in the award of

*The policies for acceleration are described in the Academic Regulations in CHAPTER IV of this bulletin. See ACCELERATION POLICIES in Section O of the Academic Regulations, especially *Acceleration by the Early Accumulation of Thirty-six Course Credits All Earned at Yale* and the sections *Two-Term* and *One-Term Accumulation by Use of Acceleration Credits.*

Yale

HENRY LUCE COURSE, 1994–95

For a description of the Henry Luce Course to be offered in 1994–95 see the Fall Supplement.

MANAGEMENT SCIENCES

(See under Operations Research.)

MATHEMATICS

(*See also* APPLIED MATHEMATICS)

Director of Undergraduate Studies: Richard Beals, 220A LOM, 432-4176 [Sp]
Walter Feit, 216 LOM, 432-7314 [Sp]

FACULTY OF THE DEPARTMENT OF MATHEMATICS

PROFESSORS
Richard Beals
Ronald Coifman
Walter Feit
Igor Frenkel
Howard Garland
Roger Howe (*Chair*)
Peter Jones
Serge Lang
Ronnie Lee
Laszlo Lovasz
Benoit Mandelbrot (*Adjunct*)
Gregory Margulis
Vincent Moncrief
George Mostow
Ilya Piatetski-Shapiro
David Pollard
Vladimir Rokhlin
George Seligman
Robert Szczarba
Tsuneo Tamagawa
Gregg Zuckerman

ASSISTANT PROFESSORS
Jay Jorgenson
Boris Khesin
Nantian Qian
Ravi Ramabrishna

J. W. GIBBS INSTRUCTORS
Hou Hong Fan
Ian Grojnowski
Nets Katz
Wei-Ping Li
Feodor Malikov
Ana Maria Vargas

Both course offerings and the major in Mathematics reflect the many roles of mathematics itself: as the language and tool of the sciences, as a cultural phenomenon with a rich historical tradition, and as a model of abstract reasoning. The Mathematics major provides a broad education in various areas of mathematics in a program flexible enough to accommodate many ranges of interest.

B.A. and B.S. degree programs. The prerequisite for both degree programs is Mathematics 120a or b or its equivalent. The B.A. degree program normally consists of ten term courses in Mathematics numbered 222a or b or higher. Each student is expected to take either Mathematics 230 or its equivalent: Mathematics 222a or b and 250a. The student is also expected to take at least two term courses in each of three of the following categories: *Analysis* (230 which counts as one term course, 246a or b, 250a, courses between 300 and 349); *Statistics and Applied Mathematics* (courses between 241 and 249, 260b, 400a; certain courses in Applied Mathematics, Computer Science, Engineering and Applied Science, and Operations Research, as listed below in "Courses in Other Departments that are Particularly Relevant to the Major"); *Algebra and Number Theory* (222a or b, 230, which counts as one term course, courses between 350 and 399); *Geometry and Topology* (425b, 430b, 435b); *Logic and Foundations* (270a, courses between 450 and 469). All Mathematics majors are urged to take at least one of either Computer Science 201a or b or 440b, which may be counted as a term course in applied mathematics. In some

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sciences permission may be granted to take additional required term courses in other departments (e.g., Computer Science, Engineering and Applied Science, Operations Research, Physics, Statistics).

A candidate for the B.S. degree must take, in addition to the ten term courses listed above as required for the major in Mathematics, at least two advanced term courses in the physical sciences, to be chosen with the approval of the Director of Undergraduate Studies.

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Any student interested in a Ph.D. degree in pure mathematics is strongly urged to include the following courses in his or her program: Mathematics 230, 301a, 305b, 310a, 350a, and 370b. Such a student should also seriously consider taking one or more graduate-level courses. Students whose interests lean more toward applications of mathematics should take Mathematics 222a or b and 250a; in addition, such students should especially consider the following courses: Mathematics 241a, 242b, 246a or b, 260b, 300b, 310a, 400a, and 435b.

The intensive major. Candidates for a degree with an intensive major in Mathematics are expected to include at least two terms of graduate course work, or of equivalent independent study, in their programs. Familiarity with the material of the following courses should be considered prerequisite to graduate courses in the respective categories: *Algebra:* two courses in the range 350–399. *Analysis:* Mathematics 301a, 305b, 310a. *Algebraic Topology:* Mathematics 301a, 350a. *Logic and Foundations:* Mathematics 270a, 454b, 456a.

Senior requirement. A student majoring in Mathematics is required during the Senior year either to take the Senior seminar (Mathematics 482a or b), or to give an oral presentation on some topic selected by members of the faculty. For details, consult the Director of Undergraduate Studies.

The following members of the department may be consulted by students through their Residential College affiliation:

BK, P. Jones
BR, R. Lee
CC, R. Beals
DC, R. Howe
TD, R. Coifman
TE, T. Tamagawa
MC, G. Seligman
PC, G. Mostow
SY, R. Szczarba
SM, R. Beals
ES, R. Beals
TC, W. Feit

M.S. DEGREE PROGRAM

Students who, by the end of their Senior year, complete the requirements of the department for the M.S. in Mathematics will be eligible to receive this degree at their Senior Commencement. Required are: (1) eight term courses numbered 500 or higher, most of which must be completed with grades of High Pass or better; (2) a reading knowledge of mathematical literature in a foreign language of importance for mathematical research (normally French, German, or Russian); (3) satisfactory performance on a general oral examination.

The master's program is in no sense a substitute for the B.A. or B.S. program; rather, it is designed to accommodate a very few exceptional students who, by means of accelerated or independent study, can satisfy the department as to their command of the content of the normal undergraduate program. Candidates must submit to the Director of Undergraduate

Studies, during spring term of Sophomore year, a proposal which foresees this level of achievement by the end of Junior year. Their status and progress will be reviewed before they are permitted to continue in the program in Senior year.

At least two terms of graduate work are to be taken in the Junior year (normally courses in algebra or analysis will be the first graduate courses taken). The general oral examination covers a list of topics available from the Director of Graduate Studies, and will be accepted in lieu of the usual Senior oral presentation. Details concerning the requirements for the master's degree may be obtained from the Director of Graduate Studies.

PLACEMENT IN COURSES

Qualified Freshmen and Sophomores may, *with the permission of the instructor,* take any of the courses numbered 222a or b or above.

There is a three-term sequence of calculus courses, Mathematics 112a or b, 115a or b, and 120a or b. Mathematics 112a or b is an introductory calculus course which presupposes only knowledge of basic techniques from algebra, analytic geometry, and trigonometry. Students who have already taken some calculus should consider Mathematics 115a or b or Mathematics 120a or b.

Freshmen taking calculus are normally placed in Mathematics 112a, 115a, or 120a, according to their backgrounds and, in particular, to their scores in Achievement or Advanced Placement tests. It is expected (but not absolutely required) that any Freshman applying for placement in an advanced course (i.e., 115a or b or higher) will have taken the Advanced Placement Test in calculus. All placement is subject to change during the term if necessary. Further information about level of placement is given in the section on Mathematics in CHAPTER VI of the booklet *Academic Handbook for Freshmen*.

From Mathematics 115a or b a student would naturally continue to 120a or b or to Mathematics 230. Mathematics 230 covers approximately the same material as do the three courses, Mathematics 120a or b, 222a or b, and 250a, but in greater depth and with more emphasis on the underlying concepts. Note that permission of the instructor is required to take Mathematics 230; such permission is routinely granted to students who received a grade of 5 on the Advanced Placement Test in mathematics or who obtain a grade of A in Mathematics 115a or b. After Mathematics 115a or b, students with a strong interest in abstract mathematics should seriously consider taking Mathematics 230.

REQUIREMENTS OF THE MAJOR

Prerequisite: Math 120a or b or equivalent
Number of Courses: *B.A. degree*—10 term courses; *B.S. degree*—12 term courses beyond prerequisite, within which totals Math 480a or b (Senior seminar), if elected, is included
Distribution of Courses: *B.A. degree*—2 courses in each of 3 categories chosen from among (a) Analysis, (b) Statistics and Applied Math, (c) Algebra and Number Theory, (d) Geometry and Topology, (e) Logic and Foundations; *B.S. degree*—same, and 2 advanced-level courses in the physical sciences, with approval of DUS
Specific Courses Required: Math 230 or the combination of Math 222a or b and 250a

Substitution Permitted: Certain relevant courses in Applied Math, Computer Science, Engineering and Applied Science, Operations Research, as listed below under "Courses in Other Depts," with permission of DUS
Senior Requirement: Senior seminar (Math 480a or b), or oral presentation on topic selected by the faculty
Comprehensive Major: 2 courses on graduate level counted among the required courses

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INTRODUCTORY COURSES: Mathematics 112a or b, 115a or b, 120a or b, 190a

ANALYSIS: Mathematics 230 (which counts as one term course), 246a or b, 250a, 300b, 301a, 305b, 310a, 315b, 320a, 325b

STATISTICS AND APPLIED MATHEMATICS: Mathematics 241a, 242b, 244a, 245b, 246a or b, 260b, 400a; Computer Science 201a or b or 440b; E&AS 194a or b; Operations Research 235a

ALGEBRA AND NUMBER THEORY: Mathematics 222a or b, 230 (which counts as one term course), 350a, 353b, 354b, 370b, 380a, 381b

GEOMETRY AND TOPOLOGY: Mathematics 425b, 430b, 435b

LOGIC AND FOUNDATIONS: Mathematics 270a, 454b, 456a, Philosophy 204a, 205b

INTRODUCTORY COURSES

No imputation of Winter term

These courses do not count toward the requirements of a major in Mathematics. Students wishing to enroll in one of these courses are expected to preregister for a specific section. In the fall, preregistration is on Tuesday, August 30, 1994, from 9.30 A.M. to 4.30 P.M. in 432 DL; in the spring, preregistration is on Monday, January 9, 1995, from 9.30 A.M. to 4.30 P.M., also in 432 DL. Those who do not preregister may be excluded from certain sections.

Mathematics 112a *or* b, CALCULUS OF FUNCTIONS OF ONE VARIABLE I. Tsuneo Tamagawa [F], George Seligman [Sp].
3 HTBA Not CR/D/F
For sections see the Fall or Winter Supplement IV(69)
Limits and their properties, differentiation of functions, applications of differentiation, integration. No prior acquaintance with calculus is assumed.

Mathematics 115a *or* b, CALCULUS OF FUNCTIONS OF ONE VARIABLE II. Ivy Jorgenson [F], Ronald Coifman [Sp].
3 HTBA Not CR/D/F
For sections see the Fall or Winter Supplement IV(69)
A continuation of Mathematics 112a or b. Applications of integration, integration techniques, improper integrals, infinite series. *After Mathematics 112a or b or the equivalent; open to Freshmen with some preparation in calculus.*

Mathematics 120a *or* b, CALCULUS OF FUNCTIONS OF SEVERAL VARIABLES. Ronnie Lee [F], Howard Garland [Sp].
3 HTBA Not CR/D/F
For sections see the Fall or Winter Supplement IV(69)
Analytic geometry in three dimensions, using vectors. Real-valued functions of two and three variables, partial derivatives, gradient and directional derivative, level curves and surfaces, maxima and minima. Parametrized curves in space, motion in space, line integrals; applications. Multiple integrals with applications. *After Mathematics* 115a *or* b, *or by permission.*

Mathematics 190a (49190), FRACTAL GEOMETRY. Staff.
MWF 11.30-12.20 IV(34)
A visual introduction to the geometry of fractals and the dynamics of chaos, accessible to nonscience students. Study of mathematical patterns repeating on many levels and expressions of these patterns in nature, art, music, and literature. *Does not count toward the requirements of the major in Mathematics.*

INTERMEDIATE AND ADVANCED COURSES

Courses counting toward the requirements of a major in Mathematics

Mathematics 222a, LINEAR ALGEBRA AND MATRIX THEORY.
Lect 1 (4922201) TTh 10.30-11.20; *disc.* 1 HTBA Howard Garland
Not CR/D/F IV(68)
Lect 2 (4922202) MWF 10.30-11.20; *disc.* 1 HTBA Ian Grojnowski
Not CR/D/F IV(68)
(Students must enroll in a discussion section assigned to their lecture.)
An introduction to the applications of vector spaces in algebra, analysis, and geometry. Matrix algebra, determinants, eigenvalues, quadratic forms, principal axes, and linear programming. *After Mathematics* 115a *or* b *or with permission.*

Mathematics 222b, LINEAR ALGEBRA AND MATRIX THEORY.
Lect 1 (4922201) MWF 8.30-9.20; *disc.* 1 HTBA Peter Schultheiss
Not CR/D/F IV(68)
Lect 2 (4922202) TTh 9-10.15; *disc.* 1 HTBA Ian Grojnowski
Not CR/D/F IV(68)
(Students must enroll in a discussion section assigned to their lecture.)
The content of this course is identical to that of Mathematics 2222. *After Mathematics* 115a *or* b *or with permission.*

★*Mathematics* 230 (49230), VECTOR CALCULUS AND LINEAR ALGEBRA. Gregory Margulis.
Lect MWF 9.30-10.20; *disc.* 1 HTBA Not CR/D/F IV(32)
A careful study of the calculus of functions of several variables, combined with linear algebra.

Mathematics 241a/*Statistics* 241a[G], PROBABILITY THEORY. Nicolas Hengartner.

Mathematics 242b/*Statistics* 242b[G], THEORY OF STATISTICS. Andrew Barron.

Mathematics 244a/*Appl.Mathematics* 244a (49244), DISCRETE MATHEMATICS I. Katalin Vesztergombi.
TTh 9-10.15 IV(21)
Basic concepts and results in discrete mathematics: graphs, trees, connectivity, Ramsey-theorem, enumeration, binomial coefficients, Stirling numbers. Properties of finite set-systems. No specific level of calculus assumed. *After Mathematics* 115a *or* b *or equivalent, or by permission.*

Mathematics 245b/*Appl.Mathematics* 245b (49245), DISCRETE MATHEMATICS II. Laszlo Lovasz.
TTh 9-10.15 IV(21)
Basic techniques of proof, algorithm design, and analysis in discrete mathematics. Graph theory: matchings, flows, planarity, extremal graphs. Finite geometries and other symmetric structures. Random graphs and other probabilistic constructions. Asymptotic formulas in combinatorics. Some linear algebra assumed. *After Mathematics* 244a *and* 120a *or* b, *or by permission.*

Mathematics 246a *or* b (49246), ORDINARY DIFFERENTIAL EQUATIONS.
246a TTh 9-10.15 Staff Not CR/D/F IV(21)
246b TTh 11.30-12.45 Frank Geschwind Not CR/D/F IV(24)
Numerical solution methods. Geometric and algebraic properties of differential equations. First-order equations, second-order equations, linear systems with constant coefficients. *After Mathematics* 120a *or* b *or the equivalent; after or concurrent with Mathematics* 222a *or* b *or equivalent.*

Mathematics 250a[G] (49250), VECTOR ANALYSIS. Roger Howe.
MWF 9.30-10.20 Not CR/D/F IV(32)
Calculus of functions of several variables, using vector and matrix methods. Inverse and implicit function theorems. Transformation of multiple integrals. Line and surface integrals of vector fields. Curl and divergence. Differential forms. Theorems of Green, Gauss, and Stokes. *After Mathematics* 120a *or* b, 222a *or* b, *or the equivalents.*

Mathematics 260b (49260), VARIATIONAL METHODS. Igor Frenkel.
MWF 9.30-10.20 Not CR/D/F IV(32)
An introduction to the calculus of variations, with connections to partial differential equations, and Sturm-Liouville eigenvalue problems. *After Mathematics* 120a *or* b, 222a *or* b, 246a *or* b, *or the equivalents.*

Mathematics 270a (49270), SET THEORY. Nets Katz.
TTh 11.30-12.45 Not CR/D/F IV(24)
Algebra of sets; finite, countable, and uncountable sets. Cardinal numbers and cardinal arithmetic. Order types and ordinal numbers. The axiom of choice and the well-ordering theorem. *After Mathematics* 120a *or* b *or the equivalent.*

Mathematics 300b (49300), TOPICS IN ANALYSIS. Staff.
MWF 1.30-2.20 Not CR/D/F IV(36)
An introductory course in analysis with topics to be chosen from infinite series, the theory of metric spaces, and fixed-point theorems with applications. Students who have taken Mathematics 230 should take Mathematics 300a instead of this course. *After Mathematics* 250a *or by permission.*

Mathematics 301a (49301), INTRODUCTION TO ANALYSIS. Richard Beals.
TTh 1-2.15 Not CR/D/F IV(26)
Foundations of real analysis, including metric spaces and point set topology, infinite series, and function spaces. *After Mathematics* 230 *or the equivalent.*

Mathematics 305b (49305), REAL ANALYSIS. Peter Jones.
TTh 1-2.15 Not CR/D/F IV(26)
The Lebesque integral, Fourier series, applications to differential equations. *After Mathematics* 301a *or by permission.*

Mathematics 310a (49310), INTRODUCTION TO COMPLEX ANALYSIS.
Serge Lang.
TTh 11.30-12.45 Not CR/D/F IV(24)
An introduction to the theory and applications of functions of a complex variable. Differentiability of complex functions. Complex integration and Cauchy's theorem. Series expansions. Calculus of residues. Conformal mapping. *After Mathematics* 230 *or* 250a *or the equivalent.*

★*Mathematics* 315b[G] (49315), INTERMEDIATE COMPLEX ANALYSIS.
Serge Lang.
TTh 11.30-12.45 Not CR/D/F Meets RP IV(24)
Continuation of Mathematics 310a. Topics may include argument principle, Rouché's theorem, Hurwitz theorem, Runge's theorem, analytic continuation, Schwarz reflection principle, Jensen's formula, infinite products, Weierstrass theorem. Functions of finite order, Hadamard's theorem, meromorphic functions. Mittag-Leffler's theorem, subharmonic functions. *After Mathematics* 310a.

★*Mathematics* 320a[G] (49320), MEASURE THEORY AND INTEGRATION. Staff.
TTh 1-2.15 Not CR/D/F Meets RP IV(26)
Construction and limit theorems for measures and integrals on general spaces; product measures; L^p spaces; integral representation of linear functionals. *After Mathematics* 305b *or the equivalent.*

★*Mathematics* 325b[G] (49325), INTRODUCTION TO FUNCTIONAL ANALYSIS.
Boris Khesin.
TTh 1-2.15 Not CR/D/F Meets RP IV(26)
Hilbert, normed, and Banach spaces; geometry of Hilbert space, Riesz-Fischer theorem; dual space; Hahn-Banach theorem; Riesz representation theorems; linear operators; Baire category theorem; uniform boundedness, open mapping, and closed graph theorems. *After Mathematics* 320a.

★*Mathematics* 350a (49350), AN INTRODUCTION TO ABSTRACT ALGEBRA.
Igor Frenkel.
MWF 11.30-12.20 Not CR/D/F IV(34)
Group theory. Rings, with emphasis on integral domains and polynomial rings; modules over Euclidean domains; applications to linear algebra. *After Mathematics* 222a *or* b *or the equivalent.*

Mathematics 353b (49353), REPRESENTATIONS OF FINITE GROUPS.
George Seligman.
MWF 1.30-2.20 IV(36)
Basic theory of representations and characters of finite groups: orthogonality relations, induced representations, exceptional characters, Brauer's theorem. *After Mathematics* 350a, *or by permission.*

Mathematics 354b (49354), NUMBER THEORY. Tsuneo Tamagawa.
TTh 11.30-12.45 Not CR/D/F IV(24)
Prime numbers; quadratic reciprocity law, Gauss sums; finite fields, equations over finite fields; ζ-functions. *After Mathematics* 350a.

[*Mathematics* 355b, GEOMETRIC ALGEBRA. 1995–96]

[*Mathematics* 370b, FIELDS AND GALOIS THEORY. 1995–96]

Mathematics 380a[G] (49380), ALGEBRA I. Walter Feit.
MF 2.30-3.45 Not CR/D/F Meets RP IV(66)
A survey of algebraic constructions and theories at a sophisticated level. Topics include categorical language, free groups and other free objects in categories, general theory of rings and modules, artinian rings, introduction to homological algebra. *After Mathematics* 350a *and* 370b.

[*Mathematics* 381b[G], ALGEBRA II. 1995–96]

[*Mathematics* 400a, INTRODUCTION TO MATHEMATICAL MECHANICS. 1995–96]

[*Mathematics* 425b[G], COMPUTATIONAL ALGEBRAIC GEOMETRY. 1995–96]

[*Mathematics* 430b, AN INTRODUCTION TO ALGEBRAIC TOPOLOGY. 1995–96]

Mathematics 435b (49435), DIFFERENTIAL GEOMETRY.
Vincent Moncrief.
TTh 9-10.15 IV(21)
Applications of calculus to the study of the geometry of curves and surfaces in Euclidean space, intrinsic differential geometric properties of manifolds, and connections with non-Euclidean geometries and topology. *After Mathematics* 230 *or* 250a *or the equivalent.*

[*Mathematics* 454b[G], FOUNDATIONS OF LOGIC PROGRAMMING. 1995–96]

[*Mathematics* 456a[G], RECURSIVE FUNCTION THEORY. 1995–96]

Mathematics 470a *or* b (49470), INDIVIDUAL STUDIES. Consult the Director of Undergraduate Studies.
Not CR/D/F IV(0)
Individual investigation of an area of mathematics outside of those covered in regular courses, involving directed reading, discussion, and either papers or an examination. A written plan of study approved by the student's adviser and the Director of Undergraduate Studies is required. The course may normally be elected for only one term.

Mathematics 480a *or* b (49480), SENIOR SEMINAR: MATHEMATICAL TOPICS. Ilya Piatetski-Shapiro [F], Staff [Sp].
3 HTBA Not CR/D/F IV(50)
A number of mathematical topics chosen each term—e.g., differential topology, Lie algebras, mathematical methods in physics—and each explored in one section of the seminar. Students present several talks on the chosen topic. Fulfills the Senior requirement.

COURSES IN OTHER DEPARTMENTS THAT ARE PARTICULARLY RELEVANT TO THE MAJOR

Normally two of the following courses may, with the permission of the Director of Undergraduate Studies, be counted with Mathematics courses toward the requirements of the major.

Appl. Mathematics 333a/*E.&A.S.* 333a, METHODS IN APPLIED MATHEMATICS. Juozas Vaisnys.

Computer Science 201a *or* b, INTRODUCTION TO COMPUTER SCIENCE. Paul Hudak [F], Drew McDermott [Sp].

Computer Science 365b, DESIGN AND ANALYSIS OF ALGORITHMS. Jeffery Westbrook.

Computer Science 366a, MODELS OF COMPUTATION. Lenore Zuck.

Computer Science 440b[G], NUMERICAL COMPUTATION I. Vladimir Rokhlin.

E.&A.S. 194a *or* b, ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS WITH APPLICATIONS. Juozas Vaisnys [F], Leslie Smith [Sp].

E.&A.S. 396b, ADVANCED ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS WITH APPLICATIONS. Nicholas Read.

E.&A.S. 496a[G], PROBABILITY AND STOCHASTIC PROCESSES. Peter Schultheiss.

Operations Research 235a, OPTIMIZATION I. Eric Denardo.

Operations Research 237b, STOCHASTIC MODELS. Offer Kella.

GRADUATE COURSES OF INTEREST

Each year the departments of Mathematics and Statistics offer a large number of graduate courses, some of which are accessible to advanced undergraduates. Further information may be obtained from the respective Directors of Undergraduate Studies whose permission, together with that of the relevant Director of Graduate Studies, is required for admission.

MATHEMATICS AND PHILOSOPHY

This major allows students to explore those areas where philosophy and mathematics meet, in particular, mathematical and philosophical logic and the philosophy of mathematics.

The prerequisite for the major is Mathematics 120a or b. A total of twelve term courses in mathematics at the level of Mathematics 120a or b or higher and in philosophy is required. At least five of these should be in mathematics and at least five in philosophy. Required courses include Set Theory (Mathematics 270a), and Foundations of Logic Programming (Mathematics 454b) or Logical Theory I (Philosophy 204a), both of which *must* be taken before the end of the Junior year, although they should preferably be taken before that year. Required courses also include:

(1) either of the following:
  (a) Logical Theory II (Philosophy 205b),
  (b) Recursive Function Theory (Mathematics 456a);
(2) an advanced philosophy course (other than Philosophy 204a, 205b, or 210b‡), with a substantive logical component;
(3) one of the seminars designated as fulfilling the Senior requirement (see below).

Requirements (1) through (3) must be satisfied separately; however, a student may satisfy (2) and (3) by taking two designated seminars, provided at least one of them is in Philosophy.

Senior requirement. Each year certain seminars offered by the Mathematics and Philosophy departments are designated as fulfilling the Senior requirement of this major. Subjects covered in these seminars vary from year to year. A student who selects one of them to satisfy requirement (3) above will be expected to give a presentation within the seminar on a topic selected in consultation with the instructor. These seminars may be taken at any time after a student has completed Mathematics 120a.

The seminars fulfilling the Senior requirement for 1994–95 are Philosophy 430b, Non-Standard Set Theories; Philosophy 432a, Philosophy of Mathematics; and Mathematics 480a or b, Senior Seminar: Mathematical Topics.

A typical program satisfying the major might consist of:
Mathematics 120a or b, 222a or b, 270a, 350a, 454b, and designated seminar;
Philosophy 110a, 204a, 205b, 210b‡, and designated seminars with presentation.

Majors should consult as advisers Richard Beals, 220A LOM, 432-4176 [F], Walter Feit, 216 LOM, 432-7314 [Sp], and Paolo Mancosu, 201 SSS, 432-1693.

REQUIREMENTS OF THE MAJOR

Prerequisite: Math 120a or b
Number of Courses: 12 term courses (within which total the prerequisites and the Senior seminar are included)
Distribution of Courses: At least 5 in each subject
Specific Courses Required: Math 270a, Math 454b or Phil 204a, Math 456a or Phil 205b, and an advanced philosophy course with substantive logical component
Senior Requirement: Senior seminar

MATHEMATICS AND PHYSICS

A minimum of fourteen term courses in mathematics and physics above the Sophomore level is required, with at least six in each of the two subjects. A Senior essay, or a project from Physics 471a, 472b, on a topic appropriate for the combined major and acceptable to both the Physics and the Mathematics departments is also required. The student must present an oral report on this essay or project to the Mathematics department. Majors should consult Vincent Moncrief, 64 SPL, 432-6930.

‡Last offered in 1993–94.

REQUIREMENTS OF THE MAJOR

Prerequisites: Math 120a or b or 230 or equivalent; Phys 150a, 151b, 300a, or Phys 180a, 181b, 300a, or Phys 200a, 201b, 300a, or Phys 260a, 261b; Phys 166Lb, or the 205La or Lb, 206La or Lb laboratory sequence
Number of Courses: 14 term courses above Sophomore level (within which total the prerequisites are not included)
Distribution of Courses: At least 6 in each subject, Math at level 222 or above, Phys at level 380 or above
Specific Courses Required: None
Senior Requirement: Senior essay or project from Phys 471a, 472b on topic acceptable to Physics and Mathematics depts; oral report on essay or project to Mathematics dept

MECHANICAL ENGINEERING

Director of Undergraduate Studies: Mitchell Smooke, M4 ML, 432-4344

FACULTY OF THE DEPARTMENT OF MECHANICAL ENGINEERING

PROFESSORS
Robert Apfel (*Chair*)
Boa-Teh Chu
Juan Fernandez de la Mora
Marshall Long
E. Turan Onat
Dennis Rader (*Adjunct*)
Mitchell Smooke
Katepalli Sreenivasan

ASSOCIATE PROFESSORS
Alessandro Gomez
John Hack
Lisa Pfefferle

ASSISTANT PROFESSORS
Joseph Crisco
Gary Povirk
Leslie Smith

LECTURER
Nahum Orlev (*Visiting*)

Mechanical engineering is among the most diversified of the traditional engineering disciplines. The mechanical engineer builds machines to extend our physical and mental capabilities and to convert traditional and novel energy sources into useful forms for our use.

The role of the mechanical engineer has changed dramatically over the last two decades, with the extensive use of computers (in such areas as design, data acquisition, control, manufacturing), with the interfacing of mechanical sensors and actuators via microprocessors to measure and control (e.g., in robot control, optimization of automobile performance), and with the advent of new materials (composite, corrosion-resistant, ceramic, superconducting) for a variety of new applications (e.g., prosthetic devices, biomaterials, stealth aircraft). These new areas offer mechanical engineering students special opportunities for creativity, but also demand that they learn not only in depth but also in breadth. Demands for the increase in energy efficiency and in the reduction of environmental impact—as might be realized, for example, in novel gas turbine-electric hybrid vehicles—require that students understand the fundamentals of mechanics, thermodynamics, fluid mechanics, combustion, and materials science.

In all these tasks, the utmost consideration of the modern mechanical engineer is the improvement of the quality of human life. The engineer must be constantly aware both of the finiteness of the earth's resources and its environment and of the burden that engineering works place on the earth and its ecosystem.

The program in mechanical engineering is designed to provide a broad education in the foundations of the disciplines mentioned above, and to

prepare students both for graduate studies in these areas and for entry into appropriate positions in research laboratories, industry, or government, with possibilities for careers in engineering, medicine, law, or business. At Yale, three types of programs leading to a B.S. or B.A. degree may be taken: a B.S. degree program with a major in Mechanical Engineering, or a B.S. degree program with a major in Engineering Sciences (Mechanical), or a B.A. degree program with a major in Engineering Sciences (Mechanical). Prospective B.S. majors in both programs are advised to complete introductory physics and mathematics through calculus (Mathematics 115a or b) by the end of their first year.

A student's undergraduate engineering program usually culminates with one or more Special Project courses (Mechanical Engineering 471a, 472b) in which the student pursues a particular interest through design-oriented projects and experimental investigations. Projects may be initiated by the student himself, may be performed in a team, or may be derived from ideas of faculty members who place undergraduates in their ongoing research projects. More information is available from the Director of Undergraduate Studies or the Chair.

B.S. degree program in Mechanical Engineering. This is a rigorous curriculum accredited by the Accreditation Board of Engineering and Technology (ABET), which leads to a B.S. degree. Requirements of the program include successful completion of courses drawn from the following four general areas:

1. *Mathematics:* Mathematics 112a or b, 115a or b, 120a or b; E.&A.S. 394a or b; and one term course from E.&A.S. 393a, 395b, 396b, 496a, or Mathematics 222a or b. For *Structures*, Mathematics 222a or b or its equivalent is required.

2. *Basic Science:* Physics 200a, 201b (or 180a, 181b) and two laboratories (one from Physics 165La, 205La or Lb, and one from Physics 166Lb, 206La or Lb or equivalents), and at least one additional term course in chemistry (e.g., one term of Chemistry 115).

3. *Engineering Science:* Mech.Engineering 211b, 280a, 361a, 383a, 385b, 389b, and one computer science course (e.g., E.&A.S. 130b) approved by the Director of Undergraduate Studies, and

(a) one course chosen from Elec. Engineering 325b or E.&A.S. 245a
(b) one course chosen from Mech. Engineering 185b, 315b, 366a, 384b, 400a, 469b, or 485b
(c) one course chosen from Mech. Engineering 340a, 341b, 357a, 365b, 380b, 387a, 463b, or 486a
(d) one additional course chosen from the previous two categories or chosen in consultation with the Director of Undergraduate Studies.

4. *Engineering Design:* Mech. Engineering 286Lb, 363Lb, 471a or 472b, and 489a.

The curricula in this program are arranged in prescribed patterns, but some departures from them are possible with the approval of the Director of Undergraduate Studies.

B.S. degree program in Engineering Sciences (Mechanical). Students who intend to pursue mechanics but who wish to follow curricula that are less stringent than those specified above may earn a B.S. degree in the program of Engineering Sciences (Mechanical). There are essentially six term courses of prerequisites in mathematics and physics, which are Mathematics 112a or b, 115a or b, 120a or b, Physics 180a, 181b (or 200a,