

## 322 / Programs and Courses

- can work in multidisciplinary teams
- can appreciate professional and ethical responsibility and the importance of continued learning after graduation
- can communicate effectively
- have a basic understanding of the impact of engineering on society, including the economy and environment
- have an elementary understanding of contemporary issues in materials science and engineering

## University Requirements

See Undergraduate Studies section.

## College Requirements

See The Marlan and Rosemary Bourns College of Engineering, Colleges and Programs section.

The Materials Science and Engineering major uses the following major requirements to satisfy the college's Natural Sciences and Mathematics breadth requirement.

1. One course in the biological sciences chosen from an approved list
2. CHEM 001A, CHEM 001LA
3. MATH 008B or MATH 009A
4. PHYS 040A, PHYS 040B

## Major Requirements

1. Lower-division requirements (68 units)
  - a) CHEM 001A, CHEM 01LA, CHEM 001B, CHEM 01LB, CHEM 001C, CHEM 01LC
  - b) CS 030
  - c) EE 001A, EE 01LA
  - e) MATH 009A, MATH 009B, MATH 009C, MATH 010A, MATH 010B, MATH 046
  - d) ME 010
  - f) MSE 001
  - g) PHYS 040A, PHYS 040B, PHYS 040C
2. Upper-division requirements (52 units)
  - a) CHEM 112A
  - b) CEE 135
  - c) CHE 100
  - d) EE 138
  - e) ENGR 180
  - f) ME 110, ME 114, ME 156
  - g) MSE 160, MSE 161, MSE 175A, MSE 175B
  - h) STAT 155
  - i) Technical Electives (20 units): chosen from BIEN 140A/CEE 140A, BIEN 140B/CEE 140B, CEE 147, EE 133, EE 136, EE 137, EE 139, ME 113, ME 116, ME 138, ME 153, ME 180

Visit the Student Affairs Office in the College of Engineering or [student.engr.ucr.edu](http://student.engr.ucr.edu) for a sample program.

## Lower-Division Course

**MSE 001. Fundamentals of Materials Science and Engineering (2)** Lecture, 1 hour; discussion, 1 hour; laboratory, 1 hour. An introduction of properties and applications of different types of materials essential for various areas of engineering. Explores the relationship between structure and properties as well as processing of the materials. Illustrates a wide range of properties required for different types of applications. Graded Satisfactory (S) or No Credit (NC).

## Upper-Division Courses

**MSE 160. Nanostructure Characterization Laboratory (4)** Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): ME 114. Covers structure of materials at the nanoscale, including semiconductors, ceramics, metals, and carbon nanotubes. Explores relationships among morphology, properties, and processing. Addresses primary methods of characterization, including scanning electron microscopy, scanning probe microscopy, X-ray diffraction, and transmission electron microscopy. Also covers elementary discussions of X-ray, vibrational, and electron waves in solids and introductory diffraction theory.

**MSE 161. Analytical Materials Characterization (4)** Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): MSE 160. Analysis of the surfaces of materials via ion, electron, and photon spectroscopies. Includes Rutherford back scattering; secondary ion mass spectroscopy; electron energy loss spectroscopy; Auger electron spectroscopy; X-ray photoelectron spectroscopy; photoluminescence; extended X-ray absorption fine structure; Fourier transform infrared spectroscopy; and Raman spectroscopy. Also covers sputtering, high-vacuum generation, and focused ion beam milling.

**MSE 175A. Senior Design (4)** Lecture, 2 hours; discussion, 1 hour; practicum, 3 hours. Prerequisite(s): CHE 116 or ME 116A; EE 139; senior standing in Materials Science and Engineering. Covers preparation of formal engineering reports and statistical analysis on a series of problems illustrating methodology from various branches of applied materials science and engineering. Addresses the entire design process: design problem definition; generation of a design specification; documentation; design review process; prototype fabrication; testing and calibration; cost estimation; and federal guidelines. Requires a term project and oral presentation. Graded In-Progress (IP) until MSE 175A and MSE 175B are completed, at which time a final, letter grades is assigned.

**MSE 175B. Senior Design (4)** Lecture, 1 hour; discussion, 1 hour; practicum, 6 hours. Prerequisite(s): MSE 175A; senior standing in Materials Science and Engineering. Covers preparation of formal engineering reports and statistical analysis on a series of problems illustrating methodology from various branches of applied materials science and engineering. Addresses the entire design process: design problem definition; generation of a design specification; documentation; design review process; prototype fabrication; testing and calibration; cost estimation; and federal guidelines. Requires a term project and oral presentation. Satisfactory (S) or No Credit (NC) grading is not available.

## Mathematics

**Subject abbreviation: MATH**  
**College of Natural and Agricultural Sciences**

Vijayanthi Chari, Ph.D., Chair  
Department Office, 202 Surge Building  
(951) 827-3113; [www.math.ucr.edu](http://www.math.ucr.edu)

### Professors

John C. Baez, Ph.D.  
Mei-Chu Chang, Ph.D.  
Vijayanthi Chari, Ph.D.  
Gerhard Gierz, Ph.D.  
Michel L. Lapidus, Ph.D.  
Yat Sun Poon, Ph.D.  
Ziv Ran, Ph.D.  
Malempati M. Rao, Ph.D.  
David E. Rush, Ph.D.  
Reinhard Schultz, Ph.D.  
Bun Wong, Ph.D.  
Feng Xu, Ph.D.  
Qi S. Zhang, Ph.D.

### Professors Emeriti

Theodore J. Barth, Ph.D.  
Richard E. Block, Ph.D.  
Bruce L. Chalmers, Ph.D.  
John E. de Pillis, Ph.D.  
Neil E. Gretsky, Ph.D.  
Lawrence H. Harper, Ph.D.  
Frederic T. Metcalf, Ph.D.  
J. Keith Oddson, Ph.D.  
Louis J. Ratliff, Jr., Ph.D.  
Victor L. Shapiro, Ph.D.  
James D. Stafney, Ph.D.  
Albert R. Stralka, Ph.D.

### Associate Professors

Le Baron O. Ferguson, Ph.D.  
Zhang-Dan Guan, Ph.D.  
Frederick H. Wilhelm, Jr., Ph.D.  
Stefano Vidussi, Ph.D.

### Assistant Professors

Marta Asaeda, Ph.D.  
Julia Bergner, Ph.D.  
Vasily Dolgushev, Ph.D.  
Wee Liang Gan, Ph.D.  
Jacob Greenstein, Ph.D.  
James Kelliher, Ph.D.

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### Cooperating Faculty

Bai-Lian "Larry" Li, Ph.D. (Botany and Plant Sciences)

## Major

The Department of Mathematics offers a B.A. and B.S. degree in programs that share a common, solid mathematical foundation but differ in their specializations in the pure and applied areas of mathematics. These programs can provide the basis for careers in mathematics itself or within the many scientific and business fields, which, in today's technological society, depend on a basic knowledge of mathematical methods.

The **B.A. in Mathematics**, following the liberal arts tradition, combines a broad coverage of the humanities and social sciences with a moderate amount of advanced mathematics in the major. It is selected most often either by students who intend to obtain a teaching credential with a specialty in mathematics or by students who wish to pursue graduate work in business or the social sciences.

The **B.S. in Mathematics** is more technical and contains a greater concentration of work in the major field. The Pure Mathematics program is directed toward students who may wish to pursue graduate work in mathematics. The Applied Mathematics programs, with options in Biology, Chemistry, Economics, Environmental Sciences, Physics, and Statistics, are designed to provide a rigorous training in mathematics together with a substantial background in the discipline of the option. The Computational Mathematics program is designed to prepare the student for professional work with computers and computer systems and for graduate work in computer science.

The **B.S. in Mathematics for Secondary Teachers** is intended for students planning to pursue a career in secondary education. Its courses cover the high school curriculum from an advanced perspective. Students are required to complete mathematics education and education courses in order to facilitate presence in the classroom early in their undergraduate career and to better prepare them for entry in a credential program.

### Academic Advising

Each Mathematics major is assigned a faculty advisor who assists the student in formulating educational goals and monitors the student's subsequent progress in an academic program. Each quarter a study list must be approved by this advisor. Advising for all math majors is conducted by the CNAS Academic Advising Center in 1223 Pierce Hall.

### Teaching Credential

Teachers in the public schools in California must have a credential approved by the State Commission on Teacher Credentialing. The credential requires an undergraduate major, baccalaureate degree, and completion of a graduate credential program such as that offered by the Graduate School of Education at UCR (see Education in this catalog). The Bachelor of Science in Mathematics for Secondary Teachers assists students in their preparation to face the challenges of a credentialing program.

Before admission and student teaching in a graduate credential program, the candidate must pass the California Basic Education Skills Test (CBEST) and demonstrate subject-matter proficiency in the fields which the candidate will teach. The candidate can demonstrate proficiency either by passing the commission's subject-matter assessment examination or completing an undergraduate program that is state approved for teacher preparation.

**California Teach-Science/Mathematics Initiative (CaTEACH-SMI)** California Teach-Science Mathematics Initiative (CaTEACH-SMI) has a goal of addressing the critical need of highly qualified K-12 science and mathematics teachers in California. With an economy increasingly reliant on science, technology, engineering, and mathematics (STEM) and the anticipated large scale retirement of qualified teachers, this is an essential time to explore and prepare for a career in teaching science or mathematics.

CaTEACH-SMI at UCR offers undergraduate students paid/unpaid opportunities to explore STEM teaching as a career option. Through CaTEACH-SMI, students receive advising and mentoring to prepare for entrance into an intern teaching credential program while diligently coordinating with academic advisors to ensure completion of STEM degree requirements. The CaTEACH-SMI Resource Center provides future STEM teachers with material and financial resources to promote planning and professional development towards a science/mathematics education career.

For more information about the CaTEACH-SMI program, please visit <http://smi.ucr.edu> or at the Resource Center at 1104 Pierce Hall.

### University Requirements

See Undergraduate Studies section.

### College Requirements

See College of Natural and Agricultural Sciences, Colleges and Programs section.

### Major Requirements for the Bachelor of Arts and Bachelor of Science in Mathematics

To fulfill the Natural Sciences requirement, the Department of Mathematics requires the following:

- One of the year sequences
  - BIOL 002, BIOL 003, BIOL 005C
  - CHEM 001A, CHEM 001B, CHEM 001C, CHEM 011A, CHEM 011B, CHEM 011C,
  - PHYS 002A, PHYS 002B, PHYS 002C or PHYS 040A, PHYS 040B, PHYS 040C
- Either one course in the physical sciences listed above if (a) above is completed or one course in the biological sciences if (b) or (c) above is completed

The major requirements for the B.A. and B.S. degrees in Mathematics are as follows:

#### For the Bachelor of Arts

- Lower-division requirements: MATH 008B or MATH 009A, MATH 009B, MATH 009C, MATH 010A, MATH 010B, MATH 046
- Four (4) units of either CS 010 or one upper-division course in Statistics
- A minimum of 36 units of upper-division mathematics, excluding courses in the MATH 190–199 series

#### For the Bachelor of Science

Lower-division requirements for all programs are MATH 008B or MATH 009A, MATH 009B, MATH 009C, MATH 010A, MATH 010B, MATH 046, CS 010 (CS 012 is recommended).

- Pure Mathematics program** (56 units)
  - Thirty-six (36) units of upper-division mathematics to include at least 24 units from MATH 131, MATH 132, MATH 145A, MATH 145B, MATH 151A, MATH 151B, MATH 151C, MATH 171, MATH 172

- At least three courses from (a) above must be from MATH 145A, MATH 145B, MATH 151A, MATH 151B, MATH 151C
- Courses in the MATH 190–199 series are excluded
- Twenty (20) additional units of upper-division mathematics, upper-division computer science, or other related courses approved by the undergraduate advisor (For students who wish to pursue graduate work, courses in complex variables, differential equations, and probability may be particularly useful.)

#### 2. Applied Mathematics programs

MATH 113 or MATH 131, MATH 132, MATH 146A, MATH 146B, MATH 146C and the courses in one of the following options:

- Biology option
  - BIOL 005A, BIOL 051A, BIOL 005B, BIOL 005C
  - MATH 149A
  - Three courses from MATH 120, MATH 121, MATH 135A, MATH 135B, MATH 149B, MATH 149C
  - BIOL 102, BIOL 105, BIOL 108, BIOL 117
  - Four (4) additional units of upper-division biology
- Chemistry option
  - CHEM 001A, CHEM 001B, CHEM 001C, CHEM 011A, CHEM 011B, CHEM 011C
  - Either PHYS 040A, PHYS 040B, PHYS 040C (preferred); or PHYS 002A, PHYS 002B, PHYS 002C
  - Four courses from MATH 120, MATH 135A, MATH 135B, MATH 149A, MATH 149B, MATH 149C, MATH 165A, MATH 165B
  - CHEM 110A, CHEM 110B, CHEM 111, CHEM 113
  - Four (4) additional units of upper-division chemistry
- Economics option
  - MATH 120, MATH 121, MATH 149A, MATH 149B, MATH 149C
  - Five upper-division economics courses (at least 20 units) to consist of ECON 102A and four courses to be chosen from ECON 102B, ECON 103A, ECON 103B, ECON 107, ECON 108, ECON 110, ECON 111, ECON 134/BUS 106, ECON 135, ECON 143A/ENSC 143A, ECON 143B/ENSC 143B, ECON 143C/ENSC 143C, ECON 156, ECON 206
- Environmental Sciences option
  - CHEM 001A, CHEM 001B, CHEM 001C, CHEM 011A, CHEM 011B, CHEM 011C

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- (2) ECON 006/ENSC 006
  - (3) GEO 001 is recommended
  - (4) MATH 149A
  - (5) Three courses from MATH 120, MATH 121, MATH 135A, MATH 135B, MATH 149B, MATH 149C, CS 177, STAT 155
  - (6) ENSC 100/SWSC 100, ENSC 101, ENSC 102
  - (7) Eight (8) additional units of upper-division environmental sciences
- e) Physics option
- (1) MATH 135A, MATH 165A, MATH 165B
  - (2) Either MATH 120 or MATH 171
  - (3) PHYS 130A, PHYS 130B
  - (4) Either PHYS 135A, PHYS 135B, PHYS 136 or PHYS 156A, PHYS 156B
- f) Statistics option
- (1) MATH 120, MATH 149A, MATH 149B, MATH 149C
  - (2) Either STAT 130 or STAT 146
  - (3) STAT 161, STAT 170A, STAT 170B, STAT 171
3. **Computational Mathematics** program
- a) MATH 011/CS 011, MATH 113 or MATH 131, MATH 120, MATH 132, MATH 135A, MATH 135B
  - b) CS 012, CS 014, CS 141, CS 150
  - c) One additional CS course to be chosen from the list of approved technical elective courses.
  - d) Twenty-four (24) units of technical electives to be chosen from
    - (1) MATH 111/CS 111, MATH 121, MATH 126, MATH 146A, MATH 146B, MATH 146C, MATH 149A, MATH 149B, MATH 149C, MATH 171
    - (2) CS 130, CS 133, CS 166, CS 170, CS 177

### Major Requirements for the Bachelor of Science in Mathematics for Secondary School Teachers

- 1. Lower-division Mathematics requirements (24 units)  
MATH 009A, MATH 009B, MATH 009C, MATH 010A, MATH 010B, MATH 046
- 2. Upper-division Mathematics requirements (36 units)
  - a. MATH 131, MATH 133, MATH 140, MATH 144, MATH 153
  - b. MATH 150A or MATH 151A
  - c. Three courses from: MATH 132, MATH 136, MATH 137, MATH 138A, MATH 145A, MATH 145B, MATH 149A, MATH 149B, MATH 149C, MATH 150B, MATH 151B, MATH 151C, MATH 171, MATH 172

- 3. Additional Mathematics and related disciplines requirements (12 units)
  - a. CS 010
  - b. CS 011/MATH 011
  - c. STAT 155
- 4. Natural Sciences (16-20 units)
  - a. BIOL 002 or BIOL 003 or BIOL 005A and BIOL 05LA
  - b. CHEM 001A and CHEM 01LA or CHEM 001HA and CHEM 1HLA
  - c. PHYS 002A or PHYS 040A
  - d. CHEM 001B and CHEM 01LB or CHEM 001HB and CHEM 1HLB or PHYS 002B or PHYS 040B or an additional laboratory Biological science course
- 5. Social Sciences (16 units)
  - a. One course in ECON or POSC
  - b. One course in ANTH
  - c. One course in PSYC
  - d. One course in SOC
- 6. Mathematics Education and Education requirements (18 or 19 units):  
EDUC 104/MATH 104, EDUC 003 or EDUC 004 or EDUC 100B or equivalent, EDUC 109, EDUC 110, EDUC 139
- 7. Recommended Courses  
LING 020 or LING 021, EDUC 116, EDUC 174, EDUC 177A

### Mathematics Honors Program

Candidates for the Honors Program in Mathematics must complete

- 1. Earn an overall GPA of at least 3.50 in Mathematics.
- 2. Earn a grade of "B" or better in each of MATH 151A, MATH 151B and MATH 151C.
- 3. Earn a grade of "B" or better in each of MATH 145B and MATH 171 OR in each of MATH 146A, MATH 146B and MATH 146C OR in each of MATH 149A, MATH 149B and MATH 149C.
- 4. Satisfactorily complete one of the following:
  - i) A research project earning a grade of "A" in MATH 197.
  - ii) Two courses chosen from one of the sequences: MATH 201A, 201B, 201C; MATH 205A, MATH 205B, MATH 205C; MATH 209A, MATH 209B, MATH 209C; MATH 210A, MATH 210B with a grade of "B" or better in each course.

It is the responsibility of the honors candidates to notify the department of their eligibility.

### Minor

The following are the requirements for a minor in Mathematics.

- 1. Lower-division courses (20 units):  
MATH 008B or MATH 009A, MATH 009B, MATH 009C, MATH 010A, MATH 010B
- 2. Upper-division requirements: 24 units of upper-division mathematics courses. Of the specified upper-division units, a minimum

of 16 must be unique to the minor and may not be used to satisfy major requirements and no more than 4 units in courses numbered 190–199.

Students with a minor in Mathematics should consult with a faculty advisor in Mathematics to construct a specific program consistent with their goals.

See Minors under the College of Natural and Agricultural Sciences in the Colleges and Programs section of this catalog for additional information on minors.

### Education Abroad Program

The EAP is an excellent opportunity to travel and learn more about another country and its culture while taking courses to earn units toward graduation. Students should plan study abroad well in advance to ensure that the courses taken fit with their overall program at UCR. Consult the departmental student affairs officer for assistance. For further details visit UCR's International Education Center at [internationalcenter.ucr.edu](http://internationalcenter.ucr.edu) or call (951) 827-4113.

See Education Abroad Program under International Education Center in the Student Services section of this catalog. A list of participating countries is found under Education Abroad Program in the Programs and Courses section. Search for programs by specific areas at [eap.ucop.edu/programwizard](http://eap.ucop.edu/programwizard).

### Graduate Programs

The Department of Mathematics offers the M.A., M.S., and Ph.D. degrees in Mathematics.

**Admission** Domestic applicants must supply GRE General Test scores (verbal, quantitative, and analytical).

### M.A. or M.S. in Mathematics

General university requirements are listed in the Graduate Studies section of this catalog. Specific requirements are as follows:

- 1. Completion of two of the following sequences: MATH 201A, MATH 201B, MATH 201C; MATH 205A, MATH 205B, MATH 205C; MATH 209A, MATH 209B, MATH 209C; or MATH 210A, MATH 210B, with a grade of "C" or better in each course and a GPA of 3.00 in each chosen sequence
- 2. As a substitute for one or more course sequences in (1), passing a Ph.D. qualifying examination fulfills the course requirement of the corresponding sequence
- 3. Taking 36 units of courses approved by the Mathematics Graduate Committee, of which at least 18 must be in the 200 series courses in Mathematics (MATH 260 cannot be used without the Mathematics Graduate Committee's approval.)
- 4. Completion of the courses MATH 131, MATH 132, MATH 151A, and MATH 151B, or their equivalents

## M.S. in Mathematics (Applied)

General university requirements are listed in the Graduate Studies section of this catalog. Specific requirements are as follows:

1. Passing written qualifying examinations at the master's level (or higher) in two of the following fields: Advanced Ordinary Differential Equations, Partial Differential Equations, Advanced Statistical Inference, Calculus of Variations, Combinatorial Theory, Real Analysis, and Advanced Numerical Analysis
2. Thirty-six (36) units of approved courses, of which 18 must be in the 200 series (MATH 260 cannot be used without the Mathematics Graduate Committee's approval.)
3. Completion of the courses MATH 131, MATH 132, MATH 151A, MATH 151B, MATH 146A, MATH 149A, or their equivalent. Also, MATH 165A is recommended, but not required

## Doctoral Degree

The Department of Mathematics offers the Ph.D. degree in Mathematics.

Specific requirements are as follows:

1. Passing the introductory courses in algebra (MATH 201A, MATH 201B, MATH 201C), complex analysis (MATH 210A, MATH 210B), real analysis (MATH 209A, MATH 209B, MATH 209C), and topology/differentiable manifolds (MATH 205A, MATH 205B, MATH 205C)
2. Passing at least three of the four qualifying examinations in algebra, complex analysis, real analysis and topology/differentiable manifolds with a grade of "A." The fourth of the above qualifying examinations must be passed with a grade of "B" or better; a student is allowed to take the qualifying examination at most twice in each area
3. Completing four quarter-courses in mathematics numbered between 211 and 259

**Normative Time to Degree** 15 quarters

## Lower-Division Courses

*Mathematics advisory examinations are scheduled before each quarter. The UCR Mathematics Advisory Exam is a prerequisite for students who wish to enroll in math courses but have not received course equivalence in MATH 005, MATH 008A, MATH 008B, MATH 009A, MATH 015, MATH 022, or MATH 023.*

**MATH 004. Introduction to College Mathematics for Business and the Social Sciences (5)** Lecture, 5 hours. Prerequisite(s): a sufficiently high score on the Mathematics Advisory Examination, as determined by the Mathematics Department. Not open to students in the Bourns College of Engineering or the College of Natural and Agricultural Sciences or to students majoring in Economics or Business Economics. Covers functions and their graphs, including linear and polynomial functions, zeroes, and inverse functions as well as exponential, logarithmic, and trigonometric functions and their inverses. Also includes

counting, including elementary probability. Involves applications to business and social sciences. Credit is awarded for only one of MATH 004, MATH 005, or MATH 008A.

**MATH 005. Precalculus (5)** Lecture, 5 hours. Prerequisite(s): a sufficiently high score on the Mathematics Advisory Examination, as determined by the Mathematics Department. A study of inequalities, absolute value, functions, graphing, logarithms, trigonometry, roots of polynomials, counting, vectors, and other elementary concepts of mathematics. Credit is awarded for only one of MATH 004, MATH 005, or MATH 008A.

**MATH 005P. MATH 005 Support Practicum (1)** Practicum, 2-4 hours; individual study, 2-4 hours. Prerequisite(s): Students must be enrolled in UCR's Summer Bridge MATH 005 program. Covers understanding course content and developing thinking and problem-solving skills. Introduces university life through exposure to test-taking techniques, effective note-taking strategies, time management, and university procedures and practices. Offered in summer only. Graded Satisfactory (S) or No Credit (NC).

**MATH 008A. Introduction to College Mathematics for the Sciences (5)** Lecture, 5 hours. Prerequisite(s): a sufficiently high score on the Mathematics Advisory Examination, as determined by the Mathematics Department. Covers functions and their graphs, including linear and polynomial functions, zeroes, and inverse functions as well as exponential, logarithmic and trigonometric functions and their inverses. Also includes counting, including elementary probability. Involves applications to the natural sciences and engineering. Credit is awarded for only one of MATH 004, MATH 005, or MATH 008A.

**MATH 008B. Introduction to College Mathematics for the Sciences (5)** Lecture, 5 hours. Prerequisite(s): MATH 008A with a grade of "C-" or better or a sufficiently high score on the Mathematics Advisory Examination, as determined by the Mathematics Department. Not intended for students who have been awarded a grade of "C-" or better in MATH 005. Involves further study of trigonometry and analytic geometry. Introduction to the differential calculus of functions of a single variable. Credit is awarded for only one of MATH 008B, MATH 009A, or MATH 09HA.

**MATH 009A. First-Year Calculus (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 005 with a grade of "C-" or better or equivalent. Introduction to the differential calculus of functions of one variable. Credit is awarded for only one of MATH 008B, MATH 009A, or MATH 09HA.

**MATH 009B. First-Year Calculus (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 008B with a grade of "C-" or better or MATH 009A with a grade of "C-" or better or MATH 09HA with a grade of "C-" or better. Introduction to the integral calculus of functions of one variable. Credit is awarded for only one of MATH 009B or MATH 09HB.

**MATH 009C. First-Year Calculus (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009B with a grade of "C-" or better or MATH 09HB with a grade of "C-" or better. Further topics from integral calculus, improper integrals, infinite series, Taylor's series, and Taylor's theorem. Credit is awarded for only one of MATH 009C or MATH 09HC.

**MATH 09HA. First-Year Honors Calculus (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): a sufficiently high score on the placement examination, as determined by the Mathematics Department. Honors course corresponding to MATH 009A for students with strong mathematical backgrounds. Introduces the

differential calculus of functions of one variable. Emphasis is on theory and rigor. Credit is awarded for only one of MATH 008B, MATH 009A, or MATH 09HA.

**MATH 09HB. First-Year Honors Calculus (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): a score of 3 or higher on the AB Advanced Placement Test in Mathematics or MATH 09HA with a grade of "B" or better. Honors course corresponding to MATH 009B for students with strong mathematical backgrounds. Introduces the integral calculus of functions of one variable. Emphasis is on theory and rigor. Credit is awarded for only one of MATH 009B or MATH 09HB.

**MATH 09HC. First-Year Honors Calculus (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 09HB with a grade of "B" or better. Honors course corresponding to MATH 009C for students with strong mathematical backgrounds. Covers further topics from integral calculus, improper integrals, infinite series, Taylor's series, and Taylor's theorem. Emphasis is on theory and rigor. Credit is awarded for only one of MATH 009C or MATH 09HC.

**MATH 010A. Calculus of Several Variables (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009B with a grade of "C-" or better or MATH 09HB with a "C-" or better or equivalent. Topics include Euclidean geometry, matrices and linear functions, determinants, partial derivatives, directional derivatives, Jacobians, gradients, chain rule, and Taylor's theorem for several variables.

**MATH 010B. Calculus of Several Variables (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A with a grade of "C-" or better or equivalent. Covers vectors; differential calculus, including implicit differentiation and extreme values; multiple integration; line integrals; vector field theory; and theorems of Gauss, Green, and Stokes.

**MATH 011. Introduction to Discrete Structures (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009A or MATH 09HA; CS 010 or MATH 009B or MATH 09HB. Introduction to basic concepts of discrete mathematics with emphasis on applications to computer science. Topics include propositional and predicate calculi, elementary set theory, functions, relations, proof techniques, elements of number theory, enumeration, and discrete probability. Cross-listed with CS 011.

**MATH 015. Contemporary Mathematics for the Humanities, Arts, and Social Sciences (4)** Lecture, 3 hours; discussion, 1 hour. Designed to fulfill the breadth requirement for students in the humanities, arts, and social sciences. Illustrates the interaction of mathematics with other subject areas through the study of selected topics of contemporary mathematics. Topics are chosen from discrete mathematics, counting and probability, and the interaction between algebra and geometry.

**MATH 022. Calculus for Business (5)** Lecture, 3 hours; discussion, 2 hours. Prerequisite(s): a sufficiently high score on the placement examination, as determined by the Mathematics Department, or MATH 004 with a grade of "C-" or better or MATH 005 with a grade of "C-" or better or MATH 008A with a grade of "C-" or better. Explores relations and functions (e.g. linear, polynomial, logarithmic, and exponential). Addresses differential calculus of functions of one and two variables, as well as integration (indefinite and definite) with applications to business and economic problems. Credit is not awarded for MATH 022 if a grade of "C-" or better has already been awarded for MATH 008B, MATH 009A, or MATH 09HA.

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**MATH 023. Applied Matrix Algebra (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): a sufficiently high score on the placement examination, as determined by the Mathematics Department, or MATH 004 with a grade of "C-" or better or MATH 005 with a grade of "C-" or better or MATH 008A with a grade of "C-" or better or MATH 009A with a grade of "C-" or better or MATH 09HA with a grade of "C-" or better or MATH 022 with a grade of "C-" or better. A study of matrix operations, linear dependence and independence, ranks and inverses, systems of linear equations, determinants, eigenvalues, and eigenvectors with business and economic applications. Designed for students who are not Mathematics majors.

**MATH 046. Introduction to Ordinary Differential Equations (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009B with a grade of "C-" or better or MATH 09HB with a grade of "C-" or better or equivalent. Introduction to first-order equations, linear second-order equations, and Laplace transforms, with applications to the physical and biological sciences.

## Upper-Division Courses

*Courses numbered MATH 100–109 do not meet upper-division mathematics requirements.*

**MATH 104. Mathematics Education (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): sophomore, junior, or senior standing. Examines contemporary instructional strategies relating to mathematics education. Includes thinking skills and problem solving strategies applicable to number theory, logic patterns and functions, statistics, probability, and geometry and algebra. Cross-listed with EDUC 104.

**MATH 111. Discrete Structures (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 010; CS 011/MATH 011; MATH 009C or MATH 09HC. Study of discrete mathematical structures with emphasis on applications to computer science. Topics include asymptotic notation, generating functions, recurrence equations, elements of graph theory, trees, algebraic structures, and number theory. Cross-listed with CS 111.

**MATH 112. Finite Mathematics (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009A or MATH 09HA; CS 010 or MATH 009B or MATH 09HB. Introduction to the basic concepts of finite and structural mathematics with emphasis on applications to computer science. Topics include axiomatic systems, combinatorics, propositional and predicate calculi, graph theory, trees, state diagrams, networks, induction, elementary enumeration, and recurrence relations.

**MATH 113. Applied Linear Algebra (5)** Lecture, 3 hours; discussion, 2 hours. Prerequisite(s): concurrent enrollment in or completion of MATH 010A. Study of matrices and systems of linear equations, determinants, Gaussian elimination and pivoting, vector spaces, linear independence and linear transformation, orthogonality, eigenvalues, and eigenvectors. Also examines selected topics and applications. Integrates numerical linear algebra and extensive computer use with these topics. Credit is awarded for only one of MATH 113 or MATH 131.

**MATH 120. Optimization (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A; MATH 113 or MATH 131 (may be taken concurrently). Introduction to classical optimization, including unconstrained and constrained problems in several variables, Jacobian and Lagrangian methods, and the Kuhn-Tucker conditions. Covers the basic concepts of linear programming, including the simplex method and duality, with applications to other subjects.

**MATH 121. Game Theory (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A. Games in extensive, normal, and characteristic form as models of conflict and/or cooperation. Two-person zero-sum games, minimax theorem, relation to linear programming. Non-zero-sum games, Nash equilibrium theorem, bargaining, the core, Shapley value. Economic market games.

**MATH 126. Combinatorics (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 111/MATH 111. A study of elements of combinatorics theory. Topics include chromatic polynomials, enumerating partitions of sets and integers, asymptotic enumeration, Polya theory, and Ramsey theory.

**MATH 131. Linear Algebra I (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): concurrent enrollment in or completion of MATH 010A. An introduction to vector spaces, matrices, and linear transformations. Credit is awarded for only one of MATH 113 or MATH 131.

**MATH 132. Linear Algebra II (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 113 with a grade of "C-" or better or MATH 131 with a grade of "C-" or better or equivalent. Further study of topics in linear algebra, including eigenvalues. Exploration of Hermitian and unitary matrices, positive definite matrices, and canonical forms.

**MATH 133. Geometry (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 113 or MATH 131 or consent of instructor. Elementary theory of affine and projective planes, the line at infinity, finite geometries, Euclidean and non-Euclidean geometries, groups of transformations, and other algebraic structures related to geometry.

**MATH 135A. Numerical Analysis (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 010 or equivalent; MATH 113 or MATH 131 (may be taken concurrently). A study of numerical methods for determining solutions to nonlinear equations and simultaneous linear equations. Topics also include interpolation, techniques of error analysis, and computer applications.

**MATH 135B. Numerical Analysis (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 010; MATH 113 or MATH 131; MATH 135A. Continuation of MATH 135A. Explores numerical methods, numerical integration, and the numerical solution of ordinary differential equations.

**MATH 136. Introduction to the Theory of Numbers (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 113 or MATH 131. Prime and composite integers, number theoretic functions, diophantine equations, congruences, quadratic reciprocity, additive arithmetic.

**MATH 137. Plane Curves (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 113 or MATH 131; MATH 171 and MATH 172 are recommended. A study of the complex projective plane, homogeneous polynomials, plane curves, intersection multiplicities, and Bezout's theorem.

**MATH 138A. Introduction to Differential Geometry (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 113 or MATH 131. Elementary theory of curves and surfaces. First and second fundamental forms.

**MATH 138B. Introduction to Differential Geometry (4) S** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 138A. Gaussian curvature; geodesics; Gauss-Bonnet Theorem.

**MATH 140. Polynomials and Number Systems (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 011/MATH 011; MATH 113 or MATH 131. Topics include number systems, elementary number theory, rings, fields, polynomials, congruencies, and applications of finite fields.

**MATH 141. Fractal Geometry with Applications (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 046, completion of or concurrent enrollment in MATH 144; or consent of instructor. Covers classical fractals, fractal dimensions, self-similar fractals, fractal curves and sets, random fractals, chaotic dynamics and fractals, iteration theory: Julia set and the Mandelbrot set. Also covers the beauty of fractals, mathematical description of irregular shapes (clouds, trees, coastlines, mountains, galaxies, lungs, snowflakes), and applications to physics, engineering, biology and computer graphics

**MATH 144. Introduction to Set Theory (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A. Algebra of subsets of a set. Algebra of relations and functions. Cardinal and ordinal numbers and their arithmetic operations. The well-ordering theorem, transfinite induction, and Zorn's lemma.

**MATH 145A. Introduction to Topology (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 144. Elementary topology in metric spaces.

**MATH 145B. Introduction to Topology (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 145A. Geometric topology, algebra associated with finite complexes and applications.

**MATH 146A. Ordinary and Partial Differential Equations (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009C or MATH 09HC; MATH 010A; MATH 131 (may be taken concurrently) or MATH 113 (may be taken concurrently) or equivalent; MATH 046 is recommended. Focuses on the theory of linear differential equations and transform methods.

**MATH 146B. Ordinary and Partial Differential Equations (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 131, MATH 146A. Further study of the theory of linear differential equations and problems in valuing ordinary differential equations.

**MATH 146C. Ordinary and Partial Differential Equations (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 146B. Explores boundary value problems for partial differential equations, orthogonal expansions, and separation of variables.

**MATH 147. Introduction to Fourier Analysis and Its Applications (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009C or MATH 09HC; MATH 010B; MATH 046 or MATH 146A; MATH 113 or MATH 131 (MATH 113 or MATH 131 may be taken concurrently). Covers Fourier series expansions of periodic functions, properties, and convergence; the Dirichlet kernel; Fourier integrals and the Fourier transform in one and several variables; the Plancherel theorem; and Fourier inversion. Includes applications of Fourier analysis (e.g., to spectral theory, numerical analysis, ordinary and partial differential equations, and wavelet transform).

**MATH 149A. Probability and Mathematical Statistics (4)** Lecture, 3 hours; laboratory, 1 hour. Prerequisite(s): MATH 010A, MATH 010B, completion of or concurrent enrollment in MATH 046. An introduction to the mathematical theory of probability and discrete and continuous distributions. Credit is awarded for only one of the MATH 149A, MATH 149B, and MATH 149C or STAT 160A, STAT 160B, and STAT 160C sequences.

**MATH 149B. Probability and Mathematical**

**Statistics (4)** Lecture, 3 hours; laboratory, 1 hour. Prerequisite(s): MATH 010A, MATH 010B, MATH 046, MATH 149A. Continuation of MATH 149A. Topics include sampling and limit distributions. Credit is awarded for only one of the MATH 149A, MATH 149B, and MATH 149C or STAT 160A, STAT 160B, and STAT 160C sequences.

**MATH 149C. Probability and Mathematical**

**Statistics (4)** Lecture, 3 hours; laboratory, 1 hour. Prerequisite(s): MATH 010A, MATH 010B, MATH 046, MATH 149A, MATH 149B. Continuation of MATH 149B. Topics include tests of hypotheses, estimation, maximum likelihood techniques, regression, and correlation. Credit is awarded for only one of the MATH 149A, MATH 149B, and MATH 149C or STAT 160A, STAT 160B, and STAT 160C sequences.

**MATH 150A. Intermediate Analysis (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009C or MATH 09HC; MATH 010B; MATH 144; or consent of instructor. A study of the concepts and theory of single-variable calculus. Covers sequences through the fundamental theorem of calculus. Introduces sequences and series, continuity, differentiation, and integration. Credit is awarded for only one of MATH 150A or MATH 151A.

**MATH 150B. Intermediate Analysis (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 131; MATH 150A or MATH 151A. MATH 132 is recommended. A study of infinite series and multivariable advanced calculus. Credit is awarded for only one of MATH 150B or MATH 151B.

**MATH 151A. Advanced Calculus (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 046, MATH 145A; or consent of instructor. Addresses the development of mathematical analysis. Also covers real and complex numbers, sequences and series, continuity, differentiation, and the Riemann-Stieltjes integral. Credit is awarded for only one of MATH 150A or MATH 151A.

**MATH 151B. Advanced Calculus (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 151A or consent of instructor. Continuation of MATH 151A. Topics include sequences and series of functions, as well as functions of several variables. Credit is awarded for only one of MATH 150B or MATH 151B.

**MATH 151C. Advanced Calculus (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A, MATH 010B, MATH 046, MATH 145A, MATH 151A, MATH 151B; or consent of instructor. Continuation of MATH 151B. Further study of several variables, integration of differential forms, and Lebesgue integration.

**MATH 153. History of Mathematics (4)** Lecture, 3 hours; discussion, 1 hour, or term paper, 3 hours. Prerequisite(s): MATH 009C or consent of instructor. A survey from a historical point of view of various developments in mathematics with particular emphasis on the nineteenth and early twentieth centuries.

**MATH 165A. Introduction to Complex Variables (4)**

Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B. An introduction to the theory of analytic functions of a complex variable. Includes mappings by elementary functions, complex integrals, as well as Cauchy's theorem, power series, and Laurent series.

**MATH 165B. Introduction to Complex Variables (4)**

Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 165A. Topics include the theory of residues, conformal mapping, and applications to physical problems.

**MATH 171. Introduction to Modern Algebra (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 131, MATH 144. An introduction to the fundamental concepts of modern algebra: groups, subgroups, quotient groups, homomorphisms, symmetry groups, fundamental properties of rings, integral domains, ideals, and quotient rings.

**MATH 172. Modern Algebra (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 171. Fundamental concepts of modern algebra: groups, fields, polynomials, geometric constructions, algebraic coding, boolean algebras.

**MATH 190. Special Studies (1-5)** To be taken with the consent of the chair of the department as a means of meeting special curricular problems. Course is repeatable.

**MATH 194. Independent Reading (1-2)** Independent reading in materials not covered in course work. Normally taken in the senior year. Total credit for MATH 194 may not exceed 4 units.

**MATH 197. Research for Undergraduates (1-4)** Outside research, 3-12 hours. Prerequisite(s): upper-division standing; consent of instructor. Involves a research project on a problem in, or related to, mathematics conducted under the supervision of a Mathematics faculty member. Students who submit a term paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable to a maximum of 8 units.

**MATH 198-I. Internship in Mathematics (1-4)** variable hours. Prerequisite(s): upper-division standing, with at least 12 units of upper-division credits toward the major. An academic internship to provide the student with career experience as a mathematician in a governmental, industrial, or research unit under the joint supervision of an off-campus sponsor and a faculty member in Mathematics. Each individual program must have the prior approval of both supervisors and the department chair. A final written report is required. Graded Satisfactory (S) or No Credit (NC). May be repeated for a total of 8 units.

## Graduate Courses

**MATH 201A. Algebra (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 171, MATH 172, or equivalents. Topics include basic theory of groups and rings, the Sylow theorems, solvable groups, and the Jordan-Holder theorem.

**MATH 201B. Algebra (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201A. Topics include rings, the functors hom and tensor, modules over a principle ideal domain, and applications to matrices.

**MATH 201C. Algebra (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201B. Topics include algebraic and transcendental extensions of fields and the Galois theory, and the tensor and exterior algebras.

**MATH 205A. Topology (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 145B or equivalent. An introduction to pointset topology.

**MATH 205B. Topology (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 205A or equivalent. Covers homotopy theory and homology theory.

**MATH 205C. Topology (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 205A, MATH 205B, or equivalents. Covers differential topology.

**MATH 209A. Real Analysis (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 151C. Topics include Lebesgue measure, integration, and differentiation.

**MATH 209B. Real Analysis (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 209A. Topics include representation theorems, Hilbert space, Lebesgue spaces, and Banach spaces.

**MATH 209C. Real Analysis (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 209B. Topics include complex measures, general measure spaces, integration on product spaces, and Lebesgue spaces.

**MATH 210A. Complex Analysis (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 151C, MATH 165A. Studies include complex analytic functions, Cauchy's theorem, Cauchy's integral formula and the Laurent series, and the residue theorem.

**MATH 210B. Complex Analysis (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 210A. Studies include entire and meromorphic functions, normal families and the Riemann mapping theorem, and harmonic functions and the Dirichlet problem.

**MATH 211A. Ordinary Differential Equations (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 146B, MATH 151C. Covers the existence and uniqueness of solutions; linear differential equations; singularities of the first and second kind; self-adjoint eigenvalue problems on a finite interval; and singular self-adjoint boundary-value problems for second-order equations.

**MATH 211B. Ordinary Differential Equations (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 211A. Topics include the method of averaging and numerical integration, autonomous systems, the method of Liapounov, and stability for linear systems.

**MATH 212. Partial Differential Equations (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 151C and MATH 165A. Classical theory of initial and boundary value problems for hyperbolic, parabolic and elliptic partial differential equations.

**MATH 216A. Combinatorial Theory (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CS 111/MATH 111. Addresses the solving of combinatorial problems by studying their morphisms (transformations preserving the problem). Covers optimum path problems and their variants. Develops general techniques and work through the solutions of challenging special cases. Particular focus given to utilizing symmetry to systematically reduce a problem.

**MATH 216B. Combinatorial Theory (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 216A. Addresses the solving of combinatorial problems by studying their morphisms (transformations preserving the problem). Covers optimum flow problems. Develops general techniques and work through the solutions of challenging special cases. Particular focus given to utilizing symmetry to systematically reduce a problem.

**MATH 217. Theory of Probability (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 209C. Topics include independence, strong limit theorems including the strong law and the Kolmogorov three-series theorem, weak law and the central limit theorem, the Helley-Bray theorem, and Bochner's theorem on positive definite functions.

**MATH 221. Several Complex Variables (4)** Lecture, 3 hours; research, 3 hours. Prerequisite(s): MATH 151A, MATH 151B, MATH 165A, MATH 165B. Hartog's theorems, domains of holomorphy, pseudoconvexity, Levi's problem, coherent analytic sheaves, Cartan's theorems A and B.

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**MATH 222. Algebraic Groups (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201B, MATH 205A. Introduction to linear algebraic groups, structure, and representation

**MATH 223. Algebraic Number Theory (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201A. Topics include algebraic number theory, principal ideal domains, integral independence, algebraic number fields, classical ideal theory in Dedekind domains, classes of ideals, valuations, and  $p$ -adic numbers.

**MATH 224. Introduction to Homological Algebra (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201C or consent of instructor. Theory of derived functors and its application to rings and associative algebras.

**MATH 225. Commutative Algebra (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201C. Covers basic theory of commutative rings, primary decomposition, integral dependence and valuation rings, and the intersection theorem of Krull.

**MATH 226. Algebraic Analysis (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201B, MATH 205A. Introduction to the theory of modules over rings of differential operators. Topics include holonomic  $D$ -modules, functorial properties, and applications.

**MATH 227A. Lie Algebras (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201A, MATH 201B. Studies include basic definitions, solvable and nilpotent Lie algebras, and structure and classification of semisimple Lie algebras.

**MATH 227B. Lie Algebras (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 227A. Studies include enveloping algebras and representation theory, representations of semisimple Lie algebras, generalization to Kac-Moody Lie algebras, and modular Lie algebras.

**MATH 228. Functional Analysis (4)** Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 209A, MATH 209B, MATH 209C. Topological linear spaces; function spaces; linear operators; spectral theory; operational calculus; and further selected topics.

**MATH 230. Deformation Theory (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201B, MATH 232B. Introduction to deformation quantization. Topics include Hochschild complexes of associative algebras, differential graded Lie algebras, quasi-isomorphisms, Kontsevich's formality theorem, and star-products.

**MATH 232A. Geometry I (Introduction to Manifolds) (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 131 and MATH 151C. Basic notions and examples; vector fields and flows; tensors and vector bundles; differential forms, integration and deRham's theorem.

**MATH 232B. Geometry II (Introduction to Differential) (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 232A. Local and global theory of curves. Surfaces in  $R^3$ : the Gauss map, fundamental forms, curvature. Riemannian geometry: the Levi-Civita connection, curvature, geodesics, exponential map, completeness, Gauss-Bonnet theorem for surfaces.

**MATH 241. Mathematical Physics: Classical Mechanics (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 205A, MATH 205B, MATH 205C; or PHYS 205; or consent of instructor. Hamilton's principle of least action. Variational methods and Lagrange's equations. Hamilton's equations. Introduction to symplectic geometry and its

applications to classical mechanics. Poisson brackets. Conserved quantities and Noether's theorem. Examples of Hamiltonian and dissipative dynamical systems. Introduction to classical chaos.

**MATH 242. Mathematical Physics: Quantum Mechanics (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 209A, MATH 209B, MATH 209C, MATH 228; or consent of instructor. Foundations of quantum theory together with the relevant mathematics. Probabilistic interpretation of quantum mechanics, self-adjoint operators and physical observables, noncommutativity and the uncertainty principle. Spectral theory for (unbounded) self-adjoint operators. Stone's theorem and other topics.

**MATH 243A. Algebraic Geometry (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 201A, MATH 201B. Topics include algebraic varieties in affine and projective space and their basic attributes such as dimension, degree, tangent space, and singularities; and products, mappings, and correspondences.

**MATH 243B. Algebraic Geometry (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 243A. Topics include further study of varieties, sheaves, and cohomology and detailed study of curves and special topics.

**MATH 246A. Algebraic Topology (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 205A; MATH 205B or equivalent. Topics include simplicial and cell complexes, polyhedra, manifolds, homology and cohomology theory, and homotopy theory.

**MATH 246B. Algebraic Topology (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 246A. Covers topics such as topological indices, Lefschetz fixed point theory, Poincaré duality, vector bundles and characteristic classes, and transformation groups.

**MATH 247. Theory of Distributions and Applications (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 146A, MATH 209C; or consent of instructor. Explores approximation of differentiable functions. Addresses theory of distributions, including basic properties, differentiation, and key operations. Covers applications to multivariable calculus and classical equations of mathematical physics. Examines particular spaces of distributions; convolution and Fourier transform; fractional differentiation; Fourier integral operators; and pseudo differential operators.

**MATH 248. Harmonic Analysis and Applications (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 146C, MATH 165B, MATH 209C; or consent of instructor. A study of Fourier series. Includes summability methods, kernels, Fourier transform, unitarity, applications to the uncertainty principle, and distributional Fourier transform. Introduces Hardy spaces, singular integral operators, and wavelet theory and its applications. Other topics include interpolation of linear operators and spectral analysis and applications.

**MATH 249. Introduction to Dynamical Systems (4)** Lecture, 3 hours; outside research, 3 hours. Prerequisite(s): MATH 146B; MATH 151C; MATH 205C or MATH 232A; or consent of instructor. Explores diffeomorphisms and flows, Poincaré maps, and Hamiltonian flows. Includes hyperbolicity, homoclinic points, center manifold theorem, structural stability, and Hopf bifurcations. Explores the Poincaré-Birkhoff theorem, basin of attraction and strange attractors, and Lyapunov exponents and entropy. Introduces chaotic dynamical systems, KAM theory, and complex dynamics.

**MATH 260. Seminar (1-4)** variable hours. Prerequisite(s): consent of department. Seminar on special topics of mathematics in preparation for individual research. Course is repeatable.

**MATH 289. Colloquium in Mathematics (1)** Prerequisite(s): graduate standing. Specialized discussions by staff, students and visiting scientists on current research topics in Mathematics. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

**MATH 290. Directed Studies (1-6)** Prerequisite(s): consent of instructor. Research and special studies in mathematics. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

**MATH 299. Research for Thesis or Dissertation (1-12)** Prerequisite(s): consent of department. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

## Professional Course

**MATH 302. Apprentice Teaching (2-4)** Lecture, 0-1 hour; seminar, 2-4 hours; consultation, 1-2 hours. Prerequisite(s): appointment as a teaching assistant or associate in Mathematics. Supervised training for teaching in lower- and upper-division Mathematics courses. Topics include effective teaching methods, such as those involved in leading mathematics discussion sections, preparing and grading examinations, and relating to students. Required each quarter of all teaching assistants and associates in Mathematics. Units to be decided in consultation with graduate advisor. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

## Mechanical Engineering

**Subject abbreviation: ME**  
**The Marlan and Rosemary Bourns**  
**College of Engineering**

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