

# Mathematics

## Subject: Mathematics

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### Mathematics ESPA

Emerging Scholars: Problem Solving Exploration (204095)

*Dusty Grundmeier*

2019 Fall (2 Credits)

**Schedule:**

TR 0900 AM - 1015 AM

**Instructor Permissions:** Instructor

**Enrollment Cap:**

n/a

In his seminal work from 1945, *How to Solve It*, George Polya introduced principles of mathematical problem solving that are widely applicable to problems in science and engineering. This year-long class focuses on building a powerful and portable problem-solving and modeling tool kit while bridging the divide between mathematics and science courses. The second semester will be organized around projects in areas of student interest. Both Math ESPA and Math ESPB must be taken in the same academic year to receive credit.

#### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
Full Year Course	Indivisible Course
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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### Mathematics ESPB

Emerging Scholars: Problem Solving Exploration (204096)

*Dusty Grundmeier*

2020 Spring (2 Credits)

**Schedule:**

TR 0900 AM - 1015 AM

**Instructor Permissions:** Instructor

**Enrollment Cap:**

n/a

In his seminal work from 1945, *How to Solve It*, George Polya introduced principles of mathematical problem solving that are widely applicable to problems in science and engineering. This year-long class focuses on building a powerful and portable problem-solving and modeling tool kit while bridging the divide between mathematics and science courses. The second semester will be organized around projects in areas of student interest. Both Math ESPA and Math ESPB must be taken in the same academic year to receive credit.

#### Additional Course Attributes:

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
Course Search Attributes	Display Only in Course Search
All: Cross Reg Availability	Available for Harvard Cross Registration
Full Year Course	Indivisible Course
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics MA

Introduction to Functions and Calculus I (111161)

*Brendan Kelly*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

The study of functions and their rates of change. Fundamental ideas of calculus are introduced early and used to provide a framework for the study of mathematical modeling involving algebraic, exponential, and logarithmic functions. Thorough understanding of differential calculus promoted by year long reinforcement. Applications to biology and economics emphasized according to the interests of our students.

**Course Notes:** This is a lecture course taught in small sections. In addition, participation in two one-hour workshops is required each week. This course, when taken together with Mathematics Mb, can be followed by Mathematics 1b. Mathematics Ma and Mb together cover all the material in Mathematics 1a (and more).

**Class Notes:** Required first meeting in Fall: Tuesday, September 3, 8:15 am, Science Center C

Fall Section Times: MWF 9:00, MWF 10:30, MWF 12, MWF 1:30, MWF 3 with sufficient enrollment

Caroline Junkins, Kate Penner, Florence Orosz, Matthew Demers, David Freund, Jill Guerra, Voula Collins, Emily Braley, Carolyn Gardener-Thomas

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics MB

Introduction to Functions and Calculus II (113464)

*Brendan Kelly*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

Continued investigation of functions and differential calculus through modeling; an introduction to integration with applications; an introduction to differential equations. Solid preparation for Mathematics 1b.

**Course Notes:** This is a lecture course taught in small sections. In addition, participation in two one-hour workshops is required each week. This course, when taken together with Mathematics Ma, can be followed by Mathematics 1b. Mathematics Ma and Mathematics Mb together cover all the material in Mathematics 1a (and more).

**Class Notes:** Spring Section Times: MWF 9:00, MWF 10:30, MWF 12, MWF 1:30, and MWF 3:00 with sufficient enrollment.

Caroline Junkins, Kate Penner, David Freund, Matthew Demers, Hakim Walker, Emily Braley, Voula Collins, Florence Orosz, Carolyn Gardener-Thomas

**Requirements:** Prerequisite: Mathematics MA

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 1A

Introduction to Calculus (123680)

*Oliver Knill*

2020 Spring (4 Credits)

**Schedule:** MWF 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

The development of calculus by Newton and Leibniz ranks among the greatest achievements of the past millennium. This course will help you see why by introducing: how differential calculus treats rates of change; how integral calculus treats accumulation; and how the fundamental theorem of calculus links the two. These ideas will be applied to problems from many other disciplines.

**Course Notes:** In the fall, Math 1a is taught in sections of 20-30 students. In the spring, Math 1a is taught in a larger lecture format. Participation in a weekly 90-minute workshop is required. Mathematics Ma and Mb together cover all of the material in Mathematics 1a (and more).

**Class Notes:** Spring Section Time: MWF 10:30 and a weekly lab section to be arranged.

**Recommended Prep:** A solid background in precalculus.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 1A

Introduction to Calculus (123680)

*Jill Guerra*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

The development of calculus by Newton and Leibniz ranks among the greatest achievements of the past millennium. This course will help you see why by introducing: how differential calculus treats rates of change; how integral calculus treats accumulation; and how the fundamental theorem of calculus links the two. These ideas will be applied to problems from many other disciplines.

**Course Notes:** In the fall, Math 1a is taught in sections of 20-30 students. In the spring, Math 1a is taught in a larger lecture format. Participation in a weekly 90-minute workshop is required. Mathematics Ma and Mb together cover all of the material in Mathematics 1a (and more).

**Class Notes:** Required first meeting in Fall: Tuesday, September 3, 7:45 am, Science Center C  
 Fall Section Times: MWF 9:00, MWF 10:30, MWF 12:00, MWF 1:30, and MWF 3:00 with sufficient enrollment.  
 Voula Collins, Elana Kalashnikov

**Recommended Prep:** A solid background in precalculus.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Undergraduate Students

## Mathematics 1B

Calculus, Series, and Differential Equations (111010)

*Robin Gottlieb*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

Speaking the language of modern mathematics requires fluency with the topics of this course: infinite series, integration, and differential equations. Model practical situations using integrals and differential equations. Learn how to represent interesting functions using series and find qualitative, numerical, and analytic ways of studying differential equations. Develop both conceptual understanding and the ability to apply it.

**Course Notes:** This is a lecture taught in small sections.

**Class Notes:** Spring Section Times: MWF 9:00, MWF 10:30, MWF 12:00, MWF 1:30, and MWF 3:00 with sufficient enrollment.  
 Hakim Walker, Forence Orosz, Elana Kalashnikov, Voula Collins

**Recommended Prep:** Mathematics 1a or Ma and Mb; or 5 on the AB advanced placement test; or an equivalent background in mathematics.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Undergraduate Students

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## Mathematics 1B

Calculus, Series, and Differential Equations (111010)

*Hakim Walker*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Speaking the language of modern mathematics requires fluency with the topics of this course: infinite series, integration, and differential equations. Model practical situations using integrals and differential equations. Learn how to represent interesting functions using series and find qualitative, numerical, and analytic ways of studying differential equations. Develop both conceptual understanding and the ability to apply it.**

**Course Notes:** This is a lecture taught in small sections.

**Class Notes:** Required first meeting in Fall: Tuesday, September 3, 8:15 am, Science Center B

**Fall Section Times:** MWF 9:00, MWF 10:30, MWF 12:00, MWF 1:30, and MWF 3:00 with sufficient enrollment.

**David Freund, Hakim Walker, Stepan Paul,**

**Recommended Prep:** Mathematics 1a or Ma and Mb; or 5 on the AB advanced placement test; or an equivalent background in mathematics.

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students

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## Mathematics 18A

Multivariable Calculus for Social Sciences (125396)

*Drew Zemke*

2019 Fall (4 Credits)

**Schedule:** MWF 0130 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Focus on concepts and techniques of multivariable calculus most useful to those studying the social sciences, particularly economics: functions of several variables; partial derivatives; directional derivatives and the gradient; constrained and unconstrained optimization, including the method of Lagrange multipliers. Covers linear and polynomial approximation and integrals for single variable and multivariable functions; modeling with derivatives. Covers topics from Math 21a most useful to social sciences.**

**Course Notes:** Mathematics 21b can be taken before or after Mathematics 18. Examples draw primarily from economics and the social sciences, though Mathematics 18 may be useful to students in certain natural sciences. Students whose main interests lie in the physical sciences, mathematics, or engineering should consider Math or Applied Math 21a.

**Recommended Prep:** Mathematics 1b or equivalent, or a 5 on the BC Advanced Placement Examination in Mathematics.

**Requirements:** **Anti-Requisite: Not to be taken in addition to Mathematics 21a or Applied Mathematics 21a**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Core Curriculum (old)	Quantitative Reasoning
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 18B/19B

Linear Algebra, Probability, and Statistics (213535)

*Stepan Paul*

2020 Spring (4 Credits)

**Schedule:** MWF 0130 AM - 0245 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

Probability, statistics and linear algebra with applications to life sciences, chemistry, environmental sciences, economics and social sciences. Students will learn to use computing software to perform relevant calculations on data sets coming from these areas of study. Linear algebra includes matrices, eigenvalues, eigenvectors, determinants, and applications to probability, statistics, dynamical systems. Basic probability and statistics are introduced, as are standard models, techniques, and their uses including the central limit theorem, Markov chains, curve fitting, regression, and pattern analysis.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students

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## Mathematics 19A

Modeling and Differential Equations for the Life Sciences (110596)

*John Cain*

2019 Fall (4 Credits)

**Schedule:** MWF 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

Considers the construction and analysis of mathematical models that arise in the life sciences, ecology and environmental life science. Introduces mathematics that include multivariable calculus, differential equations in one or more variables, vectors, matrices, and linear and non-linear dynamical systems. Taught via examples from current literature (both good and bad).

**Course Notes:**

This course is recommended over Math 21a for those planning to concentrate in the life sciences and ESPP. Can be taken with or without Mathematics 21a,b. Students with interests in the social sciences and economics might consider Mathematics 18. This course can be taken before or after Mathematics 18.

**Recommended Prep:**

A course in one variable calculus preferably at the level of Mathematics 1b.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students

**Mathematics 21A**

Multivariable Calculus (119196)

*Drew Zemke*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

To see how calculus applies in practical situations described by more than one variable, we study: Vectors, lines, planes, parameterization of curves and surfaces, partial derivatives, directional derivatives and the gradient, optimization and critical point analysis, including constrained optimization and the Method of Lagrange Multipliers, integration over curves, surfaces and solid regions using Cartesian, polar, cylindrical, and spherical coordinates, divergence and curl of vector fields, and the Green's, Stokes's, and Divergence Theorems.

**Course Notes:** This is a lecture taught in small sections. May not be taken for credit by students who have passed Applied Mathematics 21a. Activities using computers to calculate and visualize applications of these ideas will not require programming experience.

**Class Notes:** Spring Section Times: MWF 9:00, MWF 10:30, MWF 12, MWF 1:30, and MWF 3:00 with sufficient enrollment.  
Stepan Paul, Jill Guerra, Elden Elmato, Matthew Demers

**Recommended Prep:** Mathematics 1b or an equivalent background in mathematics.

**Requirements:** Anti-requisite: Not to be taken in addition to AM21a.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students

**Mathematics 21A**

Multivariable Calculus (119196)

*Oliver Knill*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

To see how calculus applies in practical situations described by more than one variable, we study: Vectors, lines, planes, parameterization of curves and surfaces, partial derivatives, directional derivatives and the gradient, optimization and critical point analysis, including constrained optimization and the Method of

Lagrange Multipliers, integration over curves, surfaces and solid regions using Cartesian, polar, cylindrical, and spherical coordinates, divergence and curl of vector fields, and the Green's, Stokes's, and Divergence Theorems.

**Course Notes:** This is a lecture taught in small sections. May not be taken for credit by students who have passed Applied Mathematics 21a. Activities using computers to calculate and visualize applications of these ideas will not require programming experience.

**Class Notes:** Required first meeting in Fall: Wednesday, September 4, 8:15 am, Science Center B  
 Fall Section times: MWF 9:00, MWF 10:30, MWF 12, MWF 1:30, and MWF 3:00 with sufficient enrollment.  
 Drew Zemke, Jameel Al-Aidroos, Stepan Paul, Florence Orosz, Arnav Tripathy, Fabian Gundlach

**Recommended Prep:** Mathematics 1b or an equivalent background in mathematics.

**Requirements:** Anti-requisite: Not to be taken in addition to AM21a.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students

## Mathematics 21B

Linear Algebra and Differential Equations (110989)

Janet Chen

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

Matrices provide the algebraic structure for solving myriad problems across the sciences. We study matrices and related topics such as linear transformations and linear spaces, determinants, eigenvalues, and eigenvectors. Applications include dynamical systems, ordinary and partial differential equations, and an introduction to Fourier series.

**Course Notes:** This is a lecture taught in small sections. May not be taken by students who have passed Applied Mathematics 21b.

**Class Notes:** Spring Section Times: MWF 9:00, MWF 10:30, MWF 12:00, MWF 1:30, MWF 3:00

Jill Guerra, Jameel Al-Aidroos David Freund, Brendan Kelly, Dori Bejleiri, Chris Gerig



**Recommended Prep:** Mathematics 1b or an equivalent background in mathematics. Mathematics 21a is commonly taken before Mathematics 21b, but is not a prerequisite, although familiarity with partial derivatives is useful.

**Requirements:** Anti-requisite: Not to be taken in addition to Math 19b or AM 21b.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 21B

Linear Algebra and Differential Equations (110989)

*Matthew Demers*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Matrices provide the algebraic structure for solving myriad problems across the sciences. We study matrices and related topics such as linear transformations and linear spaces, determinants, eigenvalues, and eigenvectors. Applications include dynamical systems, ordinary and partial differential equations, and an introduction to Fourier series.**

**Course Notes:** This is a lecture taught in small sections. May not be taken by students who have passed Applied Mathematics 21b.

**Class Notes:** Required first meeting in Fall: Tuesday, September 3, 8:15 am, Science Center D

**Fall Section Times:** MWF 9:00, MWF 10:30, MWF 12:00, MWF 1:30 with sufficient enrollment, MWF 3:00 with sufficient enrollment.

**Recommended Prep:** Mathematics 1b or an equivalent background in mathematics. Mathematics 21a is commonly taken before Mathematics 21b, but is not a prerequisite, although familiarity with partial derivatives is useful.

**Requirements:** Anti-requisite: Not to be taken in addition to Math 19b or AM 21b.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students

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## Mathematics 22A

Vector Calculus and Linear Algebra I (207485)

*Dusty Grundmeier*

2019 Fall (4 Credits)

Schedule:

MWF 1200 PM - 0115 PM

Instructor Permissions: None

Enrollment Cap:

n/a

This course covers multivariable calculus and linear algebra for students interested in mathematical sciences. It covers the same topics as Mathematics 21, but does so with more rigor. Students are taught techniques of proof and mathematical reasoning. The workload and content is comparable with the Mathematics 21 sequence. But unlike the latter, the linear algebra and calculus are more interlinked.

Additional Course Attributes:

Attribute	Value(s)
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## Mathematics 22B

Vector Calculus and Linear Algebra II (207486)

*Dusty Grundmeier*

2020 Spring (4 Credits)

Schedule:

MWF 1200 PM - 0115 PM

Instructor Permissions: Instructor

Enrollment Cap:

50

A continuation of Mathematics 22a

Additional Course Attributes:

Attribute	Value(s)
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## Mathematics 23A

Linear Algebra and Real Analysis I (111695)

*Paul Bamberg*

2019 Fall (4 Credits)

Schedule:

R 0300 PM - 0545 PM

Instructor Permissions: Instructor

Enrollment Cap:

45

Linear algebra: vectors, linear transformations and matrices, scalar and vector products, basis and dimension, eigenvectors and eigenvalues, including an introduction to the R scripting language. Single-variable real analysis: sequences and series, limits and continuity, derivatives, inverse functions, power series and Taylor series. Multivariable real analysis and calculus: topology of Euclidean space, limits, continuity, and differentiation in n dimensions, inverse and implicit functions, manifolds, Lagrange multipliers, path integrals, div, grad, and curl. Emphasis on topics that are applicable to fields such as physics, economics, and computer science, but students are also expected to learn how to prove key results.

Course Notes:

Students are expected to watch videos of the lectures from Fall 2015 before attending class. Weekly two-hour classes will consist of a one-hour seminar in which students present key definitions and proofs and a one-hour activity-based session in which students work in small groups to solve problems. Students are expected to continue in either Mathematics 23b (recommended for students who are thinking of concentrating in mathematics, the physical sciences, or engineering) or Mathematics 23c (recommended for students who are not sure of their concentration, or who are thinking about a concentration in the social sciences, economics, computer science, life sciences or data

science). Either alternative will provide a solid foundation for a concentration in mathematics or any field that uses mathematics.

**Class Notes:** Required first meeting in Fall: Tuesday, September 3, 8:15 am, Science Center A

**Recommended Prep:** Mathematics 1b or a grade of 4 or 5 on the Calculus BC Advanced Placement Examination, plus an interest both in proving mathematical results and in using them. No background in linear algebra, real analysis, or multivariable calculus is assumed.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

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**Mathematics 23A** Section: 002

Linear Algebra and Real Analysis I (111695)

*Paul Bamberg*

2019 Fall (4 Credits)

**Schedule:** R 0300 PM - 0545 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** 96

**Linear algebra:** vectors, linear transformations and matrices, scalar and vector products, basis and dimension, eigenvectors and eigenvalues, including an introduction to the R scripting language. **Single-variable real analysis:** sequences and series, limits and continuity, derivatives, inverse functions, power series and Taylor series. **Multivariable real analysis and calculus:** topology of Euclidean space, limits, continuity, and differentiation in n dimensions, inverse and implicit functions, manifolds, Lagrange multipliers, path integrals, div, grad, and curl. Emphasis on topics that are applicable to fields such as physics, economics, and computer science, but students are also expected to learn how to prove key results.

**Course Notes:** Students are expected to watch videos of the lectures from Fall 2015 before attending class. Weekly two-hour classes will consist of a one-hour seminar in which students present key definitions and proofs and a one-hour activity-based session in which students work in small groups to solve problems. Students are expected to continue in either Mathematics 23b (recommended for students who are thinking of concentrating in mathematics, the physical sciences, or engineering) or Mathematics 23c (recommended for students who are not sure of their concentration, or who are thinking about a concentration in the social sciences, economics, computer science, life sciences or data science). Either alternative will provide a solid foundation for a concentration in mathematics or any field that uses mathematics.

**Recommended Prep:** Mathematics 1b or a grade of 4 or 5 on the Calculus BC Advanced Placement Examination, plus an interest both in proving mathematical results and in using them. No background in linear algebra, real analysis, or multivariable calculus is assumed.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration

FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 23A Section: 003

Linear Algebra and Real Analysis I (111695)

*Paul Bamberg*

2019 Fall (4 Credits)

**Schedule:**

R 0300 PM - 0545 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:**

30

**Linear algebra: vectors, linear transformations and matrices, scalar and vector products, basis and dimension, eigenvectors and eigenvalues, including an introduction to the R scripting language. Single-variable real analysis: sequences and series, limits and continuity, derivatives, inverse functions, power series and Taylor series. Multivariable real analysis and calculus: topology of Euclidean space, limits, continuity, and differentiation in n dimensions, inverse and implicit functions, manifolds, Lagrange multipliers, path integrals, div, grad, and curl. Emphasis on topics that are applicable to fields such as physics, economics, and computer science, but students are also expected to learn how to prove key results.**

**Course Notes:**

**Students are expected to watch videos of the lectures from Fall 2015 before attending class. Weekly two-hour classes will consist of a one-hour seminar in which students present key definitions and proofs and a one-hour activity-based session in which students work in small groups to solve problems. Students are expected to continue in either Mathematics 23b (recommended for students who are thinking of concentrating in mathematics, the physical sciences, or engineering) or Mathematics 23c (recommended for students who are not sure of their concentration, or who are thinking about a concentration in the social sciences, economics, computer science, life sciences or data science). Either alternative will provide a solid foundation for a concentration in mathematics or any field that uses mathematics.**

**Recommended Prep:**

**Mathematics 1b or a grade of 4 or 5 on the Calculus BC Advanced Placement Examination, plus an interest both in proving mathematical results and in using them. No background in linear algebra, real analysis, or multivariable calculus is assumed.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 23A Section: 004

Linear Algebra and Real Analysis I (111695)

*Paul Bamberg*

2019 Fall (4 Credits)

**Schedule:**

F 1200 PM - 0245 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:**

30

**Linear algebra: vectors, linear transformations and matrices, scalar and vector products, basis and**

dimension, eigenvectors and eigenvalues, including an introduction to the R scripting language. Single-variable real analysis: sequences and series, limits and continuity, derivatives, inverse functions, power series and Taylor series. Multivariable real analysis and calculus: topology of Euclidean space, limits, continuity, and differentiation in n dimensions, inverse and implicit functions, manifolds, Lagrange multipliers, path integrals, div, grad, and curl. Emphasis on topics that are applicable to fields such as physics, economics, and computer science, but students are also expected to learn how to prove key results.

**Course Notes:** Students are expected to watch videos of the lectures from Fall 2015 before attending class. Weekly two-hour classes will consist of a one-hour seminar in which students present key definitions and proofs and a one-hour activity-based session in which students work in small groups to solve problems. Students are expected to continue in either Mathematics 23b (recommended for students who are thinking of concentrating in mathematics, the physical sciences, or engineering) or Mathematics 23c (recommended for students who are not sure of their concentration, or who are thinking about a concentration in the social sciences, economics, computer science, life sciences or data science). Either alternative will provide a solid foundation for a concentration in mathematics or any field that uses mathematics.

**Recommended Prep:** Mathematics 1b or a grade of 4 or 5 on the Calculus BC Advanced Placement Examination, plus an interest both in proving mathematical results and in using them. No background in linear algebra, real analysis, or multivariable calculus is assumed.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students

**Mathematics 23A** Section: 005

Linear Algebra and Real Analysis I (111695)

*Paul Bamberg*

2019 Fall (4 Credits)

**Schedule:** F 1200 PM - 0245 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** 30

**Linear algebra:** vectors, linear transformations and matrices, scalar and vector products, basis and dimension, eigenvectors and eigenvalues, including an introduction to the R scripting language. **Single-variable real analysis:** sequences and series, limits and continuity, derivatives, inverse functions, power series and Taylor series. **Multivariable real analysis and calculus:** topology of Euclidean space, limits, continuity, and differentiation in n dimensions, inverse and implicit functions, manifolds, Lagrange multipliers, path integrals, div, grad, and curl. Emphasis on topics that are applicable to fields such as physics, economics, and computer science, but students are also expected to learn how to prove key results.

**Course Notes:** Students are expected to watch videos of the lectures from Fall 2015 before attending class. Weekly two-hour classes will consist of a one-hour seminar in which students present key definitions and proofs and a one-hour activity-based session in which students work in small groups to solve problems. Students are expected to continue in either Mathematics 23b (recommended for students who are thinking of

concentrating in mathematics, the physical sciences, or engineering) or Mathematics 23c (recommended for students who are not sure of their concentration, or who are thinking about a concentration in the social sciences, economics, computer science, life sciences or data science). Either alternative will provide a solid foundation for a concentration in mathematics or any field that uses mathematics.

**Recommended Prep:** Mathematics 1b or a grade of 4 or 5 on the Calculus BC Advanced Placement Examination, plus an interest both in proving mathematical results and in using them. No background in linear algebra, real analysis, or multivariable calculus is assumed.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

**Mathematics 23A** Section: 006

Linear Algebra and Real Analysis I (111695)

*Paul Bamberg*

2019 Fall (4 Credits)

**Schedule:** F 1200 PM - 0245 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** 30

**Linear algebra:** vectors, linear transformations and matrices, scalar and vector products, basis and dimension, eigenvectors and eigenvalues, including an introduction to the R scripting language. **Single-variable real analysis:** sequences and series, limits and continuity, derivatives, inverse functions, power series and Taylor series. **Multivariable real analysis and calculus:** topology of Euclidean space, limits, continuity, and differentiation in n dimensions, inverse and implicit functions, manifolds, Lagrange multipliers, path integrals, div, grad, and curl. Emphasis on topics that are applicable to fields such as physics, economics, and computer science, but students are also expected to learn how to prove key results.

**Course Notes:** Students are expected to watch videos of the lectures from Fall 2015 before attending class. Weekly two-hour classes will consist of a one-hour seminar in which students present key definitions and proofs and a one-hour activity-based session in which students work in small groups to solve problems. Students are expected to continue in either Mathematics 23b (recommended for students who are thinking of concentrating in mathematics, the physical sciences, or engineering) or Mathematics 23c (recommended for students who are not sure of their concentration, or who are thinking about a concentration in the social sciences, economics, computer science, life sciences or data science). Either alternative will provide a solid foundation for a concentration in mathematics or any field that uses mathematics.

**Recommended Prep:** Mathematics 1b or a grade of 4 or 5 on the Calculus BC Advanced Placement Examination, plus an interest both in proving mathematical results and in using them. No background in linear algebra, real analysis, or multivariable calculus is assumed.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration

**Mathematics 23A** Section: 007

Linear Algebra and Real Analysis I (111695)

*Paul Bamberg*

2019 Fall (4 Credits)

**Schedule:**

F 1200 PM - 0245 PM

**Instructor Permissions:** Instructor**Enrollment Cap:**

30

**Linear algebra: vectors, linear transformations and matrices, scalar and vector products, basis and dimension, eigenvectors and eigenvalues, including an introduction to the R scripting language. Single-variable real analysis: sequences and series, limits and continuity, derivatives, inverse functions, power series and Taylor series. Multivariable real analysis and calculus: topology of Euclidean space, limits, continuity, and differentiation in n dimensions, inverse and implicit functions, manifolds, Lagrange multipliers, path integrals, div, grad, and curl. Emphasis on topics that are applicable to fields such as physics, economics, and computer science, but students are also expected to learn how to prove key results.**

**Course Notes:**

Students are expected to watch videos of the lectures from Fall 2015 before attending class. Weekly two-hour classes will consist of a one-hour seminar in which students present key definitions and proofs and a one-hour activity-based session in which students work in small groups to solve problems. Students are expected to continue in either Mathematics 23b (recommended for students who are thinking of concentrating in mathematics, the physical sciences, or engineering) or Mathematics 23c (recommended for students who are not sure of their concentration, or who are thinking about a concentration in the social sciences, economics, computer science, life sciences or data science). Either alternative will provide a solid foundation for a concentration in mathematics or any field that uses mathematics.

**Recommended Prep:**

Mathematics 1b or a grade of 4 or 5 on the Calculus BC Advanced Placement Examination, plus an interest both in proving mathematical results and in using them. No background in linear algebra, real analysis, or multivariable calculus is assumed.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

**Mathematics 23B**

Linear Algebra and Real Analysis II (145010)

*Paul Bamberg*

2020 Spring (4 Credits)

**Schedule:**

F 1200 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

A rigorous, integrated treatment of linear algebra and multivariable calculus. Topics: Riemann and Lebesgue integration, determinants, change of variables, volume of manifolds, differential forms, and exterior derivative. Stokes's theorem is presented both in the language of vector analysis (div, grad, and curl) and in the language of differential forms.

**Course Notes:** Mathematics 23b is a sequel to Mathematics 23a, recommended for students who are thinking of concentrating in mathematics, the physical sciences, or engineering. Students are expected to watch videos of the lectures from spring 2016 before attending class. Weekly two-hour classes will consist of a one-hour seminar in which students present key definitions and proofs and a one-hour activity-based session in which students work in small groups to solve problems.

**Recommended Prep:** Mathematics 23a.

**Requirements:** Prerequisite: MATH 23A OR (MATH 21A AND MATH 21B) AND (Not to be taken in addition to MATH 23C)

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

## Mathematics 23C

Mathematics for Computation, Statistics, and Data Science (205386)

*Paul Bamberg*

2020 Spring (4 Credits)

**Schedule:** TR 0130 AM - 0245 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Proof strategies and logic. Sets, countability, sigma fields, and axiomatic foundations of probability. Summation of series and evaluation of multiple integrals, with emphasis on calculation of expectation and variance. Abstract vector spaces and inner product spaces, with applications to analysis of large datasets. Key functions and theorems of mathematical statistics. A brief introduction to classical vector calculus as used in electromagnetic theory. Students will learn to use some of the statistical and graphical display tools in the R script language.**

**Course Notes:** This course is a sequel to Mathematics 23a, recommended for students who are not sure of their concentration or who are thinking about a concentration in the social sciences, economics, computer science, life sciences or data science. Graduate students wishing to take this course for credit should speak with Dr. Bamberg to arrange enrollment in Mathematics 370 instead.

**Recommended Prep:** Mathematics 23a or Mathematics 21a and 21b. The latter option is for seniors who are preparing for graduate programs in statistics, computer science, or data science.

**Requirements:** Prerequisite: MATH 23A OR (MATH 21A AND MATH 21B) AND (Not to be taken in addition to MATH 23B)



**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	For Undergraduate and Graduate Students
Quantitative Reasoning with Data	Yes
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 25A**

Theoretical Linear Algebra and Real Analysis I (110808)

*John Cain*

2019 Fall (4 Credits)

**Schedule:**

MWF 0900 AM - 1015 AM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

**A rigorous treatment of linear algebra. Topics include: Construction of number systems; fields, vector spaces and linear transformations; eigenvalues and eigenvectors, determinants and inner products. Metric spaces, compactness and connectedness.**

**Course Notes:** Expect to spend a lot of time doing mathematics.

**Recommended Prep:** 5 on the Calculus BC Advanced Placement Examination and some familiarity with writing proofs, or the equivalent as determined by the instructor.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration

**Mathematics 25B**

Theoretical Linear Algebra and Real Analysis II (110855)

*John Cain*

2020 Spring (4 Credits)

**Schedule:**

MWF 0900 AM - 1015 AM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

**A rigorous treatment of basic analysis. Topics include: convergence, continuity, differentiation, the Riemann integral, uniform convergence, the Stone-Weierstrass theorem, Fourier series, differentiation in several variables. Additional topics, including the classical results of vector calculus in two and three dimensions, as time allows.**

**Course Notes:** Expect to spend a lot time doing mathematics.

**Requirements:** Prerequisite: Mathematics 25A OR Mathematics 55A

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

FAS: Course Level	Primarily for Undergraduate Students
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**Mathematics 55A**

Studies in Algebra and Group Theory (113627)

*Joseph D. Harris*

2019 Fall (4 Credits) **Schedule:** MWF 1030 AM - 1145 AM

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**A rigorous introduction to abstract algebra, including group theory and linear algebra. This course covers the equivalent of Mathematics 25a and Mathematics 122, and prepares students for Mathematics 123 and other advanced courses in number theory and algebra. (A course in analysis such as Mathematics 25b or 55b is recommended for Spring semester.)**

**Course Notes:** Mathematics 55a is an intensive course for students who are comfortable with abstract mathematics. (Students without this background will gain it and learn the material from Math 55a,b in other courses by continuing into the Mathematics Concentration as sophomores.) Students can switch between Mathematics 55a and either Mathematics 25a, 23a, 22a, 21a during the first three weeks without penalty.

**Recommended Prep:** Familiarity with proofs and abstract reasoning; and commitment to a fast moving course.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 55B**

Studies in Real and Complex analysis (112871)

*Joseph D. Harris*

2020 Spring (4 Credits) **Schedule:** MWF 1030 AM - 1145 AM

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**A rigorous introduction to real and complex analysis. This course covers the equivalent of Mathematics 25b and Mathematics 113, and prepares students for Mathematics 114 and other advanced courses in analysis.**

**Course Notes:** Mathematics 55b is an intensive course for students having significant experience with abstract mathematics.

**Requirements:** Prerequisite: Mathematics 55A

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration

**Mathematics 60R**

Reading Course for Senior Honors Candidates (123883)

*Dennis Gaitsgory*

2020 Spring (4 Credits) **Schedule:** TBD

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Supervised small group tutorials in advanced reading topics not covered in courses. (See class note below for tutorial topic titles).**

**Course Notes:** Limited to candidates for honors in Mathematics who obtain the permission of both the faculty member under whom they want to work and the Director of Undergraduate Studies. May not count for concentration in Mathematics without special permission from the Director of Undergraduate Studies. Graded Sat/Unsat only.

**Class Notes:** Spring term: the two tutorial titles are mathematics in economic theory" and "Classical mechanics and symplectic geometry"

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Not Available for Cross Registration
FAS: Course Level	Primarily for Undergraduate Students

**Mathematics 60R**

Reading Course for Senior Honors Candidates (123883)

*Dennis Gaitsgory*

2019 Fall (4 Credits) **Schedule:** TBD

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**Supervised small group tutorials in advanced reading topics not covered in courses. (See class note below for tutorial topic titles).**

**Course Notes:** Limited to candidates for honors in Mathematics who obtain the permission of both the faculty member under whom they want to work and the Director of Undergraduate Studies. May not count for concentration in Mathematics without special permission from the Director of Undergraduate Studies. Graded Sat/Unsat only.

**Class Notes:** Fall term: the two tutorial titles are "Etale cohomology" and "Morse theory"

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Not Available for Cross Registration

**Mathematics 91R**

Supervised Reading and Research (111297)

*Dennis Gaitsgory*

2020 Spring (4 Credits)

**Schedule:** TBD**Instructor Permissions:** None**Enrollment Cap:** n/a**Programs of directed study supervised by a person approved by the Department.****Course Notes:** May not ordinarily count for concentration in Mathematics.**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 91R**

Supervised Reading and Research (111297)

*Dennis Gaitsgory*

2019 Fall (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Programs of directed study supervised by a person approved by the Department.****Course Notes:** May not ordinarily count for concentration in Mathematics.**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 99R**

Tutorial (117647)

*Dennis Gaitsgory*

2020 Spring (4 Credits)

**Schedule:** TBD**Instructor Permissions:** None**Enrollment Cap:** n/a

Supervised small group tutorial. Topics to be arranged.

**Course Notes:** May be repeated for course credit with permission from the Director of Undergraduate Studies. Only one tutorial may count for concentration credit.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 99R

Tutorial (117647)

*Dennis Gaitsgory*

2019 Fall (4 Credits) **Schedule:** TBD

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

Supervised small group tutorial. Topics to be arranged.

**Course Notes:** May be repeated for course credit with permission from the Director of Undergraduate Studies. Only one tutorial may count for concentration credit.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 101

Sets, Groups and Topology (122943)

*Eriko Hironaka*

2019 Fall (4 Credits) **Schedule:** TR 0130 PM - 0245 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

An introduction to rigorous mathematics, axioms, and proofs, via topics including set theory, symmetry groups, and low-dimensional topology.

**Course Notes:** Familiarity with algebra, geometry and/or calculus is desirable. Students who have already taken Mathematics 22a,b, 23a,b, 25a,b or 55a,b should not take this course for credit. This course given fall term and repeated spring term.

**Recommended Prep:** An interest in mathematical reasoning. Acquaintance with algebra, geometry and/or calculus is desirable. Students who have already taken Math 25a,b or 55a,b should not take this course for credit.

**Requirements:** Anti-Req: Not to be taken in addition to Mathematics 23a,b or 25a,b or 55a,b.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students

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**Mathematics 101** Section: 01

Sets, Groups and Topology (122943)

*Peter Kronheimer*

2020 Spring (4 Credits)

**Schedule:** MW 0300 PM - 0415 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**An introduction to rigorous mathematics, axioms, and proofs, via topics including set theory, symmetry groups, and low-dimensional topology.**

**Course Notes:** Familiarity with algebra, geometry and/or calculus is desirable. Students who have already taken Mathematics 22a,b, 23a,b, 25a,b or 55a,b should not take this course for credit. This course given fall term and repeated spring term.

**Recommended Prep:** An interest in mathematical reasoning. Acquaintance with algebra, geometry and/or calculus is desirable. Students who have already taken Math 25a,b or 55a,b should not take this course for credit.

**Requirements:** Anti-Req: Not to be taken in addition to Mathematics 23a,b or 25a,b or 55a,b.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	For Undergraduate and Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Core Curriculum (old)	Quantitative Reasoning
All: Cross Reg Availability	Available for Harvard Cross Registration

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**Mathematics 110**

Vector Space Methods for Differential Equations (126610)

*Christian Brennecke*

2020 Spring (4 Credits)

**Schedule:** TR 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Develops the theory of inner product spaces, both finite-dimensional and infinite-dimensional, and applies it to a variety of ordinary and partial differential equations. Topics: existence and uniqueness theorems, Sturm-Liouville systems, orthogonal polynomials, Fourier series, Fourier and Laplace transforms, eigenvalue problems, and solutions of Laplace's equation and the wave equation in the various coordinate systems.**

**Recommended Prep:** Mathematics 22a,b, 23a,b or 25a,b or Mathematics 19a,b or 21a,b plus any Mathematics course at the 100 level; or an equivalent background in Mathematics.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	For Undergraduate and Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 112

Introductory Real Analysis (109817)

*W. Hugh Woodin*

2020 Spring (4 Credits)

**Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**An introduction to mathematical analysis and the theory behind calculus. An emphasis on learning to understand and construct proofs. Covers limits and continuity in metric spaces, uniform convergence and spaces of functions, the Riemann integral.**

**Recommended Prep:** Mathematics 19a,b or 21a,b and either an ability to write proofs or concurrent enrollment in Mathematics 101 or 102; or an equivalent background in mathematics.

**Requirements:** **Anti-Req: Not to be taken in addition to Mathematics 23a,b or 25a,b or 55a,b.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	For Undergraduate and Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 113

Complex Analysis (113608)

*Alexander Kupers*

2020 Spring (4 Credits)

**Schedule:** TR 0300 PM - 0415 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Analytic functions of one complex variable: power series expansions, contour integrals, Cauchy's theorem, Laurent series and the residue theorem. Some applications to real analysis, including the evaluation of indefinite integrals. An introduction to some special functions.**

**Recommended Prep:** Not recommended for most students who took Mathematics 55a and/or Mathematics 55b. Talk to the Director of Undergraduate Studies in Mathematics if you took Mathematics 55a and/or 55b and wish to take this course.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	For Undergraduate and Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 114**

Analysis of Function Spaces, Measure and Integration (123227)

*Christian Brennecke*

2019 Fall (4 Credits)

**Schedule:** MW 0900 AM - 1015 AM**Instructor Permissions:** None**Enrollment Cap:** n/a**Lebesgue measure and integration; general topology; introduction to  $L^p$  spaces, Banach and Hilbert spaces, and duality.****Recommended Prep:** Mathematics 22a,b, 23a,b or 25a,b or 55a,b or 112; or an equivalent background in mathematics.**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	For Undergraduate and Graduate Students

**Mathematics 115**

Methods of Analysis (111065)

*Tianqi Wu*

2019 Fall (4 Credits)

**Schedule:** TR 0900 AM - 1015 AM**Instructor Permissions:** None**Enrollment Cap:** n/a**Complex functions; Fourier analysis; Hilbert spaces and operators; Laplace's equations; Bessel and Legendre functions; symmetries; Sturm-Liouville theory.****Course Notes:** Mathematics 115 is especially for students interested in physics.**Recommended Prep:** Mathematics 22a,b, 23a,b or 25a,b or 55a,b or 112; or an equivalent background in mathematics.**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students

**Mathematics 116**

Real Analysis, Convexity, and Optimization (118302)



Marius Lemm

2019 Fall (4 Credits)

**Schedule:**

TR 0300 PM - 0415 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Develops the theory of convex sets, normed infinite-dimensional vector spaces, and convex functionals and applies it as a unifying principle to a variety of optimization problems such as resource allocation, production planning, and optimal control. Topics include Hilbert space, dual spaces, the Hahn-Banach theorem, the Riesz representation theorem, calculus of variations, and Fenchel duality. Students will be expected to understand and come up with proofs of theorems in real and functional analysis.**

**Recommended Prep:**

**Mathematics 22a,b, 23a,b or 25a,b or 55a,b; or Mathematics 21a,b plus at least one other more advanced course in mathematics; or an equivalent background in mathematics.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students

## Mathematics 118R

Dynamical Systems (118429)

Eriko Hironaka

2020 Spring (4 Credits)

**Schedule:**

TR 0130 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Introduction to dynamical systems theory with a view toward applications. Topics include existence and uniqueness theorems for flows, qualitative study of equilibria and attractors, iterated maps, and bifurcation theory.**

**Recommended Prep:**

**Mathematics 19a,b or 21a,b or Math 22a,b, or Math 23a,b or Math 25a,b or Math 55a,b; or an equivalent background in mathematics.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students

## Mathematics 119

Introduction to Stochastic Calculus (212889)

Hong-Tzer Yau

2019 Fall (4 Credits)

**Schedule:**

TR 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**The goal of this class is to provide an introduction to Brownian motion and stochastic calculus. In addition, we will cover basic martingale theory. We will also give an intuitive derivation of Ito's formula and**

cover some of its application.

**Course Notes:** This class assumes familiarity with basic probability theory at the level of Mathematics 154.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 121

Linear Algebra and Applications (120228)

*Elden Elmanto*

2019 Fall (4 Credits)

**Schedule:** TR 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Real and complex vector spaces, linear transformations, determinants, inner products, dual spaces, and eigenvalue problems. Applications to some or all of the following: Geometry, systems of linear differential equations, optimization, and Markov processes. This course emphasizes learning to understand and write rigorous mathematics.**

**Recommended Prep:** Mathematics 19b or 21b or an equivalent background in mathematics.

**Requirements:** Anti-req: Not to be taken in addition to Mathematics 22b, 23a or 25a or 55a.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 122

Algebra I: Theory of Groups and Vector Spaces (122603)

*Brooke Ullery*

2019 Fall (4 Credits)

**Schedule:** MW 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Groups and group actions, vector spaces and their linear transformations, bilinear forms and linear representations of finite groups.**

**Recommended Prep:** Not recommended for most students who took Mathematics 55a and/or Mathematics 55b. Talk to the Director of Undergraduate Studies in Mathematics if you took Mathematics 55a and/or Mathematics 55b and wish to take this course.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	For Undergraduate and Graduate Students

**Mathematics 123**

Algebra II: Theory of Rings and Fields (116503)

*Sebastien Vasey*

2020 Spring (4 Credits)

**Schedule:** WF 1030 AM - 1145 AM**Instructor Permissions:** None**Enrollment Cap:** n/a

**Rings and modules. Polynomial rings. Field extensions and the basic theorems of Galois theory. Structure theorems for modules.**

**Requirements:****Prerequisite: Mathematics 122 or Mathematics 55a****Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 124**

Number Theory (111533)

*Michael Hopkins*

2019 Fall (4 Credits)

**Schedule:** MW 0130 PM - 0245 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

**Factorization and the primes; congruences; quadratic residues and reciprocity; continued fractions and approximations; Pell's equation; selected Diophantine equations; theory of integral quadratic forms. Also, selected applications to coding, introduction to elliptic curves and introduction to zeta functions if time permits.**

**Recommended Prep:**

**Mathematics 101 or 122 or 25a or 23a; or 55a which can be taken concurrently; or an equivalent experience and comfort level with abstract mathematics.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students

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## Mathematics 129

Number Fields (115734)

*Barry Mazur*

2020 Spring (4 Credits)

**Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Algebraic number theory: number fields, unique factorization of ideals, finiteness of class group, structure of unit group, Frobenius elements, local fields, ramification, weak approximation, adeles, and ideles.**

**Recommended Prep:** Knowledge of the material in Mathematics 123.

**Requirements:** Prerequisite: Mathematics 123

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 130

Classical Geometry (123211)

2020 Spring (4 Credits)

**Schedule:** MW 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Presents several classical geometries, these being the affine, projective, Euclidean, spherical and hyperbolic geometries. They are viewed from many different perspectives, some historical and some very topical. Emphasis on reading and writing proofs.**

**Recommended Prep:** Mathematics 19a,b or 21a,b or 22a,b or 23a or 25a or 55a which may be taken concurrently; or an equivalent background in mathematics.

### Additional Course Attributes:

Attribute	Value(s)
FAS: Course Level	For Undergraduate and Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 131

Topological Spaces and Fundamental Group (111458)

*Denis Auroux*

2019 Fall (4 Credits)

**Schedule:** MW 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**First, an introduction to abstract topological spaces, their properties (compactness, connectedness, metrizable) and their corresponding continuous functions and mappings. Then, an introduction to algebraic topology including homotopy theory, fundamental groups and covering spaces.**

**Recommended Prep:** Some acquaintance with metric space topology as taught in Mathematics 22a,b, 23a,b, 25a,b, 55a,b, 101, 102, or 112; and with groups as taught in Mathematics 101, 122 or 55a.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students

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## Mathematics 132

Differential Topology (123212)

*Alexander Kupers*

2020 Spring (4 Credits)

**Schedule:** WF 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Differential manifolds, smooth maps and transversality. Winding numbers, vector fields, index and degree. Differential forms, Stokes' theorem, introduction to cohomology.**

**Recommended Prep:** Mathematics 22a,b, 23a,b or 25a,b or 55a,b or 112; or an equivalent background in mathematics.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students

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## Mathematics 136

Differential Geometry (111133)

*Sebastien Picard*

2019 Fall (4 Credits)

**Schedule:** TR 0130 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**The course is an introduction to Riemannian geometry with the focus (for the most part) being the Riemannian geometry of curves and surfaces in space where the fundamental notions can be visualized.**

**Recommended Prep:** Mathematics 19a,b or 21a,b or 22a,b or 23a or 25a or 55a (may be taken concurrently); or an equivalent background in mathematics.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	For Undergraduate and Graduate Students

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## Mathematics 137

Algebraic Geometry (116452)

*Brooke Ullery*

2020 Spring (4 Credits)

**Schedule:** MW 0130 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Affine and projective spaces, plane curves, Bezout's theorem, singularities and genus of a plane curve, Riemann-Roch theorem.**

**Recommended Prep:** Knowledge of the material in Mathematics 123.

**Requirements:** Prerequisite: Mathematics 123

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	For Undergraduate and Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 145A

Set Theory I (156119)

*Sebastien Vasey*

2019 Fall (4 Credits)

**Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**An introduction to set theory: ordinals, cardinals, transfinite induction, the cumulative hierarchy, ZFC, the theory of the infinite, and the basics of independence.**

**Recommended Prep:** Familiarity with proofs. A previous mathematics course at the level of Mathematics 23ab, 25ab, 55ab, 101, 102, or 112 would be enough.

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	For Undergraduate and Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 152 Section: SEM

Discrete Mathematics (116191)

*Paul Bamberg*

2020 Spring (4 Credits)

**Schedule:** TR 1200 PM - 0115 PM  
TR 1030 AM - 1145 AM

**Instructor Permissions:** Instructor

**Enrollment Cap:** 16

**An introduction to finite groups, finite fields, finite geometry, finite topology, combinatorics, graph theory,**

and (for section 2 only) elementary algebraic topology. A recurring theme of the course is the symmetry group of the regular icosahedron. Elementary category theory will be introduced as a unifying principle. Taught in a seminar format: students will gain experience in presenting proofs at the blackboard.

**Course Notes:** Covers material used in Computer Science 121 and Computer Science 124. Enrollment limited to 16.

**Recommended Prep:** For section 1: Mathematics 19b or 21b. Previous experience with proofs is not required.  
For section 2: Mathematics 23a or 25a or an equivalent background in mathematics that includes experience with proofs.

**Requirements:** Not to be taken in addition to Computer Science 20, Mathematics 55a/b or Mathematics 122.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

## Mathematics 153

Mathematical Biology-Evolutionary Dynamics (119502)

*Martin Nowak*

2019 Fall (4 Credits)

**Schedule:** TR 0300 PM - 0415 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Introduces basic concepts of mathematical biology and evolutionary dynamics: evolution of genomes, quasi-species, finite and infinite population dynamics, chaos, game dynamics, evolution of cooperation and language, spatial models, evolutionary graph theory, infection dynamics, somatic evolution of cancer.**

**Recommended Prep:** Mathematics 19a,b or 21a,b or 22a,b or 23a,b or 25a,b or 55a,b; or an equivalent background in mathematics.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	For Undergraduate and Graduate Students

## Mathematics 154

Probability Theory (113811)

*Christian Brennecke*

2020 Spring (4 Credits)

**Schedule:** MW 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**An introduction to probability theory. Discrete and continuous random variables; distribution and density functions for one and two random variables; conditional probability. Generating functions, weak and strong**

laws of large numbers, and the central limit theorem. Geometrical probability, random walks, and Markov processes.

**Recommended Prep:** A previous mathematics course at the level of Mathematics 19ab, 21ab, or a higher number. For students from 19ab or 21ab, previous or concurrent enrollment in Math 101 or 102 or 112 may be helpful. Freshmen who did well in Math 22a, 23a, 25a or 55a fall term are also welcome to take the course.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	For Undergraduate and Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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**Mathematics 155R** Section: 01

Combinatorics (116196)

*Sebastien Vasey*

2019 Fall (4 Credits)

**Schedule:** TR 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**An introduction to counting techniques and other methods in finite mathematics. Possible topics include: the inclusion-exclusion principle and Mobius inversion, graph theory, generating functions, Ramsey's theorem and its variants, probabilistic methods.**

**Recommended Prep:** Prerequisites: familiarity with proofs. A previous mathematics course at the level of Mathematics 23ab, 25ab, 55ab, 101, 102, or 112 would be enough.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	For Undergraduate and Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

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**Mathematics 157**

Mathematics in the World (159763)

*Joseph D. Harris*

2020 Spring (4 Credits)

**Schedule:** TR 0130 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**An interactive introduction to problem solving with an emphasis on subjects with comprehensive applications. Each class will be focused around a group of questions with a common topic: logic, information, number theory, probability, and algorithms.**

**Recommended Prep:** Mathematics 19b or 21b or 22a,b or 23a; or an equivalent background in mathematics. More importantly, students should have a broad mathematical curiosity and be eager to brainstorm during in-class



problem solving sessions.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Undergraduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 212A

Advanced Real Analysis (116137)

*Curtis McMullen*

2019 Fall (4 Credits)

**Schedule:**

TR 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Functional analysis and applications. Topics may include distributions, elliptic regularity, spectral theory, operator algebras, unitary representations and ergodic theory.**

**Recommended Prep:** Knowledge of the material in Mathematics 114.

**Requirements:** Prerequisite: Mathematics 114

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 213A

Advanced Complex Analysis (110880)

*Peter Kronheimer*

2019 Fall (4 Credits)

**Schedule:**

WF 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Fundamentals of complex analysis, and further topics such as elliptic functions, canonical products, conformal mappings, the zeta function and prime number theorem, and Nevanlinna theory.**

**Prerequisites:** Basic complex analysis, topology of covering spaces, differential forms.

**Recommended Prep:** Basic complex analysis, topology of covering spaces, differential forms.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

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**Mathematics 213BR** Section: LEC

Riemann Surfaces (111824)

*Shing-Tung Yau*

2020 Spring (4 Credits)

**Schedule:** TR 1030 AM - 1145 AM**Instructor Permissions:** None**Enrollment Cap:** n/a

**Fundamentals of algebraic curves as complex manifolds of dimension one. Topics may include branched coverings, sheaves and cohomology, potential theory, uniformization and moduli.**

**Recommended Prep:** Knowledge of the material in Mathematics 213a.**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration

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**Mathematics 221**

Algebra (123232)

*Brooke Ullery*

2019 Fall (4 Credits)

**Schedule:** MW 0300 PM - 0415 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

**A first course in Algebra: Noetherian rings and modules, Hilbert basis theorem, Cayley-Hamilton theorem, integral dependence, Galois theory, Noether normalization, the Nullstellensatz, localization, primary decomposition. Representation theory of finite groups. Introduction to Lie groups and Lie algebras: definitions, the exponential maps, semi-simple Lie algebras, examples.**

**Recommended Prep:** Mathematics 123.**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students

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**Mathematics 222**

Lie Groups and Lie Algebras (123238)

*Dennis Gaitsgory*

2020 Spring (4 Credits)

**Schedule:** TR 1200 PM - 0115 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

**Lie theory, including the classification of semi-simple Lie algebras and/or compact Lie groups and their representations.**

**Recommended Prep:** Knowledge of the material in Mathematics 114, 123 and 132.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Graduate Students

**Mathematics 223A** Section: LECT

Algebraic Number Theory (123239)

*Fabian Gundlach*

2019 Fall (4 Credits)

**Schedule:** TR 1200 PM - 0115 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

**A graduate introduction to algebraic number theory. Topics: the structure of ideal class groups, groups of units, a study of zeta functions and L-functions, local fields, Galois cohomology, local class field theory, and local duality.**

**Recommended Prep:** Knowledge of the material in Mathematics 129.**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 229X** Section: LEC

Introduction to Analytic Number Theory (123242)

*Noam D. Elkies*

2020 Spring (4 Credits)

**Schedule:** TR 1030 AM - 1145 AM**Instructor Permissions:** None**Enrollment Cap:** n/a

**Fundamental methods, results, and problems of analytic number theory. Riemann zeta function and the Prime Number Theorem; Dirichlet's theorem on primes in arithmetic progressions; lower bounds on discriminants from functional equations; sieve methods, analytic estimates on exponential sums, and their applications.**

**Recommended Prep:** Knowledge of the material in Mathematics 113 and 123.**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students

**Mathematics 230A**

Differential Geometry (113369)

*Sebastien Picard*

2019 Fall (4 Credits)

**Schedule:** TR 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Smooth manifolds (vector fields, differential forms, and their algebraic structures; Frobenius theorem), Riemannian geometry (metrics, connections, curvatures, geodesics), Lie groups, principal bundles and associated vector bundles with their connections, curvature and characteristic classes. Other topics if time permits.**

**Recommended Prep:** Knowledge of the material in Mathematics 132 and 136.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 230BR

Advanced Differential Geometry (115039)

*Valentino Tosatti*

2020 Spring (4 Credits)

**Schedule:** TR 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**A continuation of Mathematics 230a. Topics in complex differential geometry: Complex Manifolds. Kahler metrics. Ricci curvature. Calabi Conjecture and its proof. Miyaoka-Yau Chern number inequalities and uniformization. Uniqueness of Kahler structure of projective spaces. Calabi-Yau manifolds and their moduli.**

**Recommended Prep:** Knowledge of the material in Mathematics 230a.

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 231A

Algebraic Topology (123243)

*Alexander Kupers*

2019 Fall (4 Credits)

**Schedule:** MF 0300 PM - 0415 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Covering spaces and fibrations. Simplicial and CW complexes, Homology and cohomology, universal coefficients and Künneth formulas. Hurewicz theorem. Manifolds and Poincaré duality.**

**Recommended Prep:** Knowledge of the material in Mathematics 131 and 132.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science

All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students

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## Mathematics 231BR

Advanced Algebraic Topology (123433)

2020 Spring (4 Credits)

**Schedule:** MW 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Continuation of Mathematics 231a. Topics may include stable homotopy theory, topological or algebraic K-theory, characteristic classes and vector bundles, cobordism, and categorical homotopy theory.**

**Recommended Prep:** Knowledge of the material in Mathematics 231a.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Graduate Students

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## Mathematics 232A

Introduction to Algebraic Geometry I (123441)

*Man-Wai Cheung*

2019 Fall (4 Credits)

**Schedule:** MW 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Introduction to complex algebraic curves, surfaces, and varieties.**

**Recommended Prep:** Knowledge of the material in Mathematics 123 and 132 and 137.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Graduate Students

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## Mathematics 232BR

Introduction to Schemes (123444)

*Man-Wai Cheung*

2020 Spring (4 Credits)

**Schedule:** MW 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Introduction to the theory and language of schemes. Textbooks: Algebraic Geometry by Robin Hartshorne and Geometry of Schemes by David Eisenbud and Joe Harris. Weekly homework will constitute an important part of the course.**

**Recommended Prep:** Knowledge of the material in Mathematics 232a.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Graduate Students

**Mathematics 243**

Evolutionary Dynamics (119511)

*Martin Nowak*

2020 Spring (4 Credits)

**Schedule:** TR 0300 PM - 0415 PM**Instructor Permissions:** None**Enrollment Cap:** n/a**Advanced topics of evolutionary dynamics. Seminars and research projects.****Recommended Prep:** Experience with mathematical biology at the level of Mathematics 153.**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 257Y**

Techniques of Pluricanonical Sections and Jet Differentials of Complex Manifolds (212695)

*Yum-Tong Siu*

2019 Fall (4 Credits)

**Schedule:** TR 0300 PM - 0415 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

**A discussion of recent techniques and results and open problems involving holomorphic pluricanonical sections and jet differential of of complex manifolds. Topics: The techniques introduced for the deformational invariance of plurigenera and the solution of a number of conjectures on optimal constants in alysis arising from such techniques. The analytic approach to the finite generation of the canonical ring and the abundance conjecture. The hyperbolicity of a generic high-degree complex hypersurface in a complex projective space and more generally the second main theorem in Nevanlinna theory for an entire holomorphic curve in a complex projective space and its countin function for a smooth complex hypersurface.**

**Recommended Prep:** Prerequisite for the course is basic knowledge in complex analysis, for example, at the level of Mathematics 213a.**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students

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## Mathematics 259X

Moduli Spaces in Algebraic Geometry (212692)

*Dori Bejleri*

2019 Fall (4 Credits)

**Schedule:** MW 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**The existence and construction of moduli spaces parametrizing geometric objects is a central problem in algebraic geometry. We will study the various tools and techniques used to address this problem, as well as applications. Possible topics include Hilbert schemes, geometric invariant theory, algebraic stacks, and compactifications of moduli spaces of varieties.**

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 261X

Embedded Contact Homology (212867)

*Christopher Gerig*

2019 Fall (4 Credits)

**Schedule:** WF 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**ECH is one of the 3 isomorphic Floer homologies which apply to 3-manifolds, (symplectic) 4-manifolds, and relations between them. It is defined by "counting" holomorphic curves and periodic orbits, and a big part of this course will be to study its foundations and difficulties (which plague other contact homologies. Some applications of ECH to be described include 1) distinguishing contact 3-manifolds and symplectic 4-manifolds, 2) the Weinstein conjecture on the existence of periodic orbits, and 3) the relations to Seiberg-Witten theory.**

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Graduate Students

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## Mathematics 262Y

Analytic Methods in Kahler Geometry (212872)

*Shing-Tung Yau*

2019 Fall (4 Credits)

**Schedule:** TR 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**We will discuss methods from nonlinear analytics to construct metrics and connections on bundles in Kahler and nonlinear geometry.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 263X**

Mirror Symmetry for Toric Varieties and Other GIT Quotients (212881)

*Elana Kalashnikov*

2020 Spring (4 Credits)

**Schedule:**

MW 0130 PM - 0245 PM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

**GIT quotient construction of toric varieties, relation to fan and polytope constructions, divisors, smoothness. Quantum cohomology and the moduli space of stable maps. J functions and Givental's Lagrangian cone. Quantum Lefschetz. The I function and the Hori-Vafa mirror for toric complete intersections. Non toric GIT quotients, especially quiver flag varieties. The Abelian/non-Abelian correspondence. Laurent polynomial mirrors for toric complete intersections and their properties. Mirrors of non-toric Fano varieties and the Fano classification programme.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students

**Mathematics 264X**

Algebraic Cobordism (212870)

*Elden Elmanto*

2020 Spring (4 Credits)

**Schedule:**

WF 0300 PM - 0415 PM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

**Algebraic cobordism is a cohomology theory for schemes constructed by Vladimir Voevodsky in the context of stable motivic homotopy theory, and greatly expanded by Marc Levine and Fabien Morel. It is, in some sense, simultaneously a generalization of "Fulton-style" intersection theory for Chow groups and a simplification of the latter theory. The course will revolve around a theorem of Levine and Morel which recovers the Chow groups from algebraic cobordism. To do this, we will explain the notion of an oriented theory in algebraic geometry and prove that algebraic cobordism is the "universal" oriented theory. From there, we will prove the basic theorems (such as localization, homotopy invariance, computation of the coefficient ring and the degree formula) and give a sampler of computations. Further topics will depend on the interests of the participants.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Graduate Students
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science



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**Mathematics 269** Section: 1

Topics in Combinatorics: Schubert Calculus (212690)

*Lauren Williams*

2020 Spring (4 Credits)

**Schedule:**

MW 1200 PM - 0115 PM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

This course will provide an elementary introduction to the **combinatorial aspects of Schubert calculus**, the part of enumerative geometry dealing with classical varieties such as Grassmanians, flag varieties, and their Schubert varieties. A classical example of a Schubert calculus question is the following: given a generic configuration of four 2-dimensional subspaces in a complex 4-dimensional space, how many 2-dimensional subspaces intersect each of these four in a line? To be able to answer this and related questions, one needs to concretely understand the structure of the cohomology ring of the Grassmanian. In this course we will develop the necessary combinatorial machinery to answer such enumerative questions, including Young tableaux, the Bruhat order, symmetric functions, and Schubert polynomials. More advanced topics may include (time-permitting): quantum cohomology rings, toric Schur functions, real Schubert calculus.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Undergraduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science

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**Mathematics 270X**

Topology and Condensed Matter Physics (212890)

*Michael Hopkins*

2020 Spring (4 Credits)

**Schedule:**

MW 0130 PM - 0245 PM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

This course will explain the role of algebraic topology in the classification of topological phases of matter. We will cover basic solid state physics, lattice models, topological quantum field theories, reflection positivity, and the classification of invertible topological field theories using homotopy theory.

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Graduate Students

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**Mathematics 272Y**

Rational Lattices and Their Theta Functions (212930)

*Noam D. Elkies*

2019 Fall (4 Credits)

**Schedule:**

MW 1030 AM - 1145 AM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

**Construction and uses of modular forms from theta functions (with harmonic and periodic weights) attached to rational quadratic forms. Applications include radial and angular distribution of lattice vectors, classification of integral quadratic forms of low rank and discriminant, and connections with error-correcting codes.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students

**Mathematics 274Y**

Spectral Theory and Quantum Spin Systems (212868)

*Marius Lemm*

2020 Spring (4 Credits)

**Schedule:**

WF 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Quantum spin systems lie at the interface of theoretical physics and mathematical spectral theory. They allow us to study true many-body phenomena, like phase transitions, within a solid mathematical framework. In this topics class, we will study the basic notions, main results, and open problems, of quantum spin systems. Two highlights will be the derivation of a spectral gap in the AKLT chain and the proof of spontaneous breaking of SU(2) symmetry in the Heisenberg antiferromagnet by Dyson, Lieb, and Simon. We will mainly use methods from spectral theory and matrix analysis, as well as some representation theory of SU(2).**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Primarily for Graduate Students
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

**Mathematics 281Y**

Non-Kahler Calabi-Yau Manifolds (212869)

*Sebastien Picard*

2020 Spring (4 Credits)

**Schedule:**

TR 0130 AM - 0245 AM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**This is a topics course on non-Kahler complex geometry, with a focus on non-Kahler Calabi-Yau threefolds. These objects were proposed as heterotic string compactifications by C.Hull and A. Strominger. Some of the mathematical structures which emerge include Hermitian-Yang-Mills connections, special holonomy constraints, Michelsohn's notion of balanced metrics, and Hitchin's generalized complex geometry. We will also discuss analytic methods in this field, as developed by J. Li, J.-X. Fu, and S.T. Yau.**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students

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## Mathematics 286X

Topics in Number Theory: Arithmetic Statistics (212873)

*Fabian Gundlach*

2020 Spring (4 Credits)

**Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**We will investigate different counting problems in algebraic number theory. For example, how frequent are number fields of a given degree or given Galois group? We will give an overview of different approaches, including techniques from the geometry of numbers and class field theory. Time permitting, related algorithmic problems will be discussed.**

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Primarily for Graduate Students

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## Mathematics 289

Topics on Knots, 3 and 4-Manifolds (212944)

2019 Fall (4 Credits)

**Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**The main goal will be to study smooth 4-manifolds. The plan is to start with knots in 3-manifolds and their interactions with smooth 4-manifold theory. Topics will be chosen from the topology of 4-manifolds via their handlebodies, such as various constructions of 3-and 4-manifolds, by using techniques from gluing, carving, roping, corks, plugs, Gluck construction, and applications of some 4-manifold invariants to these constructions, and state some open problems.**

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Primarily for Graduate Students

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## Mathematics 300

Teaching Undergraduate Mathematics (124821)

*Jameel Al-Aidroos*

*Robin Gottlieb*

2019 Fall (4 Credits)

**Schedule:** T 0130 PM - 0245 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Become an effective instructor. This course focuses on observation, practice, feedback, and reflection providing insight into teaching and learning. Involves iterated videotaped micro-teaching sessions, accompanied by individual consultations. Required of all mathematics graduate students.**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Not Available for Cross Registration
FAS Divisional Distribution	None
FAS: Course Level	Graduate Course

**Mathematics 304**

Topics in Algebraic Topology (121078)

*Michael Hopkins*

2020 Spring (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Requirements:** Prerequisite: Graduate Students Only**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

**Mathematics 304**

Topics in Algebraic Topology (121078)

*Michael Hopkins*

2019 Fall (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Requirements:** Prerequisite: Graduate Students Only**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

**Mathematics 305**

Topics in Symplectic Geometry (207522)

*Denis Auroux*

2020 Spring (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science

**Mathematics 305**

Topics in Symplectic Geometry (207522)

*Denis Auroux*

2019 Fall (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

**Mathematics 316**

Topics in Algebraic Geometry (203255)

*Arnav Tripathy*

2020 Spring (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

**Mathematics 316**

Topics in Algebraic Geometry (203255)

*Arnav Tripathy*

2019 Fall (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Graduate Course

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## Mathematics 318

Topics in Number Theory (121353)

*Barry Mazur*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:**

**Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

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## Mathematics 318

Topics in Number Theory (121353)

*Barry Mazur*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:**

**Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 320

Topics in Geometric Representation Theory (205137)

*Ana Balibanu*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:**

**Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 320

Topics in Geometric Representation Theory (205137)

*Ana Balibanu*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:**

**Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	None
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 321

Topics in Mathematical Physics (118656)

*Arthur Jaffe*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:**

**Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

---

## Mathematics 321

Topics in Mathematical Physics (118656)

*Arthur Jaffe*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:**

**Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	None
FAS: Course Level	Graduate Course

All: Cross Reg Availability	Available for Harvard Cross Registration
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## Mathematics 327

Topics in Several Complex Variables (113647)

*Yum-Tong Siu*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 327

Topics in Several Complex Variables (113647)

*Yum-Tong Siu*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	None
FAS: Course Level	Graduate Course

---

## Mathematics 330

Topics in Algebraic Geometry (213629)

*Dori Bejleri*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science



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**Mathematics 330** Section: 01

Topics in Algebraic Geometry (213628)

*Dori Bejleri*

2019 Fall (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

---

**Mathematics 332**

Topics in Geometry and Topology (205138)

*Alexander Kupers*

2020 Spring (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Requirements:****Prerequisite: Graduate Students Only****Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

---

**Mathematics 332**

Topics in Geometry and Topology (205138)

*Alexander Kupers*

2019 Fall (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Requirements:****Prerequisite: Graduate Students Only****Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	None
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 333

Topics in Complex Analysis, Dynamics and Geometry (126825)

*Curtis McMullen*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 333

Topics in Complex Analysis, Dynamics and Geometry (126825)

*Curtis McMullen*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	None
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 334

Topics in Algebraic K-Theory (213615)

*Elden Elmanto*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

---

## Mathematics 334

Topics in Algebraic K-Theory (213614)

*Elden Elmanto*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 335

Topics in Differential Geometry and Analysis (116319)

*Cliff Taubes*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** Prerequisite: Graduate Students Only

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 335

Topics in Differential Geometry and Analysis (116319)

*Cliff Taubes*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** Prerequisite: Graduate Students Only

### Additional Course Attributes:

Attribute	Value(s)
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

---

## Mathematics 340

Topics in Model Theory (205139)

*Sebastien Vasey*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

### Additional Course Attributes:

Attribute	Value(s)
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

---

## Mathematics 340

Topics in Model Theory (205139)

*Sebastien Vasey*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science

---

## Mathematics 345

Topics in Geometry and Topology (113664)

*Peter Kronheimer*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 345

Topics in Geometry and Topology (113664)

*Peter Kronheimer*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 346Y

Topics in Analysis: Quantum Dynamics (121102)

*Hong-Tzer Yau*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Graduate Course

---

## Mathematics 346Y

Topics in Analysis: Quantum Dynamics (121102)

*Hong-Tzer Yau*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science

All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

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## Mathematics 352

Topics in Algebraic Number Theory (125869)

*Mark Kisin*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 352

Topics in Algebraic Number Theory (125869)

*Mark Kisin*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 355

Topics in Number Theory (213619)

*Fabian Gundlach*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

FAS Divisional Distribution	Science & Engineering & Applied Science
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## Mathematics 355

Topics in Number Theory (213618)

*Fabian Gundlach*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science

## Mathematics 360

Topics in Algebraic Combinatorics (207538)

*Lauren Williams*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

## Mathematics 360

Topics in Algebraic Combinatorics (207538)

*Lauren Williams*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	None

## Mathematics 364

Topics in Algebraic Geometry (203316)

*Brooke Ullery*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 364

Topics in Algebraic Geometry (203316)

*Brooke Ullery*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science

---

## Mathematics 365

Topics in Differential Geometry (114080)

*Shing-Tung Yau*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:**

**Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	None

---

## Mathematics 365

Topics in Differential Geometry (114080)

*Shing-Tung Yau*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a



**Requirements:** Prerequisite: Graduate Students Only

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	None
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

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**Mathematics 370** Section: 01

Topics in Linear Algebra and Multivariable Calculus; and Their Applications (205357)

*Paul Bamberg*

2020 Spring (4 Credits) **Schedule:** TBD

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**Course Notes:** This course is for graduate students only.

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	None
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

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**Mathematics 375**

Topics in Mathematical Physics: Quantum Mechanics (207539)

*Christian Brennecke*

2020 Spring (4 Credits) **Schedule:** TBD

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

---

**Mathematics 375**

Topics in Mathematical Physics: Quantum Mechanics (207539)

*Christian Brennecke*

2019 Fall (4 Credits) **Schedule:** TBD

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	None

All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 377

Topics in Complex Geometry (207540)

*Sebastien Picard*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

---

## Mathematics 377

Topics in Complex Geometry (207540)

*Sebastien Picard*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
FAS: Course Level	Graduate Course
FAS Divisional Distribution	Science & Engineering & Applied Science
All: Cross Reg Availability	Available for Harvard Cross Registration

---

## Mathematics 380

Topics in Toric Geometry (213617)

*Elana Kalashnikov*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

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## Mathematics 380

Topics in Toric Geometry (213616)

Elana Kalashnikov

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	Science & Engineering & Applied Science
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 381

Introduction to Geometric Representation Theory (121082)

*Dennis Gaitsgory*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	None
FAS: Course Level	Graduate Course

---

## Mathematics 381

Introduction to Geometric Representation Theory (121082)

*Dennis Gaitsgory*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
FAS Divisional Distribution	None
All: Cross Reg Availability	Available for Harvard Cross Registration

---

## Mathematics 382

Topics in Algebraic Geometry (111210)

Joseph D. Harris

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
FAS Divisional Distribution	None
All: Cross Reg Availability	Available for Harvard Cross Registration

---

## Mathematics 382

Topics in Algebraic Geometry (111210)

Joseph D. Harris

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	None
FAS: Course Level	Graduate Course

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## Mathematics 385

Topics in Set Theory (110218)

W. Hugh Woodin

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	None
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

---

## Mathematics 385

Topics in Set Theory (110218)

*W. Hugh Woodin*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS Divisional Distribution	None
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

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## Mathematics 388

Topics in Mathematics and Biology (118701)

*Martin Nowak*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	None

---

## Mathematics 388

Topics in Mathematics and Biology (118701)

*Martin Nowak*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

**Additional Course Attributes:**

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course

FAS Divisional Distribution	None
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## Mathematics 389

Topics in Number Theory (119721)

*Noam D. Elkies*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

### Additional Course Attributes:

Attribute	Value(s)
FAS Divisional Distribution	None
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration

## Mathematics 389

Topics in Number Theory (119721)

*Noam D. Elkies*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:** **Prerequisite: Graduate Students Only**

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	None
FAS: Course Level	Graduate Course

## Mathematics 390

Topics in analysis and Quantum Physics (207547)

*Marius Lemm*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

---

## Mathematics 390

Topics in analysis and Quantum Physics (207547)

*Marius Lemm*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

Attribute	Value(s)
FAS: Course Level	Graduate Course
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	Science & Engineering & Applied Science

---

## Mathematics 395

Topics in Cluster Algebra (205141)

*Man-Wai Cheung*

2020 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:**

**Prerequisite: Graduate Students Only**

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS Divisional Distribution	None
FAS: Course Level	Graduate Course

---

## Mathematics 395

Topics in Cluster Algebra (205141)

*Man-Wai Cheung*

2019 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Requirements:**

**Prerequisite: Graduate Students Only**

### Additional Course Attributes:

Attribute	Value(s)
All: Cross Reg Availability	Available for Harvard Cross Registration
FAS: Course Level	Graduate Course
FAS Divisional Distribution	None