2018  2019

MATHEMATICS GRADUATE HANDBOOK

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I. GRADUATE DEGREE PROGRAMS IN MATHEMATICS

The Mathematics Department at UC Santa Cruz offers programs leading to the M.A. and Ph.D. degree. Students admitted to the Ph.D. program may receive an M.A. degree en route to the Ph.D. Students admitted to the M.A. program may transfer to the Ph.D. program upon passing the required preliminary examinations at the Ph.D. level.

M.A. DEGREE REQUIREMENTS

1. Students are required to complete **four of the following courses** from the three core sequences:
   - MATH 200, Algebra I
   - MATH 201, Algebra II
   - MATH 202, Algebra III
   - MATH 204, Analysis I
   - MATH 205, Analysis II
   - MATH 206, Analysis III
   - MATH 208, Manifolds I
   - MATH 209, Manifolds II
   - MATH 210, Manifolds III
2. Students are also required to complete **five additional courses in mathematics**. Courses in a related subject may be substituted by approval from the Graduate Vice Chair.
3. **Additional requirements** for the M.A. degree are dependent on the student's chosen track: the thesis track or the comprehensive examination track.

Thesis Track

Students are required to complete a master's thesis. A master's thesis does not have to consist of original research results. At the minimum, it should show mastery of a specific subject area that goes beyond the knowledge taught in the core sequences in algebra, analysis, or geometry. This track is recommended for students that want to transfer into a top Ph.D. program.

The student, in consultation with the Graduate Vice Chair, is responsible for selecting a master's thesis reading committee. The majority of the membership of a thesis reading committee shall be members of the Santa Cruz Division of the Academic Senate. The Graduate Division must approve the committee.

The Nominations for Master's Thesis Reading Committee Form must be completed and submitted by the end of the second week of the quarter in which the degree will be granted. The form can be found on the Graduate Division website or can be provided by the Mathematics Department. The form should be turned in to the Graduate Advisor and Program Coordinator for review and submission to the Graduate Division.

More information about thesis submission can be found at the Graduate Division website.

Comprehensive Examination Track
Students are required to obtain a second-level pass on one of three written preliminary examinations: algebra, analysis, or geometry. A second-level pass signifies that the student has a very good understanding of the basic concepts, but not necessarily enough to conduct independent research.

PH.D. DEGREE REQUIREMENTS

Students are required to complete *all* of the following:

1. Obtain a first-level pass on at least one of the three written preliminary examinations, and a second-level pass on at least one other. Students must complete the full sequence in the track associated with the preliminary examination they did not achieve a first-level pass*;
2. Satisfy the foreign language requirement;
3. Pass the oral qualifying examination;
4. Complete three quarters as a Teaching Assistant;
5. Complete the required coursework: six graduate courses in mathematics other than Math 200, 201, 202, 204, 205, 206, 208, 209 and 210. No more than three courses may be independent study or thesis research courses.
6. Write a Ph.D. thesis (dissertation).

**Requirements may be met through the following three combinations:*

| *1st level pass* | *1st level pass* | *1st level pass* |

| *1st level pass* | *1st level pass* | *Sequence* |

| *1st level pass* | *2nd level pass + Sequence* | *Sequence* |

ADVISING

Entering graduate students are advised initially by the Graduate Vice Chair, and then assigned a faculty mentor who will be an ongoing advising resource for the student. Within the first two years, and typically after passing the preliminary examinations, the student selects a faculty advisor in the area of the student's research interest. This is done in consultation with the Graduate Vice Chair.

Each graduate student is expected to consult with his or her advisor to formulate a plan of student and research. The student's advisor ultimately will be the student's thesis advisor.

Annual meetings with the Graduate Vice Chair and the Graduate Advisor and Program Coordinator are conducted with each M.A. and Ph.D. student on a one-on-one basis. These meetings serve to notify the student of their current progress within the program and outline expectations for the continuation of normative progress toward the Ph.D. degree. At this time, each student is determined to be making either satisfactory or unsatisfactory progress.

CORE SEQUENCES

A three-course sequence in each of the three fields of algebra, analysis, and geometry-topology (manifolds) will be offered each year. Preliminary examinations will be given for each core sequence at the beginning, middle, and end of each academic year.

First-level passage of a preliminary examination satisfies the core sequence requirement for that field. Ph.D. students are required to complete the full core sequence in the field associated with the preliminary examination in which they do not achieve a first-level pass. The core sequences are as follows:

- MATH 200, Algebra I
- MATH 201, Algebra II
- MATH 202, Algebra III
- MATH 204, Analysis I
- MATH 205, Analysis II
- MATH 206, Analysis III
- MATH 208, Manifolds I
- MATH 209, Manifolds II
- MATH 210, Manifolds III

PRELIMINARY EXAMINATIONS

Preliminary examinations are given for each core sequence in the fields of algebra, analysis, and geometry-topology at the beginning, middle, and end of each academic year. The exams will be designed and graded by a committee of three members.

A first-level pass signifies that the student has the basic knowledge to start research with a thesis advisor in this particular area. A second-level pass signifies that the student has a very good understanding of the basic concepts, but not necessarily enough to conduct independent research.

Ph.D. students must obtain a first-level pass on at least one of the three written preliminary examinations and a second-level pass on at least one other. Students must complete the full three-course sequence in the field associated with the preliminary examination in which they did not achieve a first-level pass. Students may take the preliminary examinations as often as they wish.

Ph.D. students should complete the preliminary examinations and core sequence requirements by the end of their second year in order to make satisfactory progress. If a graduate student does not fulfill these requirements by the end of their second year, they may be placed on academic probation, depending on their progress in the program. If a graduate student has not fulfilled these requirements by the end of their third year, they are subject to dismissal from the program.

II. TOPICS AND REFERENCES FOR PRELIMINARY EXAMINATIONS

TOPICS FOR THE ALGEBRA PRELIMINARY EXAMINATION

1. **Linear Algebra**
   - Matrices, determinants, vector spaces, subspaces, bases, dimensions
   - Linear maps, isomorphisms, kernel, image, rank
   - Characteristic polynomial, eigenvalues, eigenvectors
   - Vector spaces with symmetric and alternating inner products
   - Matrix representrations of linear maps and inner products
   - Normal forms for symmetric, hermetian, and general linear maps, diagonalization
   - Orthogonal, unitary, hermitian matrices
   - Multilinear algebra: tensor products, exteriors, symmetric algebras
2. **Group Theory**
   - Groups, subgroups, cosets, Lagrange's theorem, the homomorphism theorems, quotient groups
   - Permutation groups, alternating groups, matrix groups, dihedral groups, quaternion groups
   - Free groups, groups described by generators and relations, free abelian groups
   - Automorphisms, direct and semidirect products
   - P-groups, the class equation, applications
   - Group actions on a set, Sylow theorems
   - Nilpotent and solvable groups, simple groups
3. **Ring and Module Theory**
   - Ideals, integral domains, quotients rings, polynomial rings, matrix rings
   - Euclidian domains, principal ideal domains, unique factorization
   - Chinese Remainder Theorem, prime ideals, localization
   - Modules over a PID, applications to a normal form
   - Free modules, short exact sequences
4. **Field Theory**
   - Algebraic and transcendental extensions, normal extensions, separability
   - Finite algebraic extensions, splitting fields, Galois theory, perfect fields

- Finite field
- Cyclotomic polynomials, cyclotomic extensions of the rationals and of finite fields

Textbooks and references: *Algebra by Artin, Abstract Algebra second edition by Dummit and Foote, Algebra by Lang, Topics in Algebra by Herstein, Algebra by Hungerford, Algebra by Jacobson.*

TOPICS FOR THE ANALYSIS PRELIMINARY EXAMINATION

1. **Basic Analysis**
   - Sequences and series functions, uniform convergence, Fourier series
   - Differentiation and integration of real and complex valued functions
   - Functions of bounded variation, the Riemann-Stieltjes integral
   - The implicit function theorem, the inverse function theorem
2. **General Topology**
   - Open and closed sets, topological spaces, bases, Hausdorff spaces
   - Continuous functions, the product topology, Tychonoff theorem
   - Locally compact spaces, Urysohn's lemma, partition of unity
   - Nowhere dense set, set of the first category, Baire category theorem
3. **Metric Spaces**
   - Distance function, metric spaces
   - Convergence, Cauchy sequences, completeness
   - The contraction mapping theorem
   - Continuous functions on metric spaces
   - Arzela-Ascoli theorem and applications
4. **Measure and Integration**
   - Lebesgue measure, Borel sets, measurable sets, additivity
   - Abstract measure, σ-algebra, construction of measure, Caratheodory criterion
   - Measurable function, Egorov theorem
   - Pointwise convergence, uniform convergence, Vitali-Lusin theorem
   - Lebesgue integration, monotone convergence theorem, Fatou lemma
   - Lebesgue dominated convergence theorem, convergence in measure
   - Relations between different notions of convergence
   - Product measure, complete measure, Fubini theorem

- Lp space, Holder and Minkowski inequalities, Cheveshev's inequality
- Radon-Nikodym theorem, Lebesgue theorem

5. **Complex Analysis**
    - analytic functions, Cauchy-Riemann equations
    - Cauchy integral theorem, Cauchy integral formula
    - Singularities, poles, the theory of residues, evaluation of integrals
    - Maximum modulus theorem
    - Argument principle and Rouche's theorem
    - Linear fractional transformation
6. **Functional Analysis**
    - normal linear space, Banach space
    - Linear functional, linear operator, continuity and boundedness
    - Hahn-Banach theorem
    - Uniform boundedness theorem
    - Open mapping and closed graph theorems
    - Weak and weak* topology, reflexive space, Banach-Alaoglu theorem
    - Inner product, Hilbert space, orthonormal bases, Riesz representation theorem
    - Self-adjoint operator, compact operator, and their spectrum
    - Fredholm alternative property, Fredholm operator
    - Fourier transform, rapidly decreasing function, Fourier transform on L2

Textbooks and references: *The Way of Analysis by Robert Strichartz, Principles of Mathematical Analysis by Walter Rudin, Elementary Real Analysis by Brian Thomson, Judith Bruckner and Andrew Bruckner, Real and Complex Analysis by Walter Rudin, Real Variable and Integration by John Benedetto, Real Analysis by Royden, Measure and Integration Theory by H. Widom, Complex Analysis by Ahlfors, Complex Variables and Applications by Churchill, Functional Analysis by Rudin, Functional Analysis by Ronald Larson, Functional Analysis by Yosida, Partial Differential Equations by Evans.*

TOPICS FOR THE GEOMETRY-TOPOLOGY PRELIMINARY EXAMINATION

1. **Manifold and Tangent Bundle**
    - Examples of manifolds, orientation
    - Inverse function theorem and implicit function theorem, immersion, submersion

- Partition of unity, embedding, Whitney embedding theorem
- Sard's theorem
- Tangent vector, tangent bundle, push-forward
- ODE on manifolds, existence and uniqueness theory
- Flows, Lie bracket, Forbenius' theorem
- Riemannian metrics, examples
- Basic Lie groups

2. Differential Forms and Integration on Manifolds

- Cotangent bundle, exterior differentiation, contraction, Lie derivative, de Rham differential, Cartan formula
- Integration on manifolds, Stokes' theorem
- De Rham cohomology, de Rham theorem, examples
- More applications of Stokes; theorem, degree and winding number
- Frobenius' theorem, foliations, non-integrable distributions

3. Fundamental Group and Covering Space

- Fundamental groups, calculations, Van Kampen theorem
- Covering spaces, properties, classification of covering spaces

4. (Co)homology

- Simplicial and CW complexes, examples
- Singular (co)homology, properties, calculations, exact sequences for singular (co)homology
- Betti number, Euler number
- Eilenberg-Steenrod axioms for homology
- Mayers-Vietoris sequences
- Cup and cap products, and Poincare duality for manifolds
- Degree, Euler characteristics, applications
- Lefschetz fixed point theorem and applications

<u>Textbooks and references</u>: *Introduction to Smooth Manifolds by John M. Lee, Foundations of Differential Manifolds and Lie Groups by Frank W. Warner, An Introduction to Differentiable Manifolds and Riemannian Geometry by W. M. Boothby, Algebraic Topology by Allen Hatcher (available online), Introduction to Topology by V. A. Vassiliev, A Basic Course in Algebraic Topology by W. S. Massey, Algebraic Topology by Marvin J. Greenburg, Riemannian Geometry by Manfredo do Carmo.*

III. DEGREE PROGRAMS AND TIMETABLE

DEGREE TIMETABLE

Degree	Requirement	Targeted Completion
M.A.	Completion of all requirements	End of second year
Ph.D.	Preliminary Exams	End of second year
Ph.D.	Language Exam	End of third year
Ph.D.	Oral Qualifying Exam	Between seventh and twelfth quarters
Ph.D.	Dissertation	Four to six years

M.A. DEGREE TIMELINE

Students enrolled in the M.A. program are expected to meet the requirements of the degree within two years, whether on the thesis track or the comprehensive examination track. Enrollment beyond this time requires the approval of the Graduate Vice Chair.

Students enrolled in the M.A. program who wish to transfer to the Ph.D. program will be allowed to do so if they have passed the preliminary examinations in accordance with the Ph.D. examination requirements. Students in the Ph.D. program typically receive an M.A. degree in the course of their studies.

PH.D. DEGREE TIMELINE

Students enrolled in the Ph.D. program are expected to meet the timetable above, which leads to a Ph.D. in four to six years. Enrollment in the Ph.D. program beyond six years requires the approval of the Graduate Vice Chair.

Preliminary Exams

Ph.D. students should complete their preliminary exams and introductory sequence requirements by the end of their second year in order to make satisfactory progress. If a graduate student does not fulfill the above requirement by the end of their second year, they may be placed on academic probation depending on their progress. If a graduate student has not fulfilled the above requirements by the end of their third year, they may be subject to dismissal from the program.

Advancing to Candidacy

To make satisfactory progress, Ph.D. students should advance to candidacy by the end of their fourth year. A Ph.D. student who has not advanced to candidacy by the end of their fourth year may be placed on academic probation or dismissed from the program.

IV. FOREIGN LANGUAGE REQUIREMENT

The foreign language requirement must be satisfied before taking the oral qualifying examination. Graduate students in the Ph.D. program are required to demonstrate knowledge of French, German, or Russian, sufficient to read the mathematical literature in the language. Any member of the mathematics faculty may administer a foreign language examination.

The examination can be either oral or written. It typically requires translation of a text in one of the three foreign languages into English.

The Report on Language Requirement Form must be filled out by the student and the faculty member administering the examination. The form can be found on the Graduate Division website or can be provided by the Mathematics Department. The form should be turned in to the Graduate Advisor and Program Coordinator for review and submission to the Graduate Division.

V. QUALIFYING EXAMINATION FOR ADVANCEMENT TO CANDIDACY

All graduate students in the Ph.D. program are required to take an oral examination, called the oral qualifying examination, for advancement to candidacy for the Ph.D. Degree. Students typically complete this examination between their seventh and twelfth quarter in residence.

Students will demonstrate that they have a sufficient understanding of their Ph.D. thesis problem. Any student who has not passed their oral exam by the end of the fourth year may be subject to academic probation or dismissal from the program.

The Report on Qualifying Examination Form must be filled out by the qualifying examination committee immediately following the examination. The form can be found on the Graduate Division website or can be provided by the Mathematics Department. The form should be turned in to the Graduate Advisor and Program Coordinator for review and submission to the Graduate Division. The student may request to see a copy of the report.

If the student fails the examination, a re-examination can be given within the next three months. The membership of the examining committee usually remains fixed.

Qualifying Examination Committee Composition

The examining committee consists of the student's faculty advisor, at least two other faculty members from the Mathematics Department, and at least one outside tenured faculty member from either another discipline at UCSC or another academic institution (involved in research and graduate education of the same or different discipline). The student, in consultation with the student's faculty advisor, selects the committee. The chair of the committee must be someone other than the student's faculty advisor.

The Graduate Division must approve the committee. The Committee Nomination of Ph.D. Qualifying Examination Form must be completed and submitted at least one month prior to the requested exam date. The form can be found on the Graduate Division website or can be provided by the Mathematics Department. The form should be turned in to the Graduate Advisor and Program Coordinator for review and submission to the Graduate Division.

The committee decides on the topics for the examination, which should be broad enough to encompass a substantial body of knowledge in the area of the student's interest. The written list of topics to be included in the examination, along with a short bibliography, is prepared by the student. A copy is given to each committee member and a copy is put into the student's permanent records.

VI. THE DISSERTATION FOR THE PH.D. DEGREE

Each graduate student in the Ph.D. program is required to write a Ph.D. dissertation or thesis on a research topic in mathematics. The Ph.D. dissertation should contain original research results that are publishable in a peer-reviewed journal. All members of the student's dissertation committee must read and approve the dissertation.

After the dissertation has been approved, the student has an option of making a public oral presentation of the mathematical results contained in the dissertation—the "thesis defense." A recommendation by the dissertation committee will be made to the Mathematics Department and to the Graduate Council on the granting of the Ph.D. degree.

More information about dissertation submission can be found at the Graduate Division website.

Dissertation Reading Committee Composition
A Ph.D. student, in consultation with the Graduate Vice Chair, is responsible for selecting a dissertation reading committee. The committee consists of the student's advisor and at least two other members of the Mathematics faculty. In special circumstances, a committee member may be chosen from another department and/or from another institution. The student's advisor is the chair of the committee.

The Graduate Division must approve the committee. The Nominations for Dissertation Reading Committee Form must be completed and submitted prior to advancement to candidacy. The form can be found on the Graduate Division website or can be provided by the Mathematics Department. The form should be turned in to the Graduate Advisor and Program Coordinator for review and submission to the Graduate Division.

A new form must be submitted for approval if changes to the dissertation reading committee must be made.

VII. TOPICS AND SYLLABI FOR THE CORE SEQUENCES

ALGEBRA

Algebra I (Math 200)
Group and ring theory: Subgroups, cosets, normal subgroups, homomorphisms, isomorphisms, quotient groups, free groups, generators and relations, group actions on a set. Sylow theorems, semi direct products, simple groups, nilpotent groups and solvable groups. Ring theory, including Chinese remainder theorem, prime ideals, localization, Euclidean domains, PIDs, UFDs, polynomial rings.

Textbooks and references: *Basic Algebra I* by N. Jacobsen, *Abstract Algebra* by D. Dummit and R. Foote, *Algebra* by M. Artin.

Algebra II (Math 201)
Linear algebra: Vector spaces, linear transformations, eigenvalues and eigenvectors, Jordon canonical forms, bilinear forms, quadratic forms, bilinear forms, quadratic forms, real symmetric forms and real symmetric matrices, orthogonal transformations and orthogonal matrices, Euclidean space, Hermitian forms and Hermitian matrices, Hermitian space, unitary transformations and unitary matrices, skew-symmetric forms, tensor products of vector spaces, tensor algebras, symmetric algebras, exterior algebras, Clifford algebras and spin groups.

Textbooks and references: *Algebra* by M. Martin, *Abstract Algebra* by D. Dummit and R. Foote, *Basic Algebra* by N. Jacobson.

Algebra III (Math 202)
Module theory: Submodules, quotient modules, module homomorphisms, generators of modules, direct sums, free modules, torsion modules, modules over PIDs and applications to rational and Jordan canonical forms. Field theory, including field extensions, algebraic and transcendental extensions, splitting fields, algebraic closures, separable and normal extensions, the Galois theory, finite fields, Galois theory of polynomials

Textbooks and references: *Algebra* by M. Artin, *Abstract Algebra* by D. Dummit and R. Foote, *Basic Algebra I* by N. Jacobson.

Note: *The following course is recommended as a continuation course to the algebra sequence, and as preparation for the preliminary examination.*

Algebra IV (Math 203)
Topics include Tensor produce of modules over rings, Projective modules and injective modules, Jacobson radical, Weederburns' theorem, category theory, Noetherian rings,

Artinian rings, afine varieties, projective varieties, Hilberts Nullstellensatz, prime spectrum, Zariski topology, discrete valuation rings; Dedekind domains.

Textbooks and references: *Algebra* by M. Artin, *Abstract Algebra* by D. Dummit and R. Foote, *Basic Algebra I* by N. Jacobson.

ANALYSIS

Analysis I (Math 204)
Fundamentals of analysis: Completeness and compactness for real line, sequences and infinite series of functions, Fourier series, calculus on Euclidean space and implicit function theorem, metric spaces and contracting mapping theorem, Arzela-Ascoli theorem, basics of general topological spaces, Baire category theorem, Urysohn's lemma, Tychonoff theorem.

Textbooks and references: *The Way of Analysis* by Robert Stricharz, *Principles of Mathematics* by Rudin, *Elementary Real Analysis* by Thomas, Bruckner and Bruckner, *Real and Complex Analysis* by Rudin

Analysis II (Math 205)
Measure theory and integration: Lebesgue measure theory, abstract measure theory, measurable functions, integration, space of absolutely integrable functions, dominated convergence theorem, convergence in measure, Riesz representation theorem, product measure the Fubini theorem, L^p spaces, derivative of a measure and Radon-Nikodym theorem, fundamental theorem of calculus.

Textbooks and references: *Real and Complex Analysis* by Rudin, *Real Variable and Integration* by John Benedetto, *Real Analysis* by Royden, *Measure and Integrationn Theory* by H. Widom.

Analysis III (Math 206)
Functional analysis: Banach space, Hahn-Banach theorem, uniform boundedness theorem, open mapping theorem and closed graph theorem, weak and weak* topology and Banach-Alaoglu theorem, Hilbert space, self-adjoint operators, compact operators, spectral theory, Fredholm operators, space of distributions and Fourier transform, Sobolev spaces.

Textbooks and references: *Functional Analysis* by Rudin, *Functional Analysis* by Ronald Larson, *Functional Analysis* by Yosida, *Partial Differential Equations* by Evans.

Note: *The following course is recommended as a continuation course to the analysis sequence, and as preparation for the preliminary examination.*

Complex Analysis (Math 207)
Review of the basic theory of one complex variable, the Cauchy-Riemann equations, Cauchy's theorem, power series expansions, the maximum modulus principle, Classification of singularities, Residue theorem, argument principle, harmonic functions, linear fractional transformations, Conformal mappings, Riemann mapping theorem, Picard's theorem, introduction to Riemann surfaces.

Textbooks and references: *Complex Analysis* by Ahlfors, *Functions of One Complex Variable* by Conway, *Complex Variables and Applications* by Churchill, *Elementary Theory of Analytic Functions of One or Several Complex Variables* by H. Cartan.

GEOMETRY AND TOPOLOGY

Manifolds I (Math 208)
Theory of manifolds: Definitions of manifolds, tangent bundle, inverse and implicit function theorems, transversality, Sard's theorem and the Whitney embedding theorem, differential forms, exterior derivative, Stokes' theorem, integration, vector fields, flows, Lie brackets, Frobenius' theorem

Textbooks and references: *Introduction to Smooth Manifolds* by John M. Lee, *Foundations of Differential manifolds and Lie Groups* by Frank w. Warner, *An Introduction to Differentiable Manifolds and Riemannian Geometry* by W. M. Boothby, *Calculus on Manifolds* by Michael Spivak

Manifolds II (Math 209)
Differential forms and analysis on manifolds: Tensor algebra, differential forms and the associated formalism of pullback, wedge product, exterior derivative, Stokes' theorem, integration, Cartan's formula for the Lie derivative, cohomology via differential forms, Poincare lemma and the Mayer-Vietoris sequence, theorems of de Rham and Hodge.

Textbooks and references: *Introduction to Smooth Manifolds* by John M. Lee, *Foundations of Differential Manifolds and Lie Groups* by Frank W. Warner, *An Introduction to Differentiable Manifolds and Riemannian Geometry* by W. M. Boothby, *A Comprehensive Introduction to Differential Geometry* by Michael Spivak, *Analysis on Manifolds* by James R. Munkres, *Topology from the Differentiable Viewpoint* by John W. Milnor, *Foundations of Mechanics* by Ralph Abraham and Jerrold E. Marsden, *Calculus on Manifolds* by Michael Spivak, *Lie Groups* by J. F. Adams, *Differential Forms in Algebraic Tropology* by Raoul Bott and Loring W. Tu.

Manifolds III (Math 210)
Algebraic topology: The fundamental group, covering space theory and the Van Kampen's theorem (with a discussion of free and amalgamated products of groups), CW complexes, higher homotopy groups, cellular and singular cohomology, the

Eilenberg-Steenrod axioms, computational tools (including, e.g., Mayer-Vietoris exact sequences), cup products, Poincare duality, Lefschetz fixed point theorem, homotopy exact sequence of a fibration and the Hurewicz isomorphism theorem, remarks on characteristic classes.

Textbooks and references: *Algebraic Topology* by Allen Hatcher (available online), *Introduction to Topology* by V. A. Vassiliev, *A Basic Course in Algebraic Topology* by W. S. Massey, *Algebraic Topology* by Marvin J. Greenberg.

Note: *The following course is recommended as a continuation course to the geometry-topology sequence, and as preparation for the preliminary examination.*

Differential Geometry (Math 212)
Principle bundles, associated bundles and vector bundles, connections on principle and vector bundles. More advanced topics: curvature, introduction to cohomology, the Chern-Weil construction and characteristic classes, the Gauss-Bonnet Theorem or Hodge Theory, eigenvalue estimates for Beltrami Laplacian, comparison theorems in Riemannian geometry. (Formerly course 234C.)

Textbooks and references: *Riemannian Geometry* by Peter Peterson, *Riemannian Geometry* by John Lee, *Foundations of Differential Manifolds and Lie Groups* by Frank W. Warner, *A Comprehensive Introduction to Differential Geometry* by Michael Spivak, *Riemannian Geometry* by do Carmo.

VIII. INDEPENDENT STUDY/THESIS RESEARCH STUDY CODES

Graduate students must fill out the Independent Study/Thesis Research Code Request Form in order to enroll in an independent study course. Forms are located by the graduate student mailboxes and can be found on the Mathematics graduate website.

Students must obtain the instructor's approval signature and return the completed form to the Graduate Advisor and Program Coordinator. An enrollment code will be issued to the graduate student via email, with the appropriate instructor copied. It is the responsibility of the student to then enroll in the course.

IX. FINANCIAL SUPPORT

DEPARTMENT POLICY FOR GRADUATE FINANCIAL SUPPORT

The Mathematics Department is strongly committed to the financial support of graduate students who are making good progress toward either the M.A. or the Ph.D. degree. For the purpose of financial support, a student's progress is measured against the Degree Programs and Timetables. A teaching assistantship is the most common form of financial support for graduate students in good academic standing.

Students facing special financial hardship are urged to make this known to the department in a timely manner. Funding requests can be made via the Mathematics Funding Request Form located on the Mathematics graduate website. The Department will do everything in its power to ensure that all students in good standing are given sufficient financial aid to enable them to continue their study of mathematics.

FREE APPLICATION FOR FINANCIAL STUDENT AID (FAFSA)

All students are strongly urged to complete a Free Application for Financial Student Aid (FAFSA) each year by the start of fall quarter to determine eligibility for need-based awards and to apply for support from the Financial Aid Office as well as from the department. No need-based fellowship can be awarded to a student who does not have a current FAFSA on file.

X. TEACHING ASSISTANTS

UNION

Teaching Assistants are covered by a collective bargaining agreement between the University and the United Auto Workers (UAW). The agreement can be viewed electronically at the following link:

https://ucnet.universityofcalifornia.edu/labor/bargaining-units/bx/contract.html

APPOINTMENTS

TA appointments are usually made at 50% time (an assigned workload of approximately 220 hours for the quarter). Teaching Assistants are under the supervision of the faculty member responsible for the course.

ASSIGNMENTS

TA assignments are based on course enrollments. Faculty and TAs will be notified of the preliminary assignments as soon as possible. These preliminary assignments are always tentative, pending student enrollment information. Early in the quarter, TAs may be reassigned at short notice, based on the course enrollments.

DUTIES

The specific allocation of TA duties is subject to change depending on enrollments and the number of teaching assistantships available in the department. Instructors and their Teaching Assistant(s) will meet at the beginning of the quarter to complete the *Notification of TA Duties Form*, which will establish agreed-upon tasks (see page 22). The performance of these tasks will form the basis of the end-of-quarter performance evaluation, and will rely upon the following criteria: quality of work; accuracy and attention to detail; interaction with students, peers and instructor; knowledge of subject; and dependability. Teaching Assistants are hired for the period specified in their appointment letter and are expected to conduct their TA duties for the period assigned in a professional manner.

Please note that some classes now utilize online grading, which means there may be no homework for faculty, readers, or TAs to grade. In other cases, one or more readers may be assigned to the class to grade homework. In general, TA duties will likely include the following:

- TAs for upper-division courses may be asked to grade some of the homework in addition to leading 1-2 sections, writing solutions, holding 3-5 office hours, and assisting with grading midterms and finals

- TAs of lower-division courses (depending on enrollment) may be asked to grade some of the homework (except where online grading is in use or readers are assigned) in addition to leading 2-3 sections, writing solutions, holding 3 office hours, and assisting with grading midterms and finals
- TAs of entry-level math courses will be expected to lead 3-4 sections, write solutions, hold 3 office hours, and assist with grading midterms and finals.

TA TRAINING

All TAs are required to participate in the department's Teaching Assistant training program. Professor Frank Bauerle is the TA Trainer for the Mathematics Department, and he conducts a training session at the beginning of each school year to prepare first-time teaching assistants, as well as a second session including all TAs in our program. Additional workshops are conducted at the beginning of each quarter, and ongoing advising, coaching, and mentoring is provided to teaching assistants to prepare them for excellence in the classroom.

FOUR-YEAR RULE (12 Quarters)

The total length of service rendered in any one or any combination of the following titles may not exceed four years or (12 quarters): Reader on annual stipend, Teaching Assistant, Teaching Fellow and/or Associate. Under special circumstances, the Dean of Graduate Studies may authorize a longer period, but in no case for more than six years (18 quarters).

SAMPLE NOTIFICATION OF TA DUTIES FORM *rev. 08/13/18 jc*

- **This form is to be completed by the Faculty Supervisor and reviewed with the TA**

TA Name________________________________Instructor_____________________________

Course Title____________________ Course #___________________Qtr/Year___________

Location of Section________________________ Day/Time _______________________

- **Note to Faculty Supervisor:** Check required duties and fill in information below as it pertains to the TA assigned to this course. Meet with TA at the beginning of the appointment to review these duties and discuss your performance expectations. Be specific and address the performance categories under Part I including the criteria on the section student evaluation form so that the TA understands the kinds of teaching skills that will be assessed (see Evaluation of Teaching Assistant Duties and Teaching Assistant Student Evaluation forms).

______ Attend all lectures

______ Present lectures as assigned by faculty supervisor

______ Instruct ______ sections per week (review sample Student Evaluation form criteria with TA)

______ Hold ________ office hours weekly (provide range of hours)

______ Attend weekly or as scheduled meetings with Faculty Supervisor

______ Attend weekly or as scheduled meetings with TA Trainer or Head TA

______ Assign students to sections at start of quarter

______ Assist in preparation of problem sets/quizzes/exams

______ Make copies or prepare printing orders of coursework

______ Read, evaluate, and return in a timely manner _____ papers/lab reports

______ Read and evaluate _____ examinations per student (fill in or refer TA to course syllabus)

______ Proctor ______ examinations

______ Arrange/attend ______ labs/field trips/observatory sessions (circle and provide details)

______Assist in the preparation of narrative evaluations and/or make grade recommendations as appropriate for students in TA's section(s)

______ Keep records of students in TA’s section(s) (e.g., attendance and grades)

______ Assist in grading of homework, midterms and final exams

______ Schedule Review Sessions – 2-3 weeks prior to the date you wish to have the review session

______ Perform other tasks as specified (please list on reverse or attach separate piece of paper)

- **These job duties/expectations and the performance evaluation criteria have been reviewed and discussed with the TA assigned to this course at the beginning of the appointment.**

A Teaching Assistant with a 50% appointment shall not be assigned a workload of more than 220 hours per quarter (340 hours per semester) or a workload of over 40 hours in any one week. The number of hours worked in excess of 20 hours per week may not total more than 50 hours per quarter or 77 hours per semester. This standard shall apply proportionately to other percent appointments. In addition, a Teaching Assistant with an appointment of 50% or less shall not be assigned a workload of more than 40 hours in any one week or more than 8 hours in any one day. This check sheet is designed to be distributed to all ASEs except those who are designated as the Instructor of Record for the course. cc: Employment File UC/UAW Agreement Eff: 10/1/07 – 9/30/09 To be issued 30 days prior to the beginning of the term or as soon as possible

______________________________ ______________________________

Instructor/Supervisor Signature/Date TA Signature/Date

XI. LEAVE OF ABSENCE POLICY

A student wishing to apply for a leave of absence must complete a Request for Leave of Absence Form, available from the Mathematics Department office or online at: https://graddiv.ucsc.edu/current-students/applications-forms/index.html.

Department signatures are required. Only students in good standing are eligible for an approved leave of absence, which will be granted for sound educational purposes, health reasons, financial problems, and family responsibilities. The maximum term for an approved leave of absence is three academic quarters.

A request to renew a leave of absence must be submitted in advance to the Graduate Dean. Substantial justifications and department approval will be required to obtain a renewal.

While on a leave of absence, a student is not permitted the use of University facilities. All financial aid (including Teaching Assistantships and other fellowships) terminates when a student is on a leave of absence. If a student accepts any University employment, staff or academic, while on a leave of absence, it must be reported to the Division of Graduate Studies.

XII. FILING FEE

A candidate in good standing for an M.A. or Ph.D. degree does not need not be a registered student in the quarter in which they file the thesis or dissertation if, prior to the beginning of that quarter, the candidate has met all the other requirements for the degree and is in good standing. Instead of paying the University Registration fee (and nonresident tuition as applicable), the student is required to pay only the Filing Fee, amounting to one-half of the regular term University Registration Fee.

In order to be eligible for a filing fee, a student must have been either on an approved leave of absence or registered in the previous quarter. A student using the Filing Fee should submit the application for Filing Fee, signed by all members of the Reading Committee by the end of the second week of the quarter. The signatures signify that all members have read the thesis.

The *Application for Filing Fee Status* is available online at the Graduate Division website: https://graddiv.ucsc.edu/current-students/applications-forms/index.html.

XIII. READMISSION POLICY

Students on an approved leave of absence will automatically be readmitted in the quarter of return indicated on the *Request for Leave of Absence* form, unless there are conditions placed on readmission by the department, the Graduate Dean, or the Health Center.

Students wishing to reenter UCSC who are not returning from an approved leave of absence must file a readmission form with the Division of Graduate Studies and pay a readmission fee. A *Statement of Legal Residence* form must also be completed and sent to the Office of the Registrar. Students should obtain and file these forms in the Division of Graduate Studies at least six weeks prior to the beginning of the quarter in which the student plans to enroll:

https://graddiv.ucsc.edu/current-students/applications-forms/index.html

XIV. POLICY ON PART-TIME GRADUATE STUDY

A part-time graduate student has approval to enroll for one-half (or less) of the regular course load of ten units (first year graduates) or fifteen units (continuing graduate students).

The Mathematics Department will permit part-time study when (in the opinion of the faculty) there is clear justification for part-time status based upon consideration of academic progress, career employment, family responsibilities, or health conditions. The Graduate Division gives final approval of part-time status.

Part-time students will accrue time-to-degree under the Normative Time to Degree Policy at one-half the rate of full-time students for those quarters during which they are approved for part-time study.

A part-time student will pay the full Registration Fee and one-half the Educational fee paid by full-time students. Nonresident students approved for part-time status will pay one-half the nonresident tuition charge.

University employment in student titles such as Teaching Assistant and Graduate Student Researcher cannot exceed .25 FTE for part-time students.

XV. GRIEVANCES

The Mathematics Department is committed to fair treatment for all graduate students. Students who have a grievance concerning their academic progress are urged to first consult the professor responsible. If this is not satisfactory, students should consult the Graduate Vice Chair. If the grievance is still not resolved, students have the right to present the situation to a committee made up of the Department Chair, Graduate Vice Chair and their Advisor, with the Undergraduate Vice Chair substituting if the graduate has no advisor.

XVI. RESOURCES

Graduate students are encouraged to consult the following web pages for additional information concerning campus policies and calendars that govern their studies:

Division of Graduate Studies
https://graddiv.ucsc.edu/

Office of the Registrar
https://registrar.ucsc.edu/

Financial Aid Office
https://financialaid.ucsc.edu/index.html

Career Center
https://careers.ucsc.edu/

Problem and Complaint Resolution Resources
https://www.math.ucsc.edu/graduate/complaint-resources.html

Title IX Office
https://titleix.ucsc.edu/index.html