

# Mathematics (MATH)

---

## Mathematics (MATH) Courses

### Mathematics & Statistics

#### Faculty of Science

##### **MATH 0005 [0.5 credit]**

##### **Precalculus: Functions and Graphs**

Review of algebraic manipulations. Polynomials: the remainder theorem, and the factor theorem; graphing. Real and Complex roots. Absolute values. Inequalities. Functions, including composition of functions, and Inverse functions. Logarithmic and exponential functions. Not available for degree credit for students who have successfully completed: Grade 12 Mathematics - Advanced Functions, or an equivalent High School functions course.

Prerequisite(s): Grade 11 Functions (University/College Preparation), or equivalent.

Lectures three hours a week, tutorial one hour a week.

##### **MATH 0006 [0.5 credit]**

##### **Precalculus: Trigonometric Functions and Complex Numbers**

Angles and the unit circle, radian measure. Definitions of trigonometric functions. Fundamental relations, Law of Sines and Cosines. Analytic trigonometry, graphs, inverse functions.

Trigonometric identities and equations. Applications in science and engineering. Complex numbers in polar form, de Moivre's Theorem, n-th roots of complex numbers.

Prerequisite(s): Grade 11 Functions (University/College Preparation), or MATH 0005, or equivalent.

Lectures three hours a week, tutorial one hour a week.

##### **MATH 0107 [0.5 credit]**

##### **Algebra and Geometry**

Vectors in the plane and in 3-space. Linear combinations and linear independence. Equations of lines and planes in space. Solution of systems of linear equations. Proofs by induction. Binomial Theorem. Logic.

Prerequisite(s): Grade 11 Functions (University/College Preparation) or equivalent.

Lectures three hours a week, tutorial one hour a week.

##### **MATH 1002 [1.0 credit]**

##### **Calculus and Introductory Analysis I**

Elementary functions. Limits. Continuity. Differentiation. L'Hôpital's rules. Indefinite and definite integrals. Improper integrals. Sequences and series, Taylor's formulae. Introduction to differential equations. Proofs and theory will be emphasized in this course.

Strongly recommended for students intending to specialize in mathematics, statistics, physics, or related areas.

Precludes additional credit for MATH 1004, MATH 1005, MATH 1007, MATH 1009, and MATH 2007.

Prerequisite(s): Grade 12 Mathematics: Advanced Functions, and Grade 12 Mathematics: Calculus and Vectors, with grades of at least 75% in each; or MATH 0005 and MATH 0006 with grades of B/better in each; or equivalents; or permission of the School of Mathematics and Statistics.

Lectures three hours a week, tutorial one hour a week.

##### **MATH 1004 [0.5 credit]**

##### **Calculus for Engineering or Physics**

Limits. Differentiation of the elementary functions. Rules of differentiation. Inverse trigonometric functions. Applications of differentiation: max-min problems, curve sketching, approximations. Definite and indefinite integrals, techniques of integration. Applications: area, volume, centre of mass, moment of inertia.

Restricted to students in the Faculty of Engineering, or in B.Sc. programs of the Department of Physics (except Double Honours Mathematics and Physics).

Precludes additional credit for MATH 1002, MATH 1007, MATH 1009, BIT 1000, BIT 1100

Prerequisite(s): Ontario Grade 12 Mathematics: Advanced Functions, or MATH 0005 and MATH 0006, or equivalent.

Lectures three hours a week, tutorial one hour a week.

##### **MATH 1005 [0.5 credit]**

##### **Differential Equations and Infinite Series for Engineering or Physics**

First-order differential equations. Second-order linear equations with constant coefficients, undetermined coefficients, variation of parameters. Systems of equations. Sequences and series, convergence tests, estimation of sums. Power series, Taylor series, remainders. Fourier series.

Restricted to students in the Faculty of Engineering, or in B.Sc. programs of the Department of Physics (except Double Honours Mathematics and Physics).

Precludes additional credit for MATH 1002, MATH 2007, and MATH 2404.

Prerequisite(s): i) MATH 1004; and ii) MATH 1104 (or MATH 1107), either previously or concurrently; or equivalents; or permission of the School.

Lectures three hours a week, tutorial one hour a week.

**MATH 1007 [0.5 credit]****Elementary Calculus I**

Limits. Differentiation of the elementary functions, including trigonometric functions. Rules of differentiation. Applications of differentiation: max-min problems, curve sketching, approximations. Introduction to integration: definite and indefinite integrals, areas under curves, fundamental theorem of calculus.

Precludes additional credit for BIT 1000, BIT 1100, MATH 1002, MATH 1004, MATH 1009.

Prerequisite(s): Ontario Grade 12 Mathematics: Advanced Functions; or MATH 0005 and MATH 0006; or equivalent.

Lectures three hours a week, tutorial one hour a week.

**MATH 1009 [0.5 credit]****Calculus: with Applications to Business**

Applications of mathematics to business. Limits. Differentiation of the elementary functions. Rules of differentiation. Max-min problems, curve sketching. Functions of several variables, partial differentiation, constrained max-min. Definite and indefinite integrals.

This course is not acceptable for (substitute) credit in any of the following degree programs: B.Math., and also B.Sc., B.C.S., B.Eng., B.I.D.

Precludes additional credit for MATH 1002, MATH 1004, MATH 1007, MATH 1401/ECON 1401, MATH 1402/ECON 1402, BIT 1000, BIT 1100.

Prerequisite(s): Ontario Grade 12 Mathematics: Advanced Functions, or MATH 0005, or equivalent.

Lectures three hours a week, tutorial one hour a week.

**MATH 1102 [1.0 credit]****Algebra I**

Properties of numbers, modular arithmetic, mathematical induction, equivalence relations. Vector spaces, matrix algebra, linear dependence, bases, linear transformations, bilinear and quadratic forms, inner products, eigenvalues, diagonalization. Proofs and theory will be emphasized in this course.

Strongly recommended for students intending to specialize in mathematics, statistics, physics, or related areas. Note: MATH 1119 is not an acceptable substitute for half of MATH 1102.

Precludes additional credit for MATH 1104, MATH 1107, MATH 1119, MATH 2107.

Prerequisite(s): Grade 12 Mathematics: Advanced Functions, and Grade 12 Mathematics: Calculus and Vectors, with grades of at least 75% in each; or MATH 0005, MATH 0006, and MATH 0107 with grades of at least B in each; or equivalents; or permission of the School of Mathematics and Statistics.

Lectures three hours a week, tutorial one hour a week.

**MATH 1104 [0.5 credit]****Linear Algebra for Engineering or Science**

Systems of linear equations. Matrix algebra. Determinants. Complex numbers. Eigenvalues. Diagonalization and applications.

Note: MATH 1119 is not an acceptable substitute for MATH 1104.

Precludes additional credit for BIT 1001, BIT 1101, MATH 1102, MATH 1107, MATH 1119.

Prerequisite(s): Ontario Grade 12 Mathematics: Advanced Functions, or MATH 0005, or equivalent, or permission of the School. Restricted to students in the Faculty of Engineering, in B.Sc. programs of the Department of Physics (except Double Honours Mathematics and Physics), or in the School of Computer Science. .

Lectures three hours a week and tutorial one hour a week.

**MATH 1107 [0.5 credit]****Linear Algebra I**

Systems of linear equations; vector space of n-tuples, subspaces and bases; matrix transformations, kernel, range; matrix algebra and determinants. Dot product. Complex numbers (including de Moivre's Theorem, and n-th roots). Eigenvalues, diagonalization and applications.

Note: MATH 1119 is not an acceptable substitute for MATH 1107.

Precludes additional credit for BIT 1001, BIT 1101, MATH 1102, MATH 1104 and MATH 1119.

Prerequisite(s): Ontario Grade 12 Mathematics: Advanced Functions, or MATH 0005, or equivalent, or permission of the School.

Lectures three hours a week and tutorial one hour a week.

**MATH 1119 [0.5 credit]****Linear Algebra: with Applications to Business**

Introduction to systems of linear equations, geometric interpretation in two and three dimensions, introduction to matrices, vector addition and scalar multiplication, linear dependence, matrix operations, rank, inversion, invertible matrix theorem, determinants. Use of illustrative examples related to business.

This course is not acceptable for (substitute) credit in any of the following degree programs: B.Math., and also B.Sc., B.C.S., B.Eng., B.I.D.

Precludes additional credit for: MATH 1102, MATH 1104, MATH 1107.

Precludes additional credit for MATH 1109, MATH 1401/ECON 1401, MATH 1402/ECON 1402, BIT 1001, BIT 1101.

Prerequisite(s): Ontario Grade 12 Mathematics of Data Management; or Ontario Grade 12 Mathematics: Advanced Functions, or MATH 0005, or equivalent, or permission of the School.

Lectures three hours a week, tutorial one hour a week.

**MATH 1401 [0.5 credit]****Elementary Mathematics for Economics I**

Functional relations: including functional forms and error terms. Graphing economic magnitudes: scatter diagrams, time-series graphs, and functional relationships. Applied calculus: the mechanics of differentiation and integration, elasticity, and consumer/producer surplus. Applied algebra: solving systems of linear equations and Keynesian national-income analysis. Approaches to problem solving.

This course is not acceptable for (substitute) credit in any of the following degree programs: B.Math., and also B.Sc., B.C.S., B.Eng., B.I.D.

Also listed as ECON 1401.

Precludes additional credit for MATH 1009 and MATH 1119.

Prerequisite(s): Ontario Grade 12 U Advanced Functions, or MATH 0005, or equivalent; and ECON 1000 or FYSM 1003, which may be taken concurrently with MATH 1401/ ECON 1401.

Lectures three hours a week, tutorial one hour a week.

**MATH 1402 [0.5 credit]****Elementary Mathematics for Economics II**

Calculus: including partial differentiation, definite and indefinite integrals, techniques of integration, and unconstrained optimization. Vectors and matrices: scalar multiplication, inner product, linear dependence, matrix operations, rank, invertible matrix theorem, and determinants.

Economic applications such as profit maximization, comparative statics, and the Leontief input-output model.

This course is not acceptable for (substitute) credit in any of the following degree programs: B.Math., and also B.Sc., B.C.S., B.Eng., B.I.D.

Also listed as ECON 1402.

Precludes additional credit for MATH 1009 and MATH 1119.

Prerequisite(s): ECON 1000 or FYSM 1003 with a grade of C- or higher, and ECON 1401/MATH 1401 with a grade of C- or higher.

Lectures three hours a week, tutorial one hour a week.

**MATH 1805 [0.5 credit]****Discrete Structures I**

An introduction to discrete mathematics and discrete structures. Topics include: propositional and predicate calculus, Boolean algebra, introduction to complexity of algorithms, mathematical reasoning, counting, recurrences, relations, introduction to graphs.

Also listed as COMP 1805.

Prerequisite(s): two Grade 12 university-preparation Mathematics courses; and one of: COMP 1005 or or COMP 1405 or SYSC 1100 (which may be taken concurrently).

Lectures three hours a week.

**MATH 2000 [1.0 credit]****Calculus and Introductory Analysis II (Honours)**

Higher dimensional calculus, chain rule, gradient, line and multiple integrals with applications. Use of implicit and inverse function theorems. Real number axioms, limits, continuous functions, differentiability, infinite series, uniform convergence, the Riemann integral.

Precludes additional credit for MATH 2004, MATH 2008, MATH 2009 and MATH 3009.

Prerequisite(s): i) MATH 1002 with a grade of C+ or higher, or MATH 2007 with a grade of B+ or higher; and ii) MATH 1102 with a grade of C+ or higher, or MATH 1107 with a grade of B+ or higher; or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 2004 [0.5 credit]****Multivariable Calculus for Engineering or Physics**

Fourier series; expansions for even and odd functions; half-range expansions. Surfaces in  $R^3$ . Differential calculus of functions of several variables. Extrema and Lagrange multipliers. Exact differentials. Line integrals. Double integrals; polar coordinates; applications. Triple integrals; cylindrical and spherical coordinates; applications.

Precludes additional credit for: MATH 2008, MATH 2009 and MATH 2000.

Prerequisite(s): i) MATH 1005 or MATH 2007; and ii) MATH 1104 or MATH 1107; or permission of the School; enrolment in the Faculty of Engineering, or in B.Sc. programs of the Department of Physics (except Double Honours Mathematics and Physics).

Lectures three hours a week, tutorial one hour a week.

**MATH 2007 [0.5 credit]****Elementary Calculus II**

Techniques of integration, improper integrals. Polar coordinates, parametric equations. Indeterminate forms, sequences and series, Taylor's formula and series.

Precludes additional credit for MATH 1002 and MATH 1005.

Prerequisite(s): i) MATH 1004, or a grade of C- or higher in MATH 1007; or permission of the School.

Lectures three hours a week, tutorial one hour a week.

**MATH 2008 [0.5 credit]****Intermediate Calculus**

Partial differentiation, chain rule, gradient, line and multiple integrals with applications, transformations of multiple integrals.

Precludes additional credit for: MATH 2004, MATH 2009, and MATH 2000.

Prerequisite(s): one of MATH 1002, MATH 1005 or MATH 2007, and one of MATH 1102, MATH 1104 or MATH 1107.

Lectures three hours a week and one hour tutorial.

**MATH 2009 [0.5 credit]****Intermediate Calculus for Science Students**

Differential equations; differential calculus of functions of several variables; multiple integration; introduction to Fourier series.

Precludes additional credit for: MATH 2004, MATH 2008, and MATH 2000.

Prerequisite(s): i) MATH 2007, or MATH 1002; and ii) MATH 1107 or MATH 1104 or MATH 1102; or their equivalents, or permission of the School.

Lectures three hours a week, tutorial one hour a week.

**MATH 2100 [1.0 credit]****Algebra II (Honours)**

Introduction to group theory: permutation groups, Lagrange's theorem, normal subgroups, homomorphism theorems. Introduction to ring theory: ring of polynomials, integral domains, ideals, homomorphism theorems.

Hermitian form, spectral theorem for normal operators, classical groups.

Precludes additional credit for MATH 2108 and MATH 3101.

Prerequisite(s): MATH 1102 with a grade of C+ or higher, or MATH 2107 with a grade of B+ or higher, or permission of the School.

Lectures three hours a week, tutorial one hour a week.

**MATH 2107 [0.5 credit]****Linear Algebra II**

Finite-dimensional vector spaces (over  $\mathbb{R}$  and  $\mathbb{C}$ ), subspaces, linear independence and bases. Linear transformations and matrices. Inner product spaces (over  $\mathbb{R}$  and  $\mathbb{C}$ ); Orthonormal bases. Eigenvalues and diagonalization. Bilinear and quadratic forms; principal axis theorem.

Precludes additional credit for MATH 1102.

Prerequisite(s): i) MATH 1104, or a grade of C- or higher in MATH 1107 or MATH 1109; and ii) a grade of C- or higher in MATH 1007 or equivalent; or permission of the School. Note: in item i), MATH 1119 is NOT acceptable as a substitute for MATH 1109.

Lectures three hours a week and one hour tutorial.

**MATH 2108 [0.5 credit]****Abstract Algebra I**

Sets and relations, number theory, group theory, ring theory, cardinal numbers.

Precludes additional credit for MATH 3101 and MATH 2100.

Prerequisite(s): MATH 1102 or MATH 2107.

Lectures three hours a week and one hour tutorial.

**MATH 2210 [0.5 credit]****Introduction to Geometry**

An introduction to classical geometry; Euclidean plane geometry; plane tiling; polytopes in three and four dimensions; curved surfaces; Euler characteristic.

This course is intended for a general audience, and is available to B.Math. students for credit only as a free elective.

Prerequisite(s): Grade 12 Mathematics and second-year standing.

Lectures three hours a week, tutorial one hour a week.

**MATH 2404 [0.5 credit]****Ordinary Differential Equations I**

First-order equations, linear second- and higher-order equations, linear systems, stability of second-order systems.

Precludes additional credit for MATH 1005 and MATH 2454.

Prerequisite(s): MATH 1002 and MATH 1102 (or MATH 1107 and MATH 2007).

Lectures three hours a week and one hour tutorial.

**MATH 2454 [0.5 credit]****Ordinary Differential Equations (Honours)**

Existence and uniqueness theorems. First-order equations, linear second- and higher-order equations, linear systems, stability of second-order systems.

Precludes additional credit for MATH 2404.

Prerequisite(s): MATH 1002 or MATH 2007 or MATH 1005 with a grade of C+ or higher, and MATH 1102 or MATH 2107 with a grade of C+ or higher.

Lectures three hours a week, tutorial one hour a week.

**MATH 2800 [0.5 credit]****Discrete Mathematics and Algorithms**

An introduction to discrete mathematics and algorithms in the context of the computational sciences. Basic number theory and counting methods, algorithms for strings, trees and sequences. Applications to DNA and protein sequencing problems. Analysis and complexity of algorithms.

Only one of MATH 1805/COMP 1805 or MATH 2800/CMPS 2800 may count for credit in a B.Math. program. Also listed as CMPS 2800.

Prerequisite(s): COMP 1006 and at least one of MATH 1007, MATH 1107, or STAT 2507.

Lectures three hours a week.

**MATH 2907 [0.5 credit]****Directed Studies (Honours)**

Available only to Honours students whose program requires a 0.5 credit not offered by the School of Mathematics and Statistics.

**MATH 3001 [0.5 credit]****Real Analysis (Honours)**

Metric spaces and their topologies, continuous maps, completeness, compactness, connectedness, introduction to Banach spaces.

Prerequisite(s): MATH 2000 or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3002 [0.5 credit]****Calculus of Differential Forms and Geometry (Honours)**

Differential forms and vector fields. Line and surface integrals. The divergence theorem and Stokes' theorem. Exterior algebra. Geometry of curves and surfaces. Mean and Gaussian curvatures. Gauss-Bonnet theorem.  
Prerequisite(s): MATH 2000 or permission of the School.  
Lectures three hours a week and one hour tutorial.

**MATH 3007 [0.5 credit]****Functions of a Complex Variable**

Analytic functions, contour integration, residue calculus, conformal mapping. Intended for non-engineering students.

Precludes additional credit for MATH 3057 and PHYS 3807.

Prerequisite(s): one of MATH 2004, MATH 2008 or MATH 2009, or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3008 [0.5 credit]****Ordinary Differential Equations (Honours)**

Analytic ordinary differential equations: series solutions of ordinary differential equations about ordinary and regular singular points. Asymptotic solutions. Sturm-Liouville theory. Bessel and Legendre functions. Fourier series.

Precludes additional credit for MATH 3404 and PHYS 3808.

Prerequisite(s): MATH 2000; and MATH 2454.

Lectures three hours a week and one hour tutorial.

**MATH 3009 [0.5 credit]****Introductory Analysis**

The real number system, sequences and series, functions of a single real variable, derivatives, the definite integral, uniform convergence.

Precludes additional credit for MATH 2000.

Prerequisite(s): one of MATH 2004, MATH 2008, MATH 2009, or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3057 [0.5 credit]****Functions of a Complex Variable (Honours)**

Analytic functions, contour integration, residue calculus, conformal mapping.

Precludes additional credit for MATH 3007 and PHYS 3807.

Prerequisite(s): MATH 2000 or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3101 [0.5 credit]****Algebraic Structures with Computer Applications**

Introduction to algebraic structures: groups, rings, fields, lattices, and Boolean algebras; with applications of interest to students in Computer Science.

This course may not be used to meet the 3000-level course requirements in any General or Honours program in Mathematics and Statistics.

Precludes additional credit for MATH 2108 and MATH 2100.

Prerequisite(s): MATH 2107, or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3106 [0.5 credit]****Introduction to Group Theory (Honours)**

Homomorphism theorems; groups acting on sets; permutation groups and groups of matrices; Sylow theory for finite groups; finitely generated abelian groups; generators and relations; applications.

Precludes additional credit for MATH 3108.

Prerequisite(s): MATH 2100, or permission of the School.

Lectures three hours a week, tutorial one hour a week.

**MATH 3107 [0.5 credit]****Linear Algebra III**

Similarity and unitary triangularization of matrices. Direct methods of solving a system of linear equations. Iterative techniques. Bounds for eigenvalues. Power method and deflation techniques of approximation. Emphasis is primarily on computational aspects.

Prerequisite(s): i) a grade of C- or higher in MATH 1102 or MATH 2107; and ii) credit in MATH 1002 or MATH 2007; or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3108 [0.5 credit]****Abstract Algebra II**

Groups and rings. Permutations. Finite symmetry groups. Polynomials, unique factorization domains. Quotient rings, ideals. Field extensions, finite fields. Polynomial equations. Geometric constructions - three famous problems: duplication of the cube, trisection of an arbitrary angle, quadrature of the circle.

Precludes additional credit for MATH 3106 and MATH 3158.

Prerequisite(s): MATH 2108, or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3158 [0.5 credit]****Rings and Fields (Honours)**

Rings; integral domains; Euclidean and principal ideal domains; polynomial rings over a field; modules over principal ideal domains and applications; fields; algebraic extensions of fields; finite fields; applications.

Precludes additional credit for MATH 3108.

Prerequisite(s): MATH 2100, or permission of the School.

Lectures three hours a week, tutorial one hour a week.



**MATH 3206 [0.5 credit]****Plane Projective Geometry**

Axioms of Desarguesian geometry, principle of duality; projectivities, perspectivities, and the fundamental theorem; collineations (homologies and elations); correlations (polarities and conics); algebraic model; projective curves; introduction to finite projective planes. Precludes additional credit for MATH 3256.

Prerequisite(s): MATH 2100 or MATH 2108 or MATH 3101.

Lectures three hours a week and one hour tutorial.

**MATH 3210 [0.5 credit]****Euclidean and Non-Euclidean Geometry**

Euclidean isometry and similarity groups; geometry of circles; inversion; hyperbolic geometry: Poincare disk model of the hyperbolic plane.

Precludes additional credit for MATH 3205.

Prerequisite(s): MATH 2100 or MATH 2108 or MATH 3101.

Lectures three hours a week, tutorial one hour a week.

**MATH 3306 [0.5 credit]****Elements of Set Theory (Honours)**

Axioms of set theory. Development of the systems of natural numbers and the real numbers. Axiom of choice, Zorn's lemma, well-ordering. The Schröder-Bernstein theorem, cardinal numbers, ordinal numbers, transfinite induction, cardinal and ordinal arithmetics.

Prerequisite(s): MATH 2100 or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3355 [0.5 credit]****Number Theory and Applications (Honours)**

Congruences, distribution of primes, arithmetic functions, primitive roots, quadratic residues, quadratic reciprocity law, continued fractions, Diophantine equations, and applications: public key cryptography, primality testing and factoring in relation to cryptography.

Precludes additional credit for MATH 3809.

Prerequisite(s): MATH 2100, or a grade of B- or higher in MATH 2108 or MATH 3101, or permission of the School.

Lectures three hours a week, tutorial one hour a week.

**MATH 3404 [0.5 credit]****Ordinary Differential Equations II**

Series solutions of ordinary differential equations of second order about regular singular points; asymptotic solutions. Systems of ordinary differential equations of first order; matrix methods. Existence and uniqueness theorems. Nonlinear autonomous systems of order 2; qualitative theory. Numerical solutions of ordinary differential equations.

Precludes additional credit for MATH 3008.

Prerequisite(s): MATH 2404, MATH 2008; and MATH 1102 or MATH 2107.

Lectures three hours a week and one hour tutorial.

**MATH 3705 [0.5 credit]****Mathematical Methods I**

Laplace transforms, series solutions of ordinary differential equations, the Frobenius method. Fourier series and Fourier transforms, solutions of partial differential equations of mathematical physics, boundary value problems, applications.

This course may be taken for credit as a 3000-level Honours Mathematics course, by students in any Honours program in the School of Mathematics and Statistics. Precludes additional credit for PHYS 3808.

Prerequisite(s): i) MATH 1005 or MATH 2404, and ii) MATH 2004 or MATH 2008 or MATH 2009; or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3800 [0.5 credit]****Modeling and Computational Methods for Experimental Science**

Mathematical modeling in the experimental sciences: design, analysis and pitfalls. Computational methods directly applicable to problems in science will be described, including: function evaluation, interpolation, solution of linear equations, root finding, integration, solution of differential equations, Fourier series and Monte Carlo methods.

Also listed as CMPS 3800.

Precludes additional credit for MATH 3806/COMP 3806.

Prerequisite(s): i) MATH 1107 or MATH 1104; ii) MATH 1005 or MATH 2007; and iii) knowledge of a computer language.

Lectures three hours a week.

**MATH 3801 [0.5 credit]****Linear Programming**

Formulation of linear programming problems, the simplex method, duality theory, implementations, extensions and applications. Network flow problems and the network simplex method.

Precludes additional credit for ECON 4004, SYSC 3200.

Prerequisite(s): MATH 1102 or MATH 2107, or permission of the School.

Lectures three hours a week and one hour tutorial.

**MATH 3802 [0.5 credit]****Combinatorial Optimization**

Dijkstra's algorithm and Bellman-Ford algorithm for the minimum weight dipath problem, the minimum weight spanning tree problem, augmenting path algorithm and preflow-push algorithm for the max-flow min-cut problem, connections to linear programming, matchings in bipartite graphs and the assignment problem, the transportation problem, and the general minimum-cost flow problem.

Prerequisite(s): MATH 3801, or permission of the School.

Lectures three hours a week, tutorial one hour a week.

**MATH 3804 [0.5 credit]****Design and Analysis of Algorithms I**

An introduction to the design and analysis of algorithms. Topics include: recurrence relations, sorting and searching, divide-and-conquer, dynamic programming, greedy algorithms, NP-completeness.

Also listed as COMP 3804.

Prerequisite(s): COMP 2002 or COMP 2402, and either COMP 1805 or both of MATH 2007 and MATH 2108 or equivalents.

Lectures three hours a week.

**MATH 3806 [0.5 credit]****Numerical Analysis (Honours)**

Elementary discussion of error, polynomial interpolation, quadrature, linear systems of equations and matrix inversion, non-linear equations, difference equations and ordinary differential equations.

Also listed as COMP 3806.

Precludes additional credit for MATH 3800.

Prerequisite(s): i) MATH 1002, MATH 1005 or MATH 2007; and ii) MATH 1102 or MATH 2107; and (iii) knowledge of a computer language.

Lectures three hours a week and one hour tutorial.

**MATH 3807 [0.5 credit]****Mathematical Software (Honours)**

Incorporation of basic numerical methods into efficient, reliable software. The course includes examination of existing software systems, e.g., linear systems, non-linear systems, optimization, or differential equations.

Also listed as COMP 3807.

Prerequisite(s): MATH 3806.

Lectures three hours a week and one hour tutorial.

**MATH 3808 [0.5 credit]****Mathematical Analyses of Games of Chance**

This course covers mathematics used in the modern casino gaming industry. The topics include probabilities, odds, house advantages, variance and risks, optimal strategies, random walks and gambler's ruin, and gaming revenue estimation. Examples are taken from various games such as Roulette, Blackjack, and Poker.

Prerequisite(s): one of STAT 2655, STAT 2605, STAT 2507, STAT 2606, STAT 3502, or MATH 3825 or MATH 3855.

Lectures three hours a week, tutorial one hour a week.

**MATH 3809 [0.5 credit]****Introduction to Number Theory and Cryptography**

Congruences, distribution of primes, general cryptographic systems, public key cryptographic systems and authentication using number theory, primality testing and factoring in relation to cryptography, continued fractions and Diophantine equations.

Prerequisite(s): MATH 2108 or MATH 3101 or MATH 2100; knowledge of a computer language.

Lectures three hours a week and one hour tutorial.

**MATH 3815 [0.5 credit]****Mathematics for Molecular Biology**

Linear recurrences; difference equations; graph theory and trees; heuristic and approximation algorithms; software tools; DNA sequencing methods; alignment; string similarity; genetic mapping.

Prerequisite(s): MATH 1102 (or MATH 1107); and MATH 1002 (or MATH 2007).

Lectures three hours a week.

**MATH 3816 [0.5 credit]****Mathematics for Evolutionary Biology**

Population dynamics; evolutionary trees; predator-prey models; game theory; evolutionary genetics; nonlinear dynamics and chaos; pattern formation.

Prerequisite(s): MATH 1002 (or MATH 2007); and MATH 1102 (or MATH 1107).

Lectures three hours a week.

**MATH 3819 [0.5 credit]****Modern Computer Algebra**

Algorithms for multiplication, division, greatest common divisors and factorization over the integers, finite fields and polynomial rings. Basic tools include modular arithmetic, discrete Fourier transform, Chinese remainder theorem, Newton iteration, and Hensel techniques. Some properties of finite fields and applications to cryptography.

Prerequisite(s): MATH 2108 or MATH 3101 or MATH 2100, or permission of the School.

Lectures three hours a week, tutorial/laboratory one hour a week.

**MATH 3825 [0.5 credit]****Discrete Structures and Applications**

Enumeration: elementary methods, inclusion and exclusion, recurrence relations, generating functions and applications. Graph theory and algorithms: connectivity, planarity, Hamilton paths and Euler trails. Error-correcting codes.

Precludes additional credit for MATH 3805 and MATH 3855.

Prerequisite(s): one of MATH 2108 or MATH 3101.

Lectures three hours a week, tutorial one hour a week.

**MATH 3855 [0.5 credit]****Discrete Structures and Applications (Honours)**

Enumeration: inclusion and exclusion, recurrence relations, generating functions and applications. Graph theory: connectivity, planarity, Hamilton paths and Euler trails. Error-correcting codes. Designs and finite geometries. Symmetry and counting.

Also listed as COMP 3805.

Precludes additional credit for MATH 3805 and MATH 3825.

Prerequisite(s): MATH 2100, or a grade of B or higher in MATH 2108 or MATH 3101.

Lectures three hours a week, tutorial one hour a week.

**MATH 3907 [0.5 credit]****Directed Studies**

Available only to students whose program requires a 0.5 credit not offered by the School of Mathematics and Statistics.

**MATH 3999 [0.0 credit]****Co-operative Work Term Report (Honours)**

On completion of each work term, the student must submit to the School of Mathematics and Statistics a written report on the work performed. Graded Sat or Uns.

Prerequisite(s): registration in the Co-operative Education Option of an Honours program offered by the School of Mathematics and Statistics, and permission of the School. Four-month work term

**MATH 4002 [0.5 credit]****Fourier Analysis (Honours)**

Fourier series, Fourier integrals; introduction to harmonic analysis on locally compact abelian groups, Plancherel Theorem, Pontryagin duality; selected applications.

Prerequisite(s): MATH 3001 or permission of the School. Lectures three hours a week.

**MATH 4003 [0.5 credit]****Functional Analysis (Honours)**

Banach spaces and bounded linear operators, Hahn-Banach extension and separation, dual spaces, bounded inverse theorems, uniform boundedness principle, applications. Compact operators.

Prerequisite(s): MATH 4007 or permission of the School. Also offered at the graduate level, with different requirements, as MATH 5008, for which additional credit is precluded. Lectures three hours a week.

**MATH 4007 [0.5 credit]****Measure and Integration Theory (Honours)**

Lebesgue measure and integration on the real line; sigma algebras and measures; integration theory;  $L_p$  spaces; Fubini's theorem; decomposition theorems and Radon-Nikodym derivatives.

Prerequisite(s): MATH 3001 or permission of the School. Also offered at the graduate level, with different requirements, as MATH 5007, for which additional credit is precluded. Lectures three hours a week.

**MATH 4102 [0.5 credit]****Group Representations and Applications (Honours)**

An introduction to the group representations and character theory, with selected applications.

Prerequisite(s): MATH 3106, or a grade of B or higher in MATH 3108. Also offered at the graduate level, with different requirements, as MATH 5102, for which additional credit is precluded. Lectures three hours a week.

**MATH 4105 [0.5 credit]****Rings and Modules (Honours)**

Fundamental concepts in rings and modules, structure theorems, applications.

Prerequisite(s): MATH 3158 or permission of the School. Lectures three hours a week.

**MATH 4106 [0.5 credit]****Group Theory (Honours)**

Fundamental principles as applied to abelian, nilpotent, solvable, free and finite groups; representations.

Prerequisite(s): MATH 3106 or permission of the School. Also offered at the graduate level, with different requirements, as MATH 5106, for which additional credit is precluded. Lectures three hours a week.

**MATH 4107 [0.5 credit]****Commutative Algebra (Honours)**

Fields, including algebraic and transcendental extensions, Galois theory, valuation theory; Noetherian commutative rings, including Noether decomposition theorem and localization.

Prerequisite(s): MATH 3158 or permission of the School. Lectures three hours a week.

**MATH 4108 [0.5 credit]****Homological Algebra and Category Theory (Honours)**

Axioms of set theory; categories, functors, natural transformations; free, projective, injective and flat modules; tensor products and homology functors, derived functors; dimension theory.

Prerequisite(s): MATH 3158 or permission of the School. Also offered at the graduate level, with different requirements, as MATH 5108, for which additional credit is precluded. Lectures three hours a week.

**MATH 4109 [0.5 credit]****Fields and Coding Theory (Honours)**

Introduction to field theory, emphasizing the structure of finite fields, primitive elements and irreducible polynomials. The influence of computational problems will be considered. Theory and applications of error-correcting codes: algebraic codes, convolution codes, decoding algorithms, and analysis of code performance.

Prerequisite(s): MATH 2100, or MATH 3101 or MATH 2108 or equivalent; or permission of the School. Lectures three hours a week.

**MATH 4205 [0.5 credit]****Introduction to General Topology (Honours)**

Topological spaces, maps, subspaces, product and identification topologies, separation axioms, compactness, connectedness.

Prerequisite(s): MATH 3001 or permission of the School. Also offered at the graduate level, with different requirements, as MATH 5205, for which additional credit is precluded. Lectures three hours a week.



**MATH 4206 [0.5 credit]****Introduction to Algebraic Topology (Honours)**

An introduction to homotopy theory. Topics include the fundamental group, covering spaces and the classification of two-dimensional manifolds.

Prerequisite(s): MATH 3106 and MATH 4205; or permission of the School.

Also offered at the graduate level, with different requirements, as MATH 5206, for which additional credit is precluded.

Lectures three hours a week.

**MATH 4207 [0.5 credit]****Foundations of Geometry (Honours)**

A study of at least one modern axiom system of Euclidean and non-Euclidean geometry, embedding of hyperbolic and Euclidean geometries in the projective plane, groups of motions, models of non-Euclidean geometry.

Prerequisite(s): MATH 3106 (may be taken concurrently) or permission of the School.

Lectures three hours a week.

**MATH 4208 [0.5 credit]****Introduction to Differentiable Manifolds (Honours)**

Introduction to differentiable manifolds; Riemannian manifolds; vector fields and parallel transport; geodesics; differential forms on a manifold; covariant derivative; Betti numbers.

Prerequisite(s): MATH 3002 or permission of the School.

Lectures three hours a week.

**MATH 4305 [0.5 credit]****Analytic Number Theory (Honours)**

Dirichlet series, characters, Zeta-functions, prime number theorem, Dirichlet's theorem on primes in arithmetic progressions, binary quadratic forms.

Prerequisite(s): MATH 3057 or permission of the School.

Also offered at the graduate level, with different requirements, as MATH 5305, for which additional credit is precluded.

Lectures three hours a week.

**MATH 4306 [0.5 credit]****Algebraic Number Theory (Honours)**

Algebraic number fields, bases, algebraic integers, integral bases, arithmetic in algebraic number fields, ideal theory, class number.

Prerequisite(s): MATH 3158 (may be taken concurrently) or permission of the School.

Also offered at the graduate level, with different requirements, as MATH 5306, for which additional credit is precluded.

Lectures three hours a week.

**MATH 4600 [0.5 credit]****Case Studies in Operations Research (Honours)**

Applications of the principles of Operations Research to practical problems in business, management, and science. Students present at least one case and analyze cases in the published literature. Cases may also be presented by visiting practitioners.

Note: students in Honours Mathematics/Statistics programs may only take this course as a free option.

Prerequisite(s): STAT 2509 (or STAT 2559) and MATH 3801; or permission of the School.

Seminars three hours a week.

**MATH 4700 [0.5 credit]****Partial Differential Equations (Honours)**

First-order partial differential equations. Classification of second-order linear partial differential equations; the diffusion equation, wave equation and Laplace's equation; separation of variables; Fourier and Laplace transform methods for the solution of initial/boundary value problems; Green's functions.

Prerequisite(s): MATH 3057 and one of MATH 3008 or MATH 3705, or permission of the School.

Lectures three hours a week.

**MATH 4701 [0.5 credit]****Topics in Partial Differential Equations (Honours)**

Theory of distributions, initial-value problems based on 2-dimensions wave equations, Laplace transform, Fourier integral transform, diffusion problems, Helmholtz equation with application to boundary and initial-value problems in cylindrical and spherical coordinates.

Prerequisite(s): MATH 3008 and one of MATH 3002 or MATH 3057 or permission of the School.

Also offered at the graduate level, with different requirements, as MATH 5407, for which additional credit is precluded.

Lectures three hours a week.

**MATH 4703 [0.5 credit]****Dynamical Systems (Honours)**

Basic concepts of dynamical systems. Vector formulation for systems. Theory of autonomous systems in one, two and higher dimensions. Limit sets, stability. Phase plane, qualitative interpretation, limit cycles and attractors. Parametric dependence, bifurcations and chaos. Applications.

Prerequisite(s): MATH 3001 and MATH 3008 or permission of the School.

Lectures three hours a week.

**MATH 4801 [0.5 credit]****Topics in Combinatorics (Honours)**

An in-depth study of one or more topics from: generating functions, Polya's theory of counting, block designs, coding theory, partially ordered sets and Ramsey theory.

Prerequisite(s): MATH 2100 and MATH 3805 or permission of the School.

Lectures three hours a week.

**MATH 4802 [0.5 credit]****Introduction to Mathematical Logic (Honours)**

Symbolic logic, propositional and predicate calculi, set theory and model theory, completeness.

Prerequisite(s): MATH 2100 or permission of the School.

Lectures three hours a week.

**MATH 4803 [0.5 credit]****Computable Functions (Honours)**

Recursive functions and computability, algorithms, Church's thesis, Turing machines, computational logic, NP-completeness.

Also listed as COMP 4803.

Prerequisite(s): MATH 2100 or MATH 3805 or permission of the School.

Lectures three hours a week.

**MATH 4805 [0.5 credit]****Theory of Automata (Honours)**

Finite automata and regular expressions, properties of regular sets, context-free grammars, pushdown automata, deterministic context-free languages. Turing machines, the Chomsky hierarchy. Undecidability, intractable problems.

Also listed as COMP 4805.

Prerequisite(s): MATH 3805 or MATH 3106 or MATH 3158 or permission of the School.

Also offered at the graduate level, with different requirements, as MATH 5605, for which additional credit is precluded.

Lectures three hours a week.

**MATH 4806 [0.5 credit]****Numerical Linear Algebra (Honours)**

Matrix computations, conditioning and stability, direct methods for linear systems, classical iterative methods: Jacobi, Gauss-Seidel; modern iterative methods, Arnoldi decomposition, GMRES and other Krylov subspace based methods for sparse and structured matrices; numerical solution of eigenvalue problems, implementation using suitable programming language, application to differential equations and optimization problems.

Also listed as COMP 4806.

Prerequisite(s): MATH 1102 or MATH 2107; MATH 2000 and MATH 3806; or permission of the School.

Lectures three hours a week.

**MATH 4807 [0.5 credit]****Game Theory (Honours)**

Two-person zero-sum games; infinite games; multistage games; differential games; utility theory; two-person general-sum games; bargaining problem; n-person games; games with a continuum of players.

Prerequisite(s): MATH 3801 or permission of the School.

Also offered at the graduate level, with different requirements, as MATH 5607, for which additional credit is precluded.

Lectures three hours a week.

**MATH 4808 [0.5 credit]****Graph Theory and Algorithms (Honours)**

Paths, circuits, Eulerian and Hamiltonian graphs, connectivity, colouring problems, matching, Ramsey theory, network flows.

Prerequisite(s): MATH 3805 or MATH 3106 or MATH 3158 or permission of the School.

Lectures three hours a week.

**MATH 4809 [0.5 credit]****Mathematical Cryptography (Honours)**

Topics covered include: a general survey of public key cryptography; classical applications of finite fields and number theory; relevant background in geometry and algebraic curves; computational issues concerning elliptic curves; elliptic curve cryptosystems; security issues.

Prerequisite(s): MATH 3158, or permission of the School.

Lectures three hours a week.

**MATH 4811 [0.5 credit]****Combinatorial Design Theory (Honours)**

Existence and construction of combinatorial designs: finite geometries, pairwise balanced designs, balanced incomplete block designs, Steiner triple systems, symmetric designs, PBD closure, latin squares, transversal designs, and applications to information theory.

Prerequisite(s): MATH 3805, or permission of the School.

Lectures three hours a week.

**MATH 4816 [0.5 credit]****Numerical Analysis for Differential Equations (Honours)**

Floating point arithmetic; numerical solution of ODEs; finite difference methods for PDEs; stability, accuracy and convergence: von Neumann analysis, CFL condition, Lax Theorem. Finite element methods: boundary value problems and elliptic PDEs. Spectral and pseudo-spectral methods.

Prerequisite(s): MATH 2454 and MATH 3806, or permission of the School.

Also offered at the graduate level, with different requirements, as MATH 5806, for which additional credit is precluded.

Lectures three hours a week.

**MATH 4821 [0.5 credit]****Quantum Computing (Honours)**

Space of quantum bits; entanglement. Observables in quantum mechanics. Density matrix and Schmidt decomposition. Quantum cryptography. Classical and quantum logic gates. Quantum Fourier transform. Shor's quantum algorithm for factorization of integers.

Prerequisite(s): MATH 1102 (or MATH 2107) with a grade of C+ or better, and permission of the School.

Also offered at the graduate level, with different requirements, as MATH 5821, for which additional credit is precluded.

Lectures three hours a week.

**MATH 4822 [0.5 credit]****Wavelets and Digital Signal Processing (Honours)**

Lossless compression methods. Discrete Fourier transform and Fourier-based compression methods. JPEG and MPEG. Wavelet analysis. Digital filters and discrete wavelet transform. Daubechies wavelets. Wavelet compression.

Prerequisite(s): MATH 1102 (or MATH 2107) with a grade of C+ or better, and permission of the School.

Also offered at the graduate level, with different requirements, as MATH 5822, for which additional credit is precluded.

**MATH 4905 [0.5 credit]****Honours Project (Honours)**

Consists of a written report on some approved topic or topics in the field of mathematics, together with a short lecture on the report.

Prerequisite(s): B.Math.(Honours) students only.

**MATH 4906 [0.5 credit]****Directed Studies (Honours)**

Prerequisite: B.Math.(Honours) students only.

**MATH 4907 [0.5 credit]****Directed Studies (Honours)**

Prerequisite: B.Math.(Honours) students only.

**Summer session:** some of the courses listed in this Calendar are offered during the summer. Hours and scheduling for summer session courses will differ significantly from those reported in the fall/winter Calendar. To determine the scheduling and hours for summer session classes, consult the class schedule at [central.carleton.ca](http://central.carleton.ca)

Not all courses listed are offered in a given year. For an up-to-date statement of course offerings for the current session and to determine the term of offering, consult the class schedule at [central.carleton.ca](http://central.carleton.ca)