MATHEMATICS HANDBOOK

For students who joined in 2025

Contents

*Detailed outlines for Basic Algebra & Number Theory and Algebra III will be provided soon. These are the newly added required courses for a 4 year B.Sc. degree in Mathematics.

†Previously, MAT 1000 was offered as MAT 1005. Please refer to the guidelines provided in Section 4.

‡Previously, MAT 2020 was offered as MAT 2006: Probability Theory. Students who have already taken MAT 2006 cannot register for MAT 2020.

1 Introduction

Some of the most powerful and beautiful ideas occur in the field of Mathematics. The wide applicability of these ideas and their deep connection with the natural sciences have made this discipline one of the most fruitful arenas of human inquiry. Combining, as it does, the greatest creative freedom with the most stringent standards of rigor, Mathematics also happens to be the ideal training ground for learning a broad range of analytical and problem-solving skills.

Ashoka University's Mathematics major program has been designed to meet two primary goals:

1. Students should get a broad exposure to the primary areas and the central ideas of contemporary Mathematics (as well as their applications).

2. Students should develop rigorous, analytical reasoning skills, along with problem-solving ability.

Any student joining Ashoka University must attend a certain number of Foundation courses. In addition to the Foundation courses that are common across disciplines, students aiming to choose Mathematics as their major should take the Calculus course as early as possible. The Department offers the following programs in Mathematics:

1. Major in Mathematics [B.Sc.(Hons.)],

2. Major in Mathematics with research [B.Sc.(Hons) with research],

3. Major in Mathematics and Computer Science [B.Sc.(Hons.)],

4. Minor in Mathematics,

5. Concentration in Mathematics.

6. PhD. in Mathematics.

The set of elective courses may vary from semester to semester depending on student and faculty interests. At the end of the program of study, we expect students to be able to read and understand mathematical proofs; learn and apply new mathematical concepts; and, construct and communicate a correct and rigorous argument on their own. Most importantly, we expect students to be able to solve new mathematical problems on their own. Students completing this program will be well prepared to pursue Mathematics further or to take up positions that call for innovative problem solving in concert with strong analytical abilities.

2 Courses Offered

As of now the following courses are being offered by the Department of Mathematics at Ashoka University. The list of elective courses may vary from semester to semester.

- **1000 Level required courses:** Calculus, Linear Algebra, Multivariable Calculus, Basic Algebra & Number Theory.
- **2000 Level required courses:** Algebra I , Probability and Statistics, Real Analysis, Metric and Topological Spaces.
- **3000 Level required courses:** Algebra II, Complex Analysis, Mathematical modelling (differential equations), Linear Algebra and Matrix Analysis, Elementary Differential Geometry.
- **3000 Level elective courses:** Statistical Inference I, Fourier analysis, Introduction to Combinatorial techniques.
- **4000 Level required courses:** Algebra III.
- **4000 Level elective Courses:** Topological spaces, Measure theory, Functional analysis, Random graphs, Topics in analysis, Mathematical foundations of data science, Algebraic number theory, Topology and geometry.

3 Special advisory regarding the Calculus (MAT-1000) course

The Course MAT 1000 titled Calculus is offered every semester by the Mathematics Department. It is mandatory for all students who wish to take Mathematics as their major, minor or concentration subject. It is a prerequisite for most other courses in mathematics. It may also be required for other mathematics-intensive subjects. Students are advised to take it as early as possible, possibly during the first or the second semester. In particular, a student majoring in math should take Calculus in the first semester. A student who wants to decide later can take the Math FC in the first semester.

The course is designed for students who have done Mathematics in their Classes 11 and 12 in school. That means they have already learnt some calculus. College level calculus is quite different with its emphasis on concepts, rigour and reasoning in addition to calculations based on some standard techniques. Students should be prepared for this jump.

Students who have not done class 11 and 12 mathematics may also choose to take this course. You are expected to learn and master some topics of school mathematics before the course begins. The reason is that, at different points the course will draw on these topics and if you do not know them, you will find it very difficult to proceed.

(a) For your guidance a list of such topics is given below:

(i) Algebra: linear equations, quadratic equations, binomial theorem, sets and functions, graphs of functions, elementary functions like polynomials, exponential and logarithmic functions, arithmetic and geometric progressions.

(ii) Trigonometry: the sin, cos and tan functions, their basic properties, trigonometric identities, addition formulas.

(iii) Coordinate Geometry: Equations of straight lines, circles, and other curves, slopes and tangents.

(b) To check whether you are reasonably prepared, you could look at a standard college level textbook. One such book is Calculus by James Stewart. Some of these books discuss the prerequisites for a Calculus course and also give some tests to check whether a student is reasonably well prepared. You can specifically refer to diagnostic tests given in 'Calculus - early transcendentals' by J. Stewart (published by Cengage Learning). You will find other resources on the web. It is recommended that you test yourself and decide whether you are prepared.

(c) An important point to keep in mind is that students who have not done Calculus at 10+2 level will have to put in a significant amount of effort (solving problems) to get their desirable grades.

4 Degree Requirements

4.1 Major in Mathematics

For 4 year B.Sc. Hons. degree students have to take a total of 20 mathematics courses. For 3 year B.Sc. Hons. degree each student will take a total of 15 mathematics courses. For completing a 3 year B.Sc. Hons. degree in Mathematics, one must take the following 13 required courses and **two** more elective courses.

- **Required Courses for** 3 **year B.Sc. Hons. in Mathematics:** Calculus, Linear Algebra, Multivariable Calculus, Basic Algebra & Number Theory, Algebra I, Algebra II, Real Analysis, Probability and Statistics, Metric and Topological Spaces, Complex Analysis, Linear algebra and Matrix Analysis, Mathematical modelling (Differential Equations) and Elementary Differential Geometry.

For 4 year B.Sc. Hons. degree in Mathematics, one must take the following 14 required courses and **six** more elective courses.

- **Required Courses for** 4 **year B.Sc. Hons. in Mathematics:** Calculus, Linear Algebra, Multivariable Calculus, Basic Algebra & Number Theory, Algebra I, Algebra II, Real Analysis, Probability and Statistics, Metric and Topological Spaces, Complex Analysis, Linear algebra and Matrix Analysis, Mathematical modelling (Differential Equations) and Elementary Differential Geometry, Algebra III.

- **Elective Courses:** A limited list of elective courses are as follows:

  3000 Level Elective Courses: Statistical Inference I, Fourier analysis, Introduction to Combinatorial techniques.

  4000 Level Elective Courses: Topological spaces, Measure theory, Functional analysis, Random graphs, Topics in analysis, Mathematical foundations of data science, Algebraic number theory, Topology and geometry, Applied stochastic processes.

Note that the set of elective courses offered by the department is not *restricted* to the above list. Elective courses offered may vary from semester to semester depending on students' interest and availability of faculty.

Below we have suggested a course progression for students opting for 4 year B.Sc. degree in Mathematics depending on whether they are taking Calculus in the first semester or in the second semester:

Sem I	**Sem II**	**Sem III**	**Sem IV**	**Sem V**	**Sem VI**	**Sem VII**	**Sem VIII**
For students taking Calculus in the **first** *semester*							
Calculus	Linear algebra	Algebra I	Multi variable Calculus	Complex analysis	Diff geometry	Elective III	Algebra III
	Basic Algebra & Number Theory	Real analysis	Metric and Top. spaces	Diff Eqns	Linear Algebra Matrix Analysis	Elective IV	Elective V
		Prob. Statistics	Elective I	Algebra II	Elective II		Elective VI
For students taking Calculus in the **second** semester							
	Calculus	Linear algebra	Multi variable Calculus	Complex analysis	Diff geometry	Elective III	Algebra III
	Basic Algebra & Number Theory	Real analysis	Metric and Top. spaces	Diff Eqns	Linear Algebra Matrix Analysis	Elective IV	Elective V
		Prob. Statistics	Elective I	Algebra I	Elective II	Algebra II	Elective VI

Note the following key points:

- For a 4 year B.Sc. degree in Mathematics students require 80 credits which means

in addition to the 14 required courses, they have to take a minimum of 6 elective maths courses.

- For 4 year B.Sc. degree with research in Mathematics in addition to 20 math courses students need to do a capstone research in their 4-th year under the supervision of maths faculty. A capstone project spans over two semesters. Students intend to do a capstone project should consult with the department prior to their 4-th year.

Below we have suggested a course progression for students opting for 3 year B.Sc. degree in Mathematics. Do note that without doing Calculus in their first semester at Ashoka, a student may find it difficult to get a 3 year B.Sc. degree in Mathematics.

Sem I	**Sem II**	**Sem III**	**Sem IV**	**Sem V**	**Sem VI**
Calculus	Linear algebra	Algebra I	Multi variable Calculus	Complex analysis	Diff geometry
	Basic Algebra & Number Theory	Real analysis	Metric and Top. spaces	Diff Eqns	Linear Algebra Matrix Analysis
		Prob. Statistics	Elective I	Algebra II	Elective II

It should be noted that students can complete the 3 year B.Sc. degree requirements in 4 years as well.

Note the following key points:

- For a 3 year B.Sc. degree in Mathematics students require 60 credits which means in addition to the 13 required courses, they have to take a minimum of 2 elective math courses.
- Capstone research project option is applicable for students opting for 4 year B.Sc. degree only.

4.2 Major in Computer Science and Mathematics

For 4 year B.Sc. degree in Computer Science and Mathematics each student needs to take a total of **10** Mathematics courses and **10** Computer Science courses. The list of required courses for this interdisciplinary major is given below:

- **Required Courses (Mathematics):** Calculus, Linear Algebra, Multivariable Calculus, Real Analysis, Basic Algebra & Number Theory, Probability and Statistics, Statistical Inference I.
- **Required Courses (Computer Science):** Introduction to Computer Programming, Computer Organization and Systems, Algorithm Design and Analysis, Computer Networks, Introduction to Machine Learning, Computer Security and Privacy, Theory of Computation.

In addition to these required courses, students are required to take **3** additional courses from *each* of the two disciplines.

For 3 year B.Sc. degree in Computer science and Mathematics, each student will take the required **7** Mathematics courses and the required **7** Computer Science Courses and will top it up with any course offered by either by Mathematics / Computer Science departements avoiding double counting.

4.3 Minor in Mathematics

Each student will take a total of 6 mathematics courses for completing a minor in Mathematics.

- **Required Courses:** Calculus, Linear Algebra, Multi variable Calculus, Basic Algebra & Number Theory, Real Analysis and Probability and Statistics (students taking a course in probability as part of their major *may* replace this course with another course offered by the mathematics department).
- It is strongly recommended that you complete Calculus and Linear Algebra within the first three semesters at Ashoka. These courses are prerequisites for almost all advanced math courses. If you request a prerequisite waiver for these courses at a later stage, it will be declined.

4.4 Concentration in Mathematics

Each student will take a total of 4 mathematics courses for completing a concentration in Mathematics.

- **Required Courses:** Calculus, Linear algebra, Basic Algebra & Number theory.
- **Elective Courses:** Any course offered by the Mathematics department that is not listed in the above list (the CTS course cannot be counted as a math elective if counted as a CTS requirement).
- It is strongly recommended that you complete Calculus and Linear Algebra within the first three semesters at Ashoka. These courses are prerequisites for almost all advanced math courses. If you request a prerequisite waiver for these courses at a later stage, it will be declined.

4.5 Semester abroad course approval policy:

The department cooperates with students to approve courses they want to take while they spend a semester as a visiting student in a foreign university. A few things to keep in mind when applying for an approval:

1. While requesting an approval it is the responsibility of the student to present all relevant materials such as detailed syllabus (not just a basic course overview), course plan, textbooks or lecture notes to be followed. Without these the approval will not be granted.
2. A math major student wishing to replace a compulsory course MUST take the Honors version of a course at the desired university for receiving credits for major.

4.6 Remark about course offerings:

In order to provide flexibility to our students for planning their course trajectory, there are a few fundamental mathematics courses which are offered in both Monsoon and Spring semesters. Presently, the following courses are offered in each semester:

1. Calculus
2. Linear Algebra.
3. Probability and Statistics.
4. Multi variable calculus.
5. Real analysis.

Algebra I, Algebra II, Complex analysis, Differential eqn., are offered only in Monsoon semester.
Basic Algebra & Number theory, Algebra III, Metric and Top. spaces, Elementary Diff. Geom., Lin. Algb., Matrix An. and Stat. Inference I are offered only in Spring.
As Elective I, Statistical Inference I (offered every Spring Semester) is the recommended course.

5 Cross List Policy

A course id of type **Dept A xxxx/ Dept B yyyy** means Department A is the parent department and Department B is the child department. So the course will be considered as a cross-list in your trajectory if you want it to be counted towards department B, because it is being offered by department A. For example, the following courses (offered by other parent departments) are cross listed with Mathematics department:

(i) Symbolic logic and applications CS 5310/ MAT 3216 (CS is the parent department and MAT is the child department)

(ii) Introduction to Machine learning CS 3410/ MAT 3211 (CS is the parent department and MAT is the child department)

(iii) Classical Mechanics PHY 2210/ MAT 3210 (Physics is the parent department and MAT is the child department)

(iv) Numerical algorithms and optimization CS 3220/ MAT 2204 (CS is the parent department and MAT is the child department)

(v) Discrete Mathematics CS 1110/ MAT 2203 (CS is the parent department and MAT is the child department)

This list will be periodically updated.

The following courses offered by the Mathematics department as parent department are cross listed with other child departments (Computer Science, Physics).

(a) Linear algebra MAT 1001/ CS 2201

(d) Probability and Statistics MAT 2020/ CS 1209 / PHY 1208

Some questions and answers:

How will the course in item (i) (i.e., CS 1306/ MAT 1201) be counted?

This course counted towards a CS requirement would be a non-cross-listed course, but for MAT requirements it will be a cross-listed course. For students doing a minor or concentration in mathematics, cross-listed courses (where parent department is not mathematics) are NOT counted towards math minor or concentration degree requirement.

Can the course in (i) be counted towards both MAT and CS requirements?

Yes, under some conditions. If CS is your major and MAT is your minor/concentration, and if you want, it can be counted for satisfying the requirements of both departments.

You will then need to take another course to fulfill your graduation requirements. Because credit requirements for declared credentials (major/minor/concentrations) are SEPARATE from credit requirements of degree (overall graduation requirements).

For example- If you want to pursue a 4-year MAT major and a CS minor, then you will need 80 credits (20 courses) to complete a 4-year MAT major and you need 24 credits (6 courses) to complete a CS minor. Then you would have to get 80 MAT credits, 24 CS credits and 56 other credits (which consists of 36 credits from Foundations Courses, 4 credits from Co-Curricular courses, 2 credits for doing Internship and 14 credits from any other collection of courses).

If you choose to count (i) for both MAT and CS then this course would be double counted for both these departments and so you would fall short of the required 160 credits by 4 credits to get a 4 year B.Sc. Honors degree. Therefore you will have to make up this shortfall by taking some other course.

If you do not take an extra course for 4 credits in the above scenario, *you will fulfill the requirements of the Major and Minor requirements but will fail to fulfill the overall graduation requirements.*

What happens in the case of interdisciplinary (ID) majors ?

In the case of ID majors, a cross-listed course **can only count towards one of the departments NOT for BOTH.** You can still choose which department would count (i) towards a credit.

Let's say you are pursuing an 4 year Hons. degree in CS and MAT (Interdisciplinary major). For this ID Major you need 92 credits from CS + MAT courses which must include the required courses offered by the respective departments (for details see section 4.2).

If you take a cross listed course, e.g., MAT 1001/ CS 2210, then you can count it towards MAT OR towards CS but NOT for BOTH.

Therefore, taking a cross-list course does not decrease the number of courses you have to take for the ID Major. In addition you will also have to account for the overall graduation credit requirements. Thus you have to

(1) complete your ID Major (92 credits) and

(2) complete overall graduation requirements (take additional 68 credits from the Foundation Course, Co-Curricular Course, Internship and some other courses of your choice, not limited to the MAT and CS courses).

When do you violate the cross-list policy ?

The Mathematics department allows you to take **at most 4 cross-listed courses, where Mathematics is not the parent department, towards your Mathematics Major requirements**. If you take 5 cross-listed courses from that list, then only 4 courses would be counted for the Major requirement.

6 Prerequisite waiver policy

The default response for a prerequisite waiver request is *NO*. Exceptions are made for Masters's degree and PhD students. If you intend to do a major / minor / concentration in Mathematics, it is strongly advised to keep this in mind. At a later stage if you request a waiver, it will be most likely be rejected unless genuine exceptional cases appear.
Reasons like *I won't be able to graduate with a major / minor / concentration degree* OR *I will take the prerequisite alongside the main course* OR *My graduate school / job application will be incomplete or weak without completing certain course which needs a prerequisite waiver* are NOT considered as exceptional cases.

7 Course Outlines[§]

The following are brief descriptions of the mandatory courses. The contents written here are a broad guideline. The contents of the actual courses and references followed may be different.

7.1 MAT 1000: Calculus[¶]

- **Syllabus:** Number systems. Sequences and series. Functions of a real variable. Graphs of functions. Limits and continuity. Differentiation. Mean value theorem. L'Hospital rule. Maclaurin and Taylor series. Curve tracing. Riemann integral. Definite and indefinite integrals. Fundamental theorem of calculus. Applications of differential and integral calculus in areas such as optimization and mechanics.
- **Prerequisite:** Mathematics at 10+2 level.
- **Suggested Books:**
  1. J. Stewart: Calculus, Cengage Publishers, 2012.
  2. K. A. Ross: Elementary Analysis, The Theory of Calculus, Second Edition, Undergraduate Texts in Mathematics, Springer, 2013.
  3. G. B. Thomas and R. L. Finney: Calculus and Analytic Geometry, Second Edition, Addison-Wesley Publishing, 1998.

7.2 MAT 1001: Linear Algebra

- **Syllabus:** Real vector spaces, subspaces, spanning sets, basis sets, dimension of a vector space. Solution of a system of linear equations. Row space and column space of a matrix, rank of a matrix, elementary row and column operations of a matrix. Inversion of square matrices, rank factorization of a matrix. Properties of determinants. Linear transformations, range and null space of a linear transformation, rank-nullity theorem. Matrix representation of a linear transformation. Inner product spaces, normed linear spaces, examples of different normed linear spaces, orthonormal basis sets. Eigenvalues, eigenvectors, characteristic polynomials. Spectral theorem for real symmetric matrices. Singular value decomposition.
- **Prerequisite:** Mathematics at 10+2 level.
- **Suggested Books:**
  1. A. R. Rao and P. Bhimsankaram: Linear algebra, Hindustan book agency, 2000.
  2. S. H. Friedberg, A. J. Insel and L. E. Spence: Linear algebra, Pearson, 2015.
  3. D. C Lay: Linear algebra and its applications, Pearson, 2014.

[§]Detailed outlines for Basic Algebra & Number Theory and Algebra III will be provided soon. These are the newly added required courses for a 4 year B.Sc. degree in Mathematics.

[¶]Previously, MAT 1000 was offered as MAT 1005. Please refer to the guidelines provided in Section 4.

7.3 MAT 1002: Basic Algebra & Number Theory

- **Syllabus:** The course will provide an introduction to basic number theory and ring theory centered around the theory of congruences and polynomial rings. The course will also touch upon applications to cryptography. The course will cover some of the following topics (ordering is not strict): Mathematical induction, binomial theorem. Division algorithm, GCD, Euclidean algorithm, unique factorization of integers. Congruences, Chinese Remainder Theorem, Theorems of Fermat, Wilson and Euler. Polynomials, Division of polynomials, Unique factorization of polynomial rings, rational functions and Chinese remainder theorem. Applications. Introduction to cryptography, RSA. Some Diophantine equations. Introduction to rings, Euclidean rings, Principal ideal domains, some examples. Fermat's theorem on sums of two squares, quadratic reciprocity. Continued fractions, Pell's equation.

- **Prerequisite:** Mathematics at 10+2 level or completed the MAT-1000 course successfully.

- **Suggested Books:**

  1. Elementary Number theory by David M. Burton
  2. Integers, Polynomials and Rings by Ronald S. Irving.

7.4 MAT 1004: Multi variable Calculus

- **Syllabus:** Review of vectors and matrices. Curves and surfaces. Partial derivatives. Total differential and gradients. Maximum and minimum values. Lagrange multipliers. Double integrals, Fubini's theorem. Line integrals in the plane. Green's theorem. Triple integrals and surface integrals in 3-space. Stokes theorem. Applications of multivariable calculus.

- **Prerequisite(s):** MAT 1000: Calculus.

- **Desirable:** MAT 1001: Linear Algebra

- **Suggested Books:**

  1. James Stewart: Calculus, Cengage Publishers, 2012.
  2. Marsden and Tromba: Vector Calculus, W. H. Freeman, 2003.
  3. S. Lang: Calculus of several variables, Springer, 3rd edition, 1996.

7.5 MAT 2001: Algebra I

- **Syllabus:** Equivalence relations, partitions of sets. Integers, Mathematical Induction, Complete induction. Matrix groups. Basis of $\mathbb{R}^n$. Co-ordinate changes. General linear matrices. Group structure. Euclidean two dimensional affine group (rigid body motions, the group that controls equivalence). Change of basis. Conjugation. Group

acting on itself. Subgroups, cosets and partitions. Examples of important matrix groups. Quadratic forms, symmetric matrices, spectral theorem. Orthogonal matrices via inner product, group structure. Preserving inner product, metric, isometry. Group actions. Orthogonal matrices acting on $\mathbb{R}^2, \mathbb{R}^3$, General linear matrices. Lattices and the translation action: $\mathbb{Z}$ acting on $\mathbb{R}$ and $\mathbb{Z}^2$ acting on $\mathbb{R}^2$. Orbits and Stabilisers. Counting lemma. Lagrange's theorem. Reproving Fermat's and Euler's theorem in group theoretic setting. Quotient groups. Group homomorphisms. Isomorphism theorems. Automorphisms. Cyclic groups and Abelian groups. Finite groups - cyclic, symmetric, Dihedral. Plato's solids and Cayley's theorem. Free groups and presentation of groups. Direct and semi-direct products.

- **Prerequisites:** MAT 1001: Linear Algebra, MAT 1002: Basic Algebra & Number theory.
- **Desirable:** Mathematics at 10+2 level.
- **Suggested Books:**
  1. M. Artin: Algebra, Second Edition, Pearson Prentice-Hall of India, 2011.
  2. Armstrong: Groups and Symmetry
  3. Shahriar Shahriari: Algebra in action.
  4. Yvette Kosmann-Schwarzbach: Groups and Symmetries: From Finite Groups to Lie Groups by Springer, 2010.

7.6 MAT 2002: Algebra II

- **Syllabus:** Rings and Fields: Euclidean domains, U.F.D., P.I.D, factorization of polynomials. Field extensions. Straightedge and compass constructions. Splitting fields and Galois groups. Normal extensions, Separable extensions, Galois extensions. Fundamental theorem of Galois Theory. Cyclic Extensions, Solvability by radicals.

  Groups: Solvable and nilpotent groups. Sylow theorems. Fundamental theorem for finitely generated abelian groups.
- **Prerequisite(s):** MAT 1001: Linear Algebra, MAT 1002: Basic Algebra & Number theory, MAT 2001: Algebra I.
- **Suggested Books:**
  1. Shahriar Shahriari: Algebra in action. (AMS).
  2. J. Silverman: Abstract Algebra (AMS).
  3. M. Artin: Algebra, Second Edition, Pearson Prentice-Hall of India, 2011.

7.7 MAT 2003: Real Analysis

- **Syllabus:** Real and complex number systems. Limits of sequences. Monotonic sequences. Limits superior and limits inferior. Convergence of a series. Absolute and conditional convergence. Power series over real and complex numbers and their radius of convergence. Bolzano-Weierstrass Theorem, Cantor and Heine-Borel Theorems. Point wise and uniform continuity. Sequences and series of functions. Point wise and uniform convergence of sequence of functions. Integrals and derivatives of sequences and series of functions. Elementary transcendental functions. Improper integrals, Riemann-Stieltjes integral. Idea of Lebesgue integral, Weierstrass approximation Theorem.

- **Prerequisite(s):** MAT 1000: Calculus.

- **Desirable:** MAT 1004: Multivariate Calculus.

- **Suggested Books:**

  1. K. A. Ross: Elementary analysis The theory of calculus, Springer, 2013.
  2. T. M. Apostol: Mathematical Analysis, Second Edition, Addison-Wesley Publishing Company, 1974.
  3. T. Tao: Analysis I, Hindustan Book Agency, 2017.
  4. T. Tao: Analysis II, Hindustan Book Agency, 2017.

7.8 MAT 2020: Probability and Statistics[‖]

- **Syllabus:** Frequency and axiomatic definition of probability, random experiments with equally likely finite outcomes, Inclusion exclusion principle. General finite sample spaces, infinite sample spaces. Concept of probability spaces and construction of probability measures. Conditional probability, Bayes theorem, Independence of events. Random variable (discrete), probability mass function and distribution function. Examples: Bernoulli, Binomial, Poisson, Geometric distributions. Expectation and variance of a random variable, sum law and product law of expectation, moment generating functions. Random vector (discrete), joint distribution, Marginal distributions, joint moment generating functions, covariance, Multinomial distributions. Continuous random variables, density functions, distribution functions, expectation, variance, moment generating function, example: uniform, normal, and exponential. Continuous random vector, joint density function, joint distribution function, conditional density, example: multivariate normal.

  Markov's and Chebyshev's inequalities. The law of large numbers and Central Limit theorem (without proof).

[‖]Previously, MAT 2020 was offered as MAT 2006: Probability Theory. Students who have already taken MAT 2006 cannot register for MAT 2020.

Descriptive statistics, Distribution of sampling statistics, Parameter Estimation and basics of hypothesis testing.

Simple linear regression with one regressor (only if time permits).

- **Prerequisite(s):** MAT 1000: Calculus.
- **Suggested Books:**
  1. S. M. Ross: First Course in Probability, Pearson.
  2. S. M. Ross: Introduction to Probability and Statistics for Engineers and Scientists.
  3. J. L. Devore: Probability and Statistics for Engineering, Cengage, 2012.
  4. V. K. Rohatgi, E. S. Saleh: An Introduction to Probability and Statistics, Wiley-Blackwell, 3rd edition, 2015.

7.9 MAT 2026: Metric and Topological Spaces

- **Syllabus:** Metric spaces, open and closed sets. Euclidean spaces, normed linear spaces, examples of different normed linear spaces, sequence spaces. Completeness, Baire category Theorem. Compactness, characterization of compact spaces. Product spaces, Tychonoff's theorem. Continuous functions, equicontinuous families, Arzela-Ascoli Theorem. Connectedness, path connectedness.

  Inverse function theorem, Implicit function theorem.

  Introduction to general topological spaces, separation axioms. Hausdorff spaces. Convergence of nets.
- **Prerequisite(s):** MAT 1000: Calculus, MAT 1001: Linear Algebra, MAT 2003: Real Analysis.
- **Desirable:** MAT 1004: Multivariate Calculus.
- **Suggested Books:**
  1. J. F. Simmons: Introduction to topology and modern analysis, Krieger Publishing, 2003.
  2. M. O. Searcoid: Metric Spaces, Springer, 2007.
  3. S. Shirali and H. L. Vasudeva: Metric Spaces, Springer, 2006.
  4. S. Kumaresan: Topology of metric spaces, Narosa.
  5. J. R. Munkres: Topology, Pearson, 2nd edition, 2000.

7.10 MAT 3013: Mathematical modelling (Differential Equations)

- **Syllabus:** Differential equation associated to real life problems, First order differential equation on $\mathbb{R}$ of the form $y'(x) = f(x, y(x))$, Equivalent integral equation, Existence of approximate solutions of equation upto error ϵ by Cauchy-Euler method, Existence and uniqueness of solutions when f is Lipshitz continuous in the second variable, Necessary conditions for $f(x, y)$ to be Lipshitz continuous in y, Picard's method of solutions of equation, Higher order differential equations, Vector valued ordinary differential equations, Reformulation of higher order differential equations as first order vector valued differential equations, Linear vector valued first order differential equation, $Y'(x) = AY(x) + C(x)$ — Homogeneous case, $C = 0$, Characteristic values, characteristic vectors of square matrices, Solution when A is independent of x, Linear independence of solutions associated to characteristic values, General solution of the inhomogeneous equation, Peano's approximation method for existence of solution.

- **Prerequisite(s):** MAT 1000: Calculus, MAT 1001: Linear Algebra, MAT 1004: Multivariate Calculus, MAT 2003: Real Analysis, MAT 2026: Metric and Topological Spaces.

- **Suggested Books:**

  1. E. A. Coddington: An Introduction to ordinary differential equations, Prentice Hall India, 1968
  2. V. I. Arnold: Ordinary Differential Equations, MIT Press.

7.11 MAT 3018: Complex Analysis

- **Syllabus:** The algebra and geometry of complex numbers, representations of a complex number. Exponential and logarithmic functions. Differentiation, analytic functions, Cauchy-Riemann equations. Contour integrals, Independence of path. Cauchy's Integral Theorem, Cauchy's Integral Formula, Liouville's Theorem and its applications. Complex power series, uniform convergence. Removable and isolated singularities, Taylor's and Laurent's Theorems. The residue theorem and applications.

- **Prerequisite(s):** MAT 1000: Calculus, MAT 1001: Linear Algebra, MAT 1004: Multivariate Calculus, MAT 2003: Real Analysis, MAT 2026: Metric and Topological Spaces.

- **Suggested Books:**

  1. I. V. Ahlfors: Complex Analysis, Mcgraw Hill, 1979.
  2. J. B. Conway: Functions of one complex variable, Springer.
  3. T. W. Gamelin: Complex Analysis, Springer, 2003.

7.12 MAT 3000: Elementary Differential Geometry

- **Syllabus:** Plane curves, Space curves, Curvature and orientability of surfaces, Geodesics and Parallel transport, Theorema Egregium, Gauss-Bonnet theorem, Brief introduction to metric geometry
- **Prerequisite(s):** MAT 1000: Calculus, MAT 1001: Linear Algebra, MAT 1004: Multivariate Calculus, MAT 2003: Real Analysis, MAT 2026: Metric and Topological Spaces.
- **Suggested Books:**
  1. M P. do Carmo: Differential Geometry of Curves and Surfaces, Prentice-Hall, 1976.
  2. A. Pressley: Elementary Differential Geometry, Springer, 2010.

7.13 MAT 3120: Linear Algebra and Matrix Analysis

- **Syllabus:** Bases, dimension. Subspaces. Norms and inner products. Linear operators. Matrix representations. Similarity and unitary similarity. Dual spaces. Transpose and adjoint. Eigenvalues, singular values and norms of operators. Special classes of operators: hermitian, normal, unitary, positive definite, projections. Spectral theorem. Singular value decomposition. Schur triangular form. QR decomposition. Applications. Commuting operators and simultaneous reduction to diagonal and triangular forms. Additional topics to be chosen from the following (suggested) list: Variational principles for eigenvalues and singular values, The Jordan canonical form; nonnegative matrices and the Perron Frobenius theory; applications of singular value decomposition, discrete Fourier transform.
- **Prerequisite(s):** MAT 1000: Calculus, MAT 1001: Linear algebra, MAT 1004: Multivariate Calculus, MAT 2003: Real Analysis.
- **Suggested Books:**
  1. S. Axler: Linear Algebra Done Right , Second Edition, UTM, Springer, 1997
  2. M. E. Taylor, Linear Algebra.
  3. S. R. Garcia and R. Horn: A Second Course in Linear Algebra.

8 Frequently asked questions

If your questions do not appear in the list below, then consult one of the contacts mentioned below.

Q 1. *Is the 1000/2000/3000 level system an equivalent of the 100/200/300 level system?*

A 1. Yes.

Q 2. *Is it mandatory for majors to take calculus by the end of first year?*

A 2. Yes. Otherwise it would be very difficult to complete your math major in 3 years. Indeed, it is extremely helpful to take calculus by the end of first year in case you intend to major in other mathematically-oriented majors such as Physics, Computer Science and Economics.

Q 3. *Is Multi variable Calculus the same course as Calculus II?*

A 3. Yes.

Q 4. *Is 'Probability and Statistics' course the same course as Probability theory?*

A 4. Yes, it will be treated as the same course. Students who joined in 2019 or earlier are required to take the Probability theory course and students who joined in 2020 (or later) need to take the Probability and Statistics course to complete a math major.

Q 5. *Now the Probability and Statistics course is started, will the Statistical Inference course be offered?*

A 5. Yes, it will be offered as an elective course and the course content for Statistical Inference is different from Probability and Statistics.

Q 6. *Is it mandatory for majors to take multivariable calculus by the end of second year?*

A 6. No, it is not mandatory. But it would be helpful while doing real analysis. But if you cannot do it in the first year, you can still do it later. This course is offered every semester.

Q 7. *Is it mandatory for majors to take linear algebra by the end of second year?*

A 7. No, but it is strongly recommended.

Q 8. *What is the policy on cross-listed courses?*

A 8. Cross-listed courses are those courses offered by other parent departments but are cross-listed with mathematics. The students can take cross-listed courses towards their Major. For details please see the cross-list policy section.

Q 9. *I took a course in Monsoon 2019 which was cross-listed with CS. It is being offered again in 2020 but is not showing as cross-listed. Is this a problem?*

A 9. No. It is normal for courses to not be cross-listed with other departments in every semester that they're offered. If you took a course, which was cross-listed in the semester that you took it, it will count towards your degree. Please cross-check the course code of such courses in your LMS.

Q 10. *Can I write a thesis in the third year?*

A 10. No. Only fourth year mathematics majors with prior approval from the department can write a capstone thesis with the department.

Q 11. *I'm going on a semester abroad. Can I substitute the required courses with a summer abroad course?*

A 11. The specific course along with its detailed syllabus will need to be shared with the Head of the Department. There is a committee who will look into it and a decision will be taken on a case-by-case basis.

Q 12. *Whom should I contact for further queries?*

A 12. You can email the Mathematics Representative math.rep@ashoka.edu.in, with a copy to our Department Manager, Puneet Kaur puneet.kaur@ashoka.edu.in. For course-related inquiries, you may also contact Professor Pritam Ghosh (pritam.ghosh@ashoka.edu.in).

Q 13. *I am confused about which elective courses to opt for. Is there someone I can talk to?*

A 13. You may consult the course descriptions provided on the AMS or may reach out to your peers or seniors who have already taken courses you may be interested in. You may also seek guidance from the respective instructor.

Q 14. *Is there an order that courses have to be taken in?*

A 14. Yes. The course progression section provides a recommended order, which takes into account the prerequisites of each course.

Q 15. *Where can I find more information related to course descriptions and syllabus?*

A 15. You can consult the website (https://ashoka.edu.in/mathematicsdepartment) and under the tab 'Programs' click on 'Math Major'. Each semester's courses will have descriptions on AMS as well.