गोंय विद्यापीठ
ताळगांव पठार
गोंय - ४०३ २०६
फोन: +९१-८६६९६०९०४८

Goa University
Taleigao Plateau, Goa - 403 206
Tel : +91-8669609048
Email : registrar@unigoa.ac.in
Website: www.unigoa.ac.in

(Accredited by NAAC)

GU/Acad –PG/BoS -NEP/2023/56/3 Date:18.05.2023

Ref: GU/Acad –PG/BoS -NEP/2022/339/7 dated 18.08.2022

CIRCULAR

In supersession to the above referred Circular, the updated approved Syllabus with revised Course Codes of the **Master of Science in Mathematics** Programme is enclosed.

The Dean/ Vice-Deans of the School of Physical and Applied Sciences/ Principals of Affiliated Colleges offering the **Master of Science in Mathematics** Programme are requested to take note of the above and bring the contents of this Circular to the notice of all concerned**.**

ASHWIN VYAS LAWANDE
Digitally signed by ASHWIN VYAS LAWANDE
Date: 2023.05.18 15:51:33 +05'30'

(Ashwin Lawande)
Assistant Registrar – Academic-PG

To,

1. The Dean, School of Physical and Applied Sciences, Goa University.
2. The Vice-Deans, School of Physical and Applied Sciences, Goa University.
3. The Principal of Affiliated Colleges offering the Master in Sciences in Mathematics Programme.

Copy to:

1. The Chairperson, Board of Studies in Mathematics.
2. The Programme Director, M. Sc. Mathematics, Goa University.
3. The Controller of Examinations, Goa University.
4. The Assistant Registrar, PG Examinations, Goa University.
5. Directorate of Internal Quality Assurance, Goa University for uploading the Syllabus on the University website.

Goa University

School of Physical and Applied Sciences

Syllabus for the MSc Mathematics

New Syllabus from Academic year 2022-23 onwards

Semester 1	
Paper Code	**Paper Title**
MAT-500	Real Analysis (4 Credit)
MAT-501	Advanced Linear Algebra (4 Credit)
MAT-502	Algebra (4 Credit)
MAT-503	Advanced Complex Analysis (4 Credit)
MAT-521-530	Discipline Specific Elective Courses (4 Credit)
Semester 2	
Paper Code	**Paper Title**
MAT-504	Topology (4 Credit)
MAT-505*	Differential Equations (4 Credit)
MAT-506	Several variable calculus (4 Credit)
MAT-507	Functional Analysis (4 Credit)
MAT-521-530	Discipline Specific Elective Courses (4 Credit)
*Syllabus of this paper is revised in June 2023	
Semester 3	
Paper Code	**Paper Title**
MAT-600-609	Research Specific Elective Course (4 Credit)
	Research Specific Elective Course (4 Credit)
MAT-621-626	Generic Elective Course (4 Credit)
	Generic Elective Course (4 Credit)
	Generic Elective Course (4 Credit)
Semester 4	
Paper Code	**Paper Title**
MAT-600-609	Research Specific Elective Course (4 Credit)
MAT-651	Discipline Specific Dissertation (16 Credit)

List of Elective Courses:

(1) Discipline Specific Elective Courses

Semester 1 and 2	
MAT-521	Mathematical Methods (4 credits)
MAT-522	Difference Equations (4 credits)
MAT-523	Special Functions (4 credits)
MAT-524	Partial Differential Equations (4 credits)
MAT-525	Integral Equations (4 credits)
MAT-526	Finite Element Method (4 Credits)
MAT-527	Combinatorics (4 Credits)
MAT-528	Computational Mathematics using Python (2 Credits)
MAT-529	Elementary Number Theory (2 Credits)
MAT-530	Discrete Mathematical Structures (4 Credits)

(2) Research Specific Optional Courses

Semester 3 and 4	
MAT-600	Mathematical Modelling (4 Credits)
MAT-601	Algebraic Topology (4 Credits)
MAT-602	Number Theory (4 Credits)
MAT-603	Lie Algebra (4 Credits)
MAT-604	Graphs and Networks (4 Credits)
MAT-605	Advanced Graph Theory (4 Credits)
MAT-606	Measure Theory-I (4 Credits)
MAT-607	Measure Theory-II (4 Credits)
MAT-608	Functional Analysis-II (4 Credits)
MAT-609	Symmetry Methods for Differential Equations (4 Credits)

(3) Optional Generic Courses

Semester 3	
MAT-621	Basic Mathematics for Social Science (4 Credits)
MAT-622	Operations Research (4 Credits)
MAT-623	Mathematics for Financial Management and Insurance (4 Credits)
MAT-624	Mathematics for Financial Market (4 Credits)
MAT-625	Latex for Mathematics (2 Credits)
MAT-626	Probability and Statistics (4 Credits)

\Semester I

Programme: M. Sc. (Mathematics)
Course Code: MAT-500 **Title of the Course:** REAL ANALYSIS
Number of Credits: 4
Effective from AY: 2022 June

Prerequisitesf or the course:	Basic Mathematical Analysis	
Course Objective:	This course will develop fundamental concepts in Real Analysis and make the student acquainted with tools of analysis which is essential for the study and appreciation of many related branches of mathematics and applications.	
Content	**1.Real Number System** Peano's Axioms for Natural Numbers and Induction Principle, equivalence of induction, strong induction and the well-ordering principle, Finite sets, cardinality of finite sets, Subset of finite sets , a proper subset of a finite set has cardinality strictly less that the super set, Integers and Rational numbers (Discussion), Ordered sets and LUB Property, Ordered Field Axioms, Field of Real Numbers and Completeness, Archimedean property, integral part of a real number, density of rationals, and irrationals in the reals, Existence of n^{th} roots of nonnegative reals, proof of existence of decimal representation of reals, Countable sets – definition and equivalent reformulations of countability, Countability of unions and Cartesian products of sets, Uncountable sets, Countabilty of Rationals, Uncountability of Reals, Extended Real Number System. **2.Elements of Point Set Toplogy** Metric Spaces, Euclidean Spaces, Open balls and Open sets in $\mathbb{R}^n$, Structure of open sets in $\mathbb{R}^1$, Adherent points and Accumulation points, Closed sets, Perfect sets, Every non-empty perfect set of $\mathbb{R}^n$ is uncountable, Bolzano- Weierstrass Theorem, Cantor Intersection Theorem, Lindel$\ddot{o}$f Covering Theorem, The Heine-Borel Covering Theorem, Compactness in $\mathbb{R}^n$, Compactness in metric spaces, Connected sets in metric spaces, Connected subsets of $\mathbb{R}$, Cantor set-constrction and basic properties, Cantor set and ternary expansion. **3.Limits and Continuity** Convergent sequences in a Metric space , Cauchy sequences and Complete metric spaces, Limit inferior and Limit superior of a sequence, Limit of a Function- (Real valued, complex valued, vector valued functions), Continuous Functions, Continuity and Compactness, Continuity and Connectedness, Bolzano's Theorem and Intermediate value Theorem, Uniform Continuity, Uniform Continuity and Compactness, Discontinuities of Real valued Functions, Monotonic Functions, Infinite limits and Limits at	18 Hours 14 Hours 14 Hours

	infinity. **4.Derivatives** Derivatives and Continuity, Algebra of Derivatives and Chain rule (Statements only),One sided derivatives and Infinite Derivatives, Functions with non-zero derivatives, Zero derivatives and Local extrema, Rolle's Theorem, Mean value Theorems and consequences, Intermediate value Theorem for Derivatives, Taylor's Formula with Remainder, Derivatives of Vector valued Functions and Complex valued Functions, Derivatives of Higher Order, L'Hospital's Rules with proof.	 14 Hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings	1. Mathematical Analysis, Tom M. Apostol, Narosa Publishing House, 1996. 2. Principles of Mathematical Analysis, Walter Rudin, McGraw-Hill International Editions,1976. 3.A Foundation Course in Mathematics, Ajith Kumar, S.Kumaresan, B.K. Sarma, Narosa Publishing House, 2018. 4. A Basic Course in Real Analysis, Kumar and Kumaresan, CRC Press, 2015. 5. Real Analysis, N.L. Carothers, Cambridge University Press, 2000. 6.Calculus with Applications, Peter D. Lax, Maria Shea Terrel, Springer, 2014.	
Course Outcomes	Student will be able to 1. Describe the difference between rational numbers and real numbers. 2. Understand LUB property and apply it to proofs and solutions of problems. 3. Calculate limit inferior and limit superior 4. Understand and use concepts related to metric spaces such as continuity, compactness and connectedness 5. Apply mean value theorem to problems in the context of Real Analysis	

Programme: M. Sc. (Mathematics)

Course Code: MAT-501 **Title of the Course: LINEAR ALGEBRA**

Number of Credits: 4

Effective from: June 2022 onwards

Prerequisites for the course	Should have passed B.Sc. with Linear Algebra as subject and familiar with the notions of vector spaces, basis, dimension, Linear maps, matrix representation and their algebra, and Rank-Nullity theorem	
Course Objective	To prepare students to handle solving problems involving linear equations and determining the qualitative properties of the solution set.	
Content	1. **Review:** System of linear equations, Vector spaces, Basis and Dimension, Linear Transformations, Matrix of a Linear Transformation.	10 Hours
	2. **Linear Functionals**: Linear Functional on Vector Spaces, Dual of Vector Spaces and Properties, Double Dual, Annihilator, The Transpose of a Linear Transformation and the Matrix, Row Rank equal to Column Rank.	12 Hours
	3. **Algebra of Polynomials**: Polynomial Algebra, Polynomial Ideals, Greatest Common Divisors of Polynomials and Prime Factorization of Polynomials. (Quick review)	4 Hours
	4. **Elementary Canonical Forms**: Characteristic Values and Characteristic Vectors, Characteristic Spaces, Annihilating Polynomials, Invariant Subspaces, Simultaneous Triangulation; Simultaneous Diagonalization, Direct Sum Decompositions, Invariant Direct Sums, The Primary Decomposition Theorem.	16 Hours
	5. **The Rational and Jordan Forms**: Cyclic Subspaces and Annihilators, Cyclic Decompositions and the Rational Form, The Jordan Form, Computation of Invariant Factors. Summary; Semi-Simple Operators.	18 Hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings	1. Kenneth Hoffmann and Ray Kunze, Linear Algebra, PHI, 1997. 2. S. Kumaresan, Linear Algebra, PHI, 2000. 3. I.R.Shafarevich and A. O. Remiz Linear Algebra and Geometry, Springer Verlag., 2012 4. Y.I. Manim, Linear Algebra and Geometry, CRC Press., 1997	
Course Outcomes	Student will be able to 1 understand basic Functional analysis, 2 understand Several Variable Calculus, 3 understand Advanced Algebra, 4 understand Differential Equations	

Programme: M. Sc. (Mathematics)
Course Code: MAT-502 **Title of the Course:** ALGEBRA
Number of Credits: 4
Effective from: June, 2022

Prerequisites for the course:	Basic Group Theory	
Course Objectives	This course develops concepts in advanced Group Theory, Basics of Ring Theory and their applications., This course will also be a prerequisite for courses such as Field Theory and Galois Theory and Commutative Algebra.	
Content	**1. Permutation Group** Symmetric groups, Permutations; Alternating groups; Group actions, Orbits and stabilizers; Caley's Theorem;	4 Hours
	2, Series of groups Subnormal Normal series. Jordan Holder Theorem.	8 Hours
	3. Sylow Theorems Conjugacy Classes. The Class Equation, Cauchy's Theorem, p-groups. The Sylow Theorems. Applications of Sylow Theorems. Finite Simple Groups . Non simplicity Tests. The simplicity of A_5	8 Hours
	4. Rings and Fields Rings. Fields. Integral Domains-definitions and Examples. Characteristic of Rings. Ideals and Factor Rings. Prime ideals and Maximal ideals. Ring Homomorphisms. Field of Quotients of an Integral Domain.	8 Hours
	5. Polynomial Rings and Factorization of Polynomials Polynomial Rings-Notations and Terminologies, The Division algorithm and Consequences, Mod p Test for irreducibility over UFD. Gauss Lemma over UFD, Eienstein Criterion, g.c.d., l.c.m., in UFD. In UFD R, f(x) in R[x] is irreducible iff f(x) is irreduclible over the field of quotients of R, R is a UFD implies R[x] is a UFD.	16 Hours
	6. Divisibility in Integral Domains Irreducibles. Primes. Unique Factorization Domains. Principal Ideal Domains. PID implies UFD. Euclidean Domains. Euclidian Domain implies PID. Gaussian Integers and Fermat's $p = a^2+b^2$ Theorem.	16 Hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings	1. Contemporary Abstract Algebra, Joseph A. Gallian, Narosa Publishing House,1999. 2. A First Course in Absract Algebra, John B. Fraleigh, Pearson (India), 2014. 3. Topics in Algebra, I.N.Herstein, Wiley India Edition,2006. 4. Abstract Algebra, David S.Dummit and Richard M. Foote, Second Edition, John Wiley & Sons, 1999.	

Course Outcomes	Student will be able to 1. Explain Concepts in Algebra regarding Groups, Rings and related structures, 2. Develop the ability to work with various algebraic structures. 3. Lay foundation for research topics in Algebra, Number Theory, 4. Lay foundation for research topics in Algebraic Geometry	

Programme: M. Sc. Mathematics
Course Code: MAT-503 **Title of the Course:** COMPLEX ANALYSIS
Number of Credits: 04
Effective from AY: June 2022.

Prerequisites for the course:	Should have studied a basic course in Complex Analysis familiarising the students with the notions of Analytic Functions, Cauchy's Integral Formula, convergence series, Taylor/Laurent series.	
Course Objectives:	This course will further enhance the knowledge of the student in the fundamental concepts in complex analysis and prepare them to apply it to problems involving complex analysis and also gives the foundation for advanced courses in complex analysis.	
Content	**Introduction to the Concept of Analytic Function**: (Limits and Continuity, Analytic Functions, Polynomials, Rational Functions), **Elementary Theory of Power Series**: (Sequences, Series, Uniform Convergence, Power Series, Abel's Limit Theorem), The Exponential and Trigonometric Functions, Periodicity & Logarithm.	12 Hours
	Analytic Functions: Conformality, Arcs and Closed Curves, Analytic Functions in Regions, Conformal Mapping, Linear Transformations, Oriented Circles, Families of Circles, Elementary Conformal Mappings, A Survey of Elementary Mappings.	16 Hours
	Complex Integration: Line Integrals, Rectifiable Arcs, Line Integrals as Functions of Arcs, Cauchy's Theorem for a Rectangle, Cauchy's Theorem in a Disk. Cauchy's Integral Formula, Higher Derivatives. **Local Properties of Analytical Functions:** Removable Singularities. Taylor's Theorem, Laurents Theorem, Zeros, and Poles, Local Mapping, Maximum Principle.	19 Hours
	The General Form of Cauchy's Theorem: Chains and Cycles, Simple Connectivity. **The Calculus of Residues**: The Residue Theorem, The Argument Principle, Evaluation of Definite Integrals.	13 Hours
Pedagogy	Classroom lectures, tutorials, assignments, and library references.	
References/ Readings	1. Ahlfors, L. V. (1979). COMPLEX ANALYSIS. McGraw-Hill Book Company 2. J B Conway, Functions of a Complex Variable, Narosa. 1995 3. S Kumaresan. A Pathway to COMPLEX ANALYSIS. Techno World, Kolkata. 2021 4. James Ward Brown and Ruel V. Churchill, Complex Variables and Applications, Sixth Edition, McGraw-Hill International, 1996.	

	5. A.R. Shastri, *Complex Analysis*. MacMillan, 2011 6. S. Ponnusamy, Foundations of Complex Analysis, Narosa Publisher, 2011
Course Outcomes	Student will be able to: 1. Analyze limit, continuity and differentiation of functions of complex variables. 2. Apprehend elementary theory of Power Series. 3. Understand analytic functions, conformal mapping and their various properties. 4. Understand Cauchy theorem and Cauchy integral formulas and apply these to evaluate complex contour integrals. 5. Represent functions as Taylor and Laurent series; classify singularities and poles; find residues and evaluate complex integrals using the residue theorem.

Semester 2

Programme: M.Sc. Mathematics
Course Code: MAT-504 **Title of the Course: TOPOLOGY**
Number of Credits: 04
Effective from: June, 2022

Prerequisites for the course:	Should have undergone a basic course in Real Analysis. Should be familiar with the notions of set theory. It is desirable to have familiarity with the metric topology.
Course Objectives:	To prepare students to handle courses involving topology and geometry including complex analysis, functional analysis and several variable calculus.
Contents	**1. Topological Spaces and Continuous Functions**: Topological spaces, Basis for a Topology, The Order Topology, The Product Topology on $X \times Y$, The Subspace Topology, Closed Sets and Limit Points, Continuous Functions, The Product Topology, The Metric Topology, The Quotient Topology. — 32 hours **2. Connectedness**: Connected Spaces, Connected Subspaces of$\mathbb{R}$, Components and Local Connectedness. — 8 hours **3. Compactness**: Compact Topological Spaces, Compact Subspaces of $\mathbb{R}$, Limit Point Compactness, Local Compactness, — 12 hours **4. Countability and Separation Axioms**: Countability Axioms, Separation Axioms, Hausdorff Spaces, Regular Spaces, Normal Spaces. — 8 hours
Pedagogy	Class room lectures and tutorials, assignments and library reference.
References/ Readings:	1. James Munkres, Topology and Introduction, Pearson Education, 2002. 2. Stephen Willard, General Topology, Dover, 1941 3. M AAmstrong, Basic Topology, Springer Verlag, 1983. 4. J. Dugunji, Topology, Allyn and Bcon, 1966
Course Outcomes	Students will be able to 1 Comprehend basic courses in Complex Analysis, 2 Understand basic courses in Functional Analysis, Several Variable Calculus, 3 Explore basic courses in Measure Theory etc. and 4 Understand advanced courses in Topology and Geometry.

Programme: M.Sc. Mathematics
Course Code: MAT-505 Title of the Course: DIFFERENTIAL EQUATIONS
Number of Credits: 04
Effective from: June, 2023.

Prerequisites for the course:	Knowledge of basic Real Analysis, Linear Algebra and Differential equations.	
Course Objectives;	This course develops the ability to understand the qualitative theory and some properties of solution of differential equations.	
Contents	1.Review of linear differential equations of the first and higher order. Linear differential equations with constant and variable coefficients. Exact equations, Wronskian, Separable equations, Euler's equation, reduction of order of equation, variation of parameters, Abel's Formula.	10 hours
	3. Existence and uniqueness of solutions of first order differential equation. Lipschitz condition, Picard's successive approximation method, Gronwall's type integral inequality. Continuation of Solution and dependence on initial conditions. Non local existence of solution.	16 hours
	4. Systems of Linear differential equations. Existence and Uniqueness of solutions. Vector matrix form. Linear system with Constant and variable coefficients. Fundamental matrix, matrix exp, and repeated eigenvalue. Non homogeneous linear systems and variation of parameters. Conversion of nth order equation to system of first order.	22 hours
	5. Self-adjoint second order differential equation. Sturm Liouville Problem. Greens functions. Picard's theorem. Zeros of solutions. Comparison Theorems. Linear oscillations. Oscillations of $x''(t) + a(t)x(t) = 0$.	12 hours
Pedagogy	Lectures/ tutorials/assignments/self-study	
References/ Readings:	1. Deo S.G.; Raghvendra V.; RasmitaKar, Lakshmikantham V. : Text book of Ordinary Differential equations, 3rd edition, Tata McGraw Hill, New Delhi 2015. 2. E.A. Coddington; An introduction to Ordinary Differential Equations, Prentice Hall,India,2003. 3. Kelly W. Patterson A.C. : Theory of Differential Equations, Springer, 2010 4. Simmons G.F.; Differential Equations with Historical Notes, Tata Mcgraw Hill, 2017	
Course Outcomes:	Students will able to 1 Solve system of ordinary differential equations 2 Analyse the properties of solution. 3 Distinguish between linear, nonlinear, partial and ordinary differential equations 4 Solve basic application problems described by second order linear differential eq. with constant coefficients	

	5	Find approximate solutions to differential equations using numerical techniques

Programme: M.Sc. Mathematics
Course Code: MAT-506 **Title of the Course:** SEVERAL VARIABLE CALCULUS
Number of Credits: 04
Effective from: June 2022

Prerequisites for the course:	Knowledge of basic Real Analysis and Linear Algebra. Knowledge of Integration of real-valued functions on a subset of R is desirable.	
Course Objectives:	This course develops the ability to understand concepts of functions of severable variables.	
Contents	**1.Derivative of Function of more than one Variable:** Partial Derivative. Total derivative of a function of more than one Variable. Jacobian. Sufficient Condition for differentiability. Mean Value Theorem. Higher-order derivatives. Condition for Equality of Mixed Partial Derivatives. Taylor's Theorem.	12 hours
	2.Maximum Minimum: Critical Point, Maximum Minimum, Second Derivative Condition for Maximum/minimum, Conditional Optimum, and Lagrange Multipliers.	12 hours
	3.Inverse Function Theorem: Regular and Singular Points, Open Mapping Theorem, Inverse Function Theorem, Implicit Function Theorem.	10 hours
	4.Riemann Integration: Rectangles in IRn and Riemann sums over Rectangles. Upper and Lower Riemann Sums. Riemann Integral of a bounded Function. Algebra of Riemann Integrals. Sets of Jordan Measure Zero. Oscillation of a Function at a point, Integrability versus points of discontinuity of a Function.	16 hours
	5.Fubini's Theorem. Mean value theorem for multiple integrals. Partitions of unity (Statement only). Change of variable formula	10 hours
Pedagogy	Classroom lectures, tutorials, assignments, and library references.	
References/ Readings:	**Main Texts:** 1. Tom M Apostol, Mathematical Analysis, Addison Wesley Publishing Company, 1996. 2. M.Spivak, Calculus on Manifolds, Benjamin Cummings, London. 1965 **Reference texts :** 1. Walter Rudin, Principles of Mathematical Analysis, International Student Edition.1976 2. James Munkres, Analysis on Manifolds, Addison Wesley Publishing Company,1991. 3. T. M. Apostol, Calculus Vol.II. John Wiley and sons.1969 4. B.V.Limaye&S.Ghorpade, A course in multivariable calculus, Springer 2006	

Course Outcomes:	Student will be able to: 1. Apprehend derivatives of a multivariable function. 2. Evaluate maximum-minimum for a multivariable function. 3. Understand the Inverse function theorem, Implicit function theorem. 4. Understand Riemann Integration, MVT for Multiple integrals, and Change of Variable formula. 5. Develop a clear understanding of the fundamental concepts of multivariable calculus and a range of skills allowing them to work effectively with the concepts.

Programme: M. Sc. (Mathematics)
Course Code: MAT-507 **Title of the Course:** FUNCTION ALANALYSIS
Number of Credits: 4
Effective from AY: 2022-2023

Prerequisites for the course:	A first course in Real Analysis, Linear Algebra and Metric Toplogy. Basic understanding of Lebesgue Integral Theory is desirable.	
Course Objectives:	Starting with the basics this course will cover the foundations of Functional Analysis such as normed spaces, inner product spaces, Banach spaces, Hilbert spaces, bounded linear operators and bounded functional, and the four fundamental theorems-Hahn-Banach Theorem. Uniform Boundedness Principle, Open Mapping Theorem and Closed Graph Theorem.	
Content	**1.Preliminaries from Metric Spaces** Definition of the standard sequence spaces $s, c,\ c_0, c_{00}, l^p; 1 \leq p \leq \infty$, and standard function spaces $C[a, b]$and $B[a, b]$. Idea of completion of a metric space, completeness and separability properties of these standard spaces	12Hours
	2.Normed Spaces, Banach Spaces Normed spaces- Properties and Banach spaces, Standard normed spaces –Sequence spaces , Function spaces and subspaces, Finite dimensional normed spaces and subspaces, Equivalence of norms, Compactness and finite dimension, Linear Operators-Boundedness and Continuity. Linear functional. Normed spaces of Operators, Dual space-Algebraic and Topological duals.	16 Hours
	3.Inner Product Spaces, Hilbert Spaces Inner Product Spaces- Properties and Hilbert spaces, Orthogonal Complement and Direct Sums, Orthonormal Sets and Sequences, Total Orthonormal Sets and Sequences, Representation of Functional on Hilbert Spaces, Hilbert -Adjoint Operator, Self Adjoint, Unitary and Normal Operators.	16 Hours
	4.Fundamental Theorems for Normed and Banach Spaces Hahn-Banach Theorem **(**Statements and idea of proof for the case of vector spaces, statement and proof for normed spaces**)**, Applications to Existence of Functionals, Adjoint Operators, Reflexivity of Spaces, Baire Category Theorem **(**Statement only**)**, Uniform Boundedness Theorem, Open Mapping Theorem, Closed Graph Theorem.	16 Hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	

References/ Readings:	1. Introductory Functional Analysis with Applications, Ervin Kreyszig, John Wiley & Sons, 1978. 2. Functional Analysis, Balmohan V. Limaye, III edition. 1996 3. Functional Analysis, A First Course, S.Kumaresan and D.Sukumar, Narosa, 2020 4. Functional Analysis, George Bachman and Lawrence Narici, DoverPublishing House, 2000 5. Basic Operator Theory, IsrayelGohberg and Seymour Goldberg, Birkh$\ddot{a}$user, 1981. 6. Linear Real analysis for Scientists and Engineers, B.V.Limaye, Springer. 2016	
Course Outcomes:	Student will be able to 1. Understand the basic concepts and fundamental theorems of Functional Analysis 2. Appreciate Functional Analysis as an important field for application oriented Mathematics. 3. Relate and apply the concepts learnt in the course to problems. 4. Develop foundation for higher courses in Functional analysis, Operator Theory, PDE etc.	

Semester I&II

Programme: M.Sc. Mathematics
Course Code: MAT-521 **Title of the Course: Mathematical Methods**
Number of Credits: 04
Effective from: June, 2022.

Prerequisites for the course:	Knowledge of basic Real Analysis, Linear Algebra, Differential Equations.	
Course Objectives:	This course develops the ability to apply mathematics to some of the problems of Mathematics and Physics.	
Contents	**1. Improper Integrals**. Review , Properties and L^2 convergence.	08 hours
	2. Fourier series: Generalized Fourier series, Fourier sine/cosine series. Point wise and uniform convergence. Differentiation and integration of Fourier series.	08 hours
	3. Fourier Transforms and its properties: : Fourier Transform of L^1 (IR)—functions. Basic properties related to translation, dilation and linearity. Computation of Fourier transform of simple functions. Fourier Inversion. Statement of Fourier inversion Theorem. Convolution. Convolution Theorem. Examples. Parsevaal's Identity. Fourier Integral Formula. An Integration Formula and Lemmas. Fourier Integral Theorem. The Cosine and Sine Integrals.	14 hours
	4. Variational problems: Variational problems with fixed boundaries. Euler-Lagrange equations and Brachistochrone problem, Elementary variational problems with moving boundaries. One-side variation, Isoperimetric problem, Canonical forms of Euler equations. Sufficient conditions for extremum.	30 hours
Pedagogy	Lectures/ tutorials/assignments/self-study	
References/ Readings:	**<u>Main Texts:</u>** 1. J.W.Brown and R.V.Churchill, Fourier series and Boundary Value Problems, McGraw Hill. (2012) [Chapters 2 and 6] 2. K.SankaraRao, Introduction to Partial Differential Equations, Prentice Hall of India, 1995. 3. Lev Elsgolts, Introduction to the Calculus of Variations, MIR Publications. 2003 4. T. Apostal Mathematical analysis, Narosa Publishers. 1973 **<u>Reference texts :</u>** 1. G.B.Arfken and H. Weber, Mathematical methods for Physicists. Elsevier Publications. 2012 2. R. Weinstock, Calculus of Variations, Dover Publication. 1952 3. I.M.Gelfand and S.V.Fomin, Calculus of Variations. Dover Publication.	

	1963
Course Outcomes:	Student will be able to 1. Learn Theory and applications of Fourier Series 2. Comprehend techniques of applying Fourier Transform. 3. Understands basic concepts of variational problems 4. Understand Fourier Transform

Programme: M.Sc. Mathematics

Course Code: MAT-522 **Title of the Course: DIFFERENCE EQUATIONS**

Number of Credits: 04

Effective from: June, 2022.

<table>
<tr><td>Prerequisites for the course:</td><td>Knowledge of basic Real Analysis, Linear Algebra and Differential equations.</td></tr>
<tr><td>Course Objectives:</td><td>This course helps in understanding basic concepts of discrete calculus. It develops the ability to solve difference equations by standard methods. It will help students to take up further studies in discrete dynamical systems and numerical modeling.</td></tr>
<tr><td>Contents:</td><td><table>
<tr><td>1. Calculus of finite differences: Review of basic concepts.</td><td>10 hours</td></tr>
<tr><td>2. Nonlinear Difference Equations. Equilibrium Points and their dynamics. Logistic equation.</td><td>12 hours</td></tr>
<tr><td>3. Linear difference equations. Basic theory. Method of Undetermined Coefficients and Variation of Parameters Formula. Higher Order equations. Behaviour of Solutions.
Nonlinear equations transformable to linear equations</td><td>16 hours</td></tr>
<tr><td>4. Systems of linear Difference Equations. Basic Theory. Linear Periodic systems. Stability theory of Linear Systems.</td><td>12 hours</td></tr>
<tr><td>5. Z-Transforms and its applications. Volterra Difference Equation of Convolution Type.</td><td>10 hours</td></tr>
</table></td></tr>
<tr><td>Pedagogy</td><td>Lectures/ tutorials/assignments/self-study..</td></tr>
<tr><td>References/ Readings:</td><td><u>Main Texts:</u>
1. S. N. Elaydi, An Introduction to Difference Equations, Springer Verlag. 1996
<u>Reference texts:</u>
2. S. Goldberg , Introduction to Difference equations, Wiley Publication.1987
3. V. Lakshmikantham and D. Trigiante, Theory of difference equations, Academic Press. 1988
4. K. Miller, Linear Difference equations, W. A. Benjam. 1968</td></tr>
<tr><td>Course Outcomes:</td><td>Student will be able to
1. Learn to solve difference equations.
2. Analyse the properties of solution.
3. Learn about discrete models and their stability
4. Find Z-Transform of various difference equation</td></tr>
</table>

Programme: M. Sc. (Mathematics)

Course Code: MAT-523 **Title of the Course:** SPECIAL FUNCTIONS

Number of Credits: 4

Effective from: June 2022

Prerequisites for the course:	Some basic Complex Analysis and Differential Equations.	
Course Objectives:	This course develops concepts in Gamma, Beta functions and also studies Legendre polynomials and Bessels functions.	
Content:	1. **Infinite products**:- Introduction, definition of an infinite product, a necessary condition for convergence, the associated series of logarithms, absolute convergence, uniform convergence.	6 hours
	2. **The Gamma and Beta functions**:- The Euler and Mascheroni constant, the Gamma function, a series for Γ’(z)/ Γ(z), evaluation of Γ(1) and Γ’(1), the Euler product for Γ(z), the difference equation Γ(z + 1) = zΓ(z), evaluation of certain infinite products, Euler’s integral for Γ(z), the Beta function, the value of Γ(z) Γ(1 - z), the factorial function, Legendre’s duplication formulae, Gauss’ multiplication theorem, a summation formula due to Euler.	12 hours
	3. **The hypergeometric function**:- The function F(a,b; c; z), a simple integral form, F(a,b,c,1) as a function of the parameters, evaluation of F(a,b,c,1), the contiguous function relations, the hypergeometric differential equation, F(a,b,c,z) as a function of its parameters, elementary series manipulations, simple transformations.	10 hours
	4. **Series solution of differential equations**. Method of Frobenius.	8 hours
	5. **Legendre Polynomials and Functions**. Legendre equation and its solution. Generating function. Legendre series. Associated legendre functions. Properties of associated Legendre functions.	8 hours
	6. **Bessel function, Bessel’s equation and its solutions**. Generating function. Integral representation. Recurrence relations. Hankel functions. Equations reducible to Bessel’s equation. Modified Bessels functions. Recurrence relations for modified Bessels functions. Hermite Polynomials, Lauerre Polynomials	8 hours
Pedagogy:	lectures/ tutorials/assignments/self-study.	
References/Readings	1. E.D. Rainville, Special functions, Chelsa Publishing Company, New York, 1960.	

	2. W.W. Bell, Special Functions for scientists and engineers, Dover Publications, New York, 2004. 3. G.E. Andrews, R. Askey, R. Roy, Special Functions, Encyclopedia of Mathematics and its Applications 71, Cambridge University Press, Cambridge.1999.	
Course Outcomes	Student will be able to 1 Get acquainted with Gamma, Beta functions. 2 Understand Legendre and Bessel Functions. 3 Apply the knowledge to Engineering Mathematics. 4 Learn Hypergeometric functions	

Programme: M.Sc. Mathematics
Course Code: MAT-524 **Title of the Course: PARTIAL DIFFERENTIAL EQUATIONS**
Number of Credits: 04
Effective from: June, 2022

Prerequisites for the course;	Knowledge of Real Analysis, Calculus of Several Variables, Ordinary differential equations, Methods of Applied Mathematics.	
Course Objectives:	This course develops the ability to solve partial differential equations of first and second order by standard methods.	
Contents	**1.Simultaneous differential equations of the first and first degree in three variables:** Methods of solutions of $dx/P = dy/Q = dz/R$. Pfaffian differential forms and equations. Solution ofPfaffian differential equations in three variables.	6 hours
	2. First order PDE's: Origin and classifications. Solution of Linear and Nonlinear First order PDE's. Methods of characteristics. Charpit's Methods. Jacobi's method.	14 hours
	3. Second Order Linear Partial Differential Equations: Origin. Linear equations with constant coefficients in two independence Variables. Linear equations with variable coefficients. Classification.Reduction to Canonical Form. (only for the case of two independent variables).	8 hours
	4. Methods of solving PDE : Method of Separation of variables. Use of Integral transforms (Laplace and Fourier).	10 hours
	5. Wave Equation. One dimensional Wave equation.D' Alembert' solution, Wave equation-Infinite string case. **Laplace Equation :**Harmonic function. Basic properties of harmonic functions. Laplace equation.Translational and rotational invariance of Laplace equation. Boundary value problems. Uniqueness of solutions of Dirichlet and Neumann problems. Mean value theorem for harmonic functions. Maximum and minimum principle for harmonic functions. Uniqueness and stability for Dirichlet problem. **Heat equation**- Infinite rod case. Non homogeneous equation.	22 hours
Pedagogy	Lectures/ tutorials/assignments/self-study	
References/ Readings:	**Main Texts:** 1. I. Sneddon, Elements of Partial Differential Equations, McGrow Hill. 1957 2. T. Amarnath, An elementary course in Partial Differential Equations, Narosa Publishing company, 1997. **Reference texts:** 1. K. Sankara Rao, Introduction to Partial Differential Equations, Prentice Hall of India, 1995. 2. F. John, Partial Differential equations, Springer Verlag Ltd. 1952 3. C. R. Chester, Techniques of Partial Differential Equations. McGraw Hill. 1970	

	4. R. Dennemeyer, *Introduction to Partial Differential Equations and Boundary Value Problems*, McGraw Hill. 1968 5. T. M. Hu, L. Debnath, Linear Partial differential equations for scientists and Engineers, Birkhauser. 2007
Course Outcomes	Students will be able to 1. Solve partial differential equations of first and second order. 2. Model initial and boundary value problems. 3. Analyse the properties of solution. 4. Interpret solutions in a physical contest 5. Understand analogies between mathematical descriptions of different (wave) phenomena in physics and engineering.

Programme: M.Sc. Mathematics
Course Code MAT-525 **Title of the Course: INTEGRAL EQUATIONS**
Number of Credits: 04
Effective from: June, 2022

Prerequisites for the course:	Knowledge of Real Analysis, Linear Algebra, Differential equations, Several variable calculus.
Course Objectives:	This course helps in understanding basic concepts of Integral Equations. It develops the ability to solve integral equations by standard methods.
Content	1. Basic concepts of Integral equations. Classification. Integral Equations with Separable Kernels. Method of Successive Approximations. Resolvent Kernel and its Properties. Decomposition methods. — 18 hours 2. Applications to Ordinary Differential Equations, Initial Value Problems and Boundary Value Problems, Green's functions. — 14 hours 3. Classical Fredholm Theory. Symmetric Kernels, Hilbert-Schmidt Theory. — 12 hours 4. Singular Integral Equations, Abel and Cauchy Type and Hilbert Kernel. Integral Transform Methods (Laplace, Fourier and Hilbert). — 16 hours
Pedagogy	Lectures/ tutorials/assignments/self-study
References/ Readings:	**Main Texts:** 1. Ram P Kanwal, Linear Integral Equations, Theory and applications. Springer. 1971 **Reference texts :** 2. Courant and Hilbertt, Methods of Mathematical Physics, Vol. I. 1989 3. S.G.Mikhilin, Integral Equations. Courier Dover Publisher, 2020 4. I. G. Petrovsky, Lectures on the theory of Integral equations. Mir Publisher, 1971 5. K.Yoshida, Lectures on Differential and Integral Equations Interscience Publisher, 1960
Course Outcomes:	Student will be able to: 1. Understand Basic concepts of Integral equations, Classify them, study and solve Integral Equations with Separable Kernels, Use Method of Successive Approximations, Study resolvent Kernel and its Properties, Understand decomposition methods. 2. Apply the above theory to Ordinary Differential Equations, Initial Value Problems and Boundary Value Problems and use Green's functions. 3. Understand Classical Fredholm Theory, Symmetric Kernels, Hilbert-Schmidt Theory. 4. Apprehend Singular Integral Equations, Abel and Cauchy Type and Hilbert Kernel. 5. Use Integral Transform Methods (Laplace, Fourier and Hilbert).

Programme: M.Sc.(Mathematics)
Course Code: MAT-526 **Tittle of the Course: FINITE ELEMENT METHODS**
Number of Credits: 4
Effective from AY:2022 June

Prerequisits for the course:	Basic knowledge of Algebra, Differential Equations, Linear Algebra	
Course Objectives:	The course aims to provide the fundamental concepts of the element method mainly including shape functions and general linear and higher order elements up to 3 dimensions. The course objective is to acquaint the students about application of finite element methods for solving various boundary value problems	
Contents:		
	Unit I: General theory of finite element methods, difference between finite element and finite difference methods, review of some integral formulae, concept of discretization, different coordinates, one dimensional finite elements,	15hours
	Unit II: Numerical integration, construction of shape functions: linear elements (one dimensional bar element, two dimensional-triangular element)	15hours
	Unit III: Higher order elements: one dimensional quadratic element, two dimensional triangular element, rectangular element.	15hours
	Unit IV: Weighted residual and variational approaches (Galerkin method, collocation method, Rayleigh Ritz method etc.), solving one-dimensional problems. Application of finite element methods for solving various boundary value problems.	15hours
Pedagogy	Lectures/Tutorials/Self study	
References/ Readings:	1. Rao, S. S. The Finite Element Method in Engineering. 5 th edition, Butterworth-Heinemann, 2017. 2. Hughes, T. J. R. The Finite Element Method (Linear Static and Dynamic Finite Element Analysis). Courier Corporation, 2007. 3. Zienkiewicz, O. C. and Taylor, R. L. The Finite Element Method: The Basis. Butterworth-Heinemann, 2000. 4. Smith, G. D. Numerical solution of Partial Differential Equations: Finite difference methods. Oxford Applied Mathematics and Computing Science Series, 1985.	
Course Outcome:	Student will be able to 1. Understand the general theory of Finite Element method and its difference with finite difference method 2. Use the role and significance of shape functions in finite element formulations and use of linear, quadratic, and cubic shape functions for interpolation 3. Formulate some important 1, 2 and 3 dimensional	

	elements 4. Apply the weighted residual and variational approaches in solving some boundary value problems	

Programme: M. Sc. (Mathematics)
Course Code: MAT-527 **Title of the Course: COMBINATORICS**
Number of Credits: 4
Effective from AY: 2022-23

Prerequisites for the Course:	Basics of - Set Theory, Algebra, Linear Algebra	
Course Objectives:	Starting from the basic principles of counting, this course aims to give an introductory exposition to different aspects of Combinatorics. The course will emphasise on the importance of enumeration tools and techniques in diverse branches of Mathematics and applied fields.	
Content	**1.Basic Counting Principles and Techniques** Review of basic Counting Principles-Addition Principle, Multiplication Principle, Method of two-way Counting, Method of Bijections, Permutations and Combinations, Circular Permutations, Counting Objects with Repetitions, Binomial and Multinomial Theorems (Combinatorial Proofs), Binomial and Multinomial Coefficients and Identities.	12hours
	2.The Fundamental Counting Problem Statement of the Problem-The Sxteen Cases, Partition Numbers P(n,k) and P(n), Stirling Numbers S(n,k) and s(n,k), Bell numbers B(n).	2hours
	3.Recurrence Relations and Explicit Formulas The Inclusion-Exclusion Principle, Derangements and D(n), Recurrence Relations and Explicit Formulas for P(n,k),P(n), S(n,k), s(n,k), B(n), and D(n). Idea of Generating Functions , Method of solving Linear Recurrence Relations Using Generating Functions, Generating Functions for P(n,k), P(n), S(n,k), s(n,k), B(n) and D(n).	12hours
	4.Pigeonhole Principle (PHP) The Pigeonhoe Principle - its different formulations and examples, Applications of PHP to some standard Problems in Geometry, Number Theory , Graph Theory and Colouring of Plane.	6hours
	5.Sequnces and Partial Orders Applications of PHP to Sequences and Partial Orders- The Erd*ö*s-Szekeres Theorem, Dilworth's Lemma, Dilworth's Theorem, Sperner's Theorem.	6hours

	6.Ramsey Theory Ramsey's Theorem –First version (for 2 colours) , Second version (for r colours), and Infinitary version, Ramsey Numbers and bounds, Computations of small Ramsey Numbers, Schur's Theorem, van der Waerden's Theorem (Statement and Discussion).	10hours
	7. Polya's Theory of Counting Group actions on sets, Burside's Lemma, Labelings, Cycle indexes, computation of cycle indexes of standard groups, Polya's theorem and examples.	12hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings:	1. Introduction to Combinatorics, Martin J. Erickson, John Wiley,1996. 2. Cominatorial Techniques, Sharad S. Sane, Hindustan Book Agency, 2013. 3. Introducion to Combinatorics, W.D. Wallis and J.C. George, 2011. 4. A Walk Through Combinatorics, M. Bona, World Scientific Publishing Company, 2002. 5. Combinatorics, V.K. Balakrishnan, Schaum Series, McGraw-Hill,	
Course Outcomes:	Student will be able to 1 Appreciate the importance of combinatorial techniques in diverse branches of Mathematics and Applied fields. 2 understand and deal with enumerative problems 3 Apply combinatorial techniques to solve a range of application problems in Optimization, 4 Apply combinatorial techniques to Graph Theory and Networking.	

Programme: M. Sc. (Mathematics)

Course Code: MAT-528 **Title of the Course:** COMPUTATIONAL MATHEMATICS USING PYTHON

Number of Credits: 2P

Effective from AY: 2022 June

Prerequisites for the Course:	This course assumes that the student has done an undergraduate course of Numerical Methods and Matrix Algebra using Python Programming. Basic Number Theory, Algebra, Linear Algebra, Graph Theory and Differential equations.	
Course Objectives:	To equip students with the skills of python programming which aid the study and understanding of Mathematics.	
Content	**1. Introduction to Python (Review)** IDLE (Installation in Windows/Linux), Python strings, Relational Operators, Logical Operators, Precedence of Operators, Variables and assignment statements, Keywords, Script mode.	4 hours
	2. Functions (Review) Built-in functions*; input, eval, composition, print, type, round, min, max, pow* Type conversion, Random number generation; *randint* Functions from *math* module, complete list of Built-in functions using help and dir Function Definition and call, fruitful and void functions, function help, default parameter values, keyword arguments Importing User-defined modules, Assert statement.	6 hours
	3. Control Structures (Review) General form of *if* , *if-else* , *if-elif-else* conditional statement Nested *if-elif-else* conditional statement. *For* and *While* statements and their comparison, Nested loops, *Break, Continue, Pass* statements *Else statement* associated with a For/While statement Testing, Debugging	4 hours
	4. Scope of Variables/Names Objects and Object ids, Namespaces; Global and Local variables, LEGB Rule	2 hours
	5. Strings Slicing, membership, basic functions and methods on strings.	2 hours
	6. Mutable and Immutable Objects Lists, functions and methods on lists, List comprehension, copying lists, Sets, functions and methods on sets, Tuples,	8 hours

	functions and methods on tuples, Dictionary, dictionary operations, functions. **7. Recursion** Iterative Approach and recursive approach, Program to find Minors and Determinant of a matrix. **8. Files and Exceptions** File handling, writing structures to a file, exceptions **9. Classes and Objects** Class attributes, class variables, destructor, Person, Graphs: as an example of a class, Highest degree and least degree, operator overloading, instance method, static method, composition and inheritance. **10. Graphics** 2D graphics, mathplotlib, matplotlib installation, points, lines. **11. Algorithms to be implemented in Python**** i. Expressing the elements of the Symmetric group as a product of disjoint cycles. ii. Characteristic Equation of a nxn matrix. Synthetic Division to find rational roots of a polynomial when rational roots exist. iii. Row Reduction to (Reduced)Row Echelon form. Generating nxn Identity Matrix Inverse of a matrix using row reduction iv. Finding Basis for the Row Space, Column Space of a matrix A and solution space of AX=B. v. Single step and multi-step Methods vi. Dijkstra's Algorithm to find shortest path. vii. Kruskal's Algorithm to find minimum spanning tree viii. Havel and Hakimi's Algorithm for degree sequences. ix. Welsh and Powell algorithm for graph coloring x. Fitting of straight line and quadratic curve to given data xi. Solutions of linear Diaphontine Equations **Any 7 of these algorithms should be implemented.	 4 hours 4 hours 8 hours 4 hours 14 hours
Pedagogy	Laboratory Sessions/Assignments/Self-study	
References/ Readings:	1. Python Programming: A modular approach by Sheetal Taneja and Naveen Kumar, Pearson Education, 2020. 2. Python Programming: Beginner to Pro by Michael Urban, Mike Murach Publishing, 2016.	
Course Outcomes:	Student will be able to 1. Create programs to implement computational	

	mathematical algorithms. 2. Create classes of mathematical objects and be able to randomly generate instances for testing formulas. 3. Create simple 2D graphics in python 4. Learn to handle files	

Programme: M. Sc. (Mathematics)
Course Code: MAT-529 **Title of the Course: ELEMENTARY NUMBER THEORY**
Number of Credits: 2
Effective from AY: 2022-23

Prerequisites for the course:	A basic course in Number Theory	
Course Objectives:	At the end of this course the student will gain basic knowledge of primitive roots, quadratic reciprocity and continued fractions	
Content	**1. PRIMITIVE ROOTS AND INDICES:** The order of an integer modulo n, Primitive Roots for Primes, Composite numbers having primitive roots, The theory of indices	4 Hours
	2. THE QUADRATIC RECIPROCITY LAW: Euler's criterion, the Legendre symbol and its properties, Quadratic reciprocity, Quadratic congruences with composite moduli	6 Hours
	3. NUMBERS OF SPECIAL FORM: Marine Mersenne, Perfect numbers, Mersenne primes and amicable numbers, Fermat numbers	4 Hours
	4. REPRESENTATION OF INTEGERS AS SUMS OF SQUARES: Sums of two squares, Sums of more than two squares	4 Hours
	5. CONTINUED FRACTIONS: Finite continued fractions, Infinite continued fractions, Farey fractions, Pell's equation	12 Hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings:	1. David M. Burton, Elementary Number Theory, Mc Graw Hill, 2017 2. Kenneth H Rosen, Elementary Number Theory, Pearson, 2015	
Course Outcomes:	Students will be able to 1. Recollect the various definitions and theorems in Primitive Roots 2. Learn Quadratic Reciprocity and Continued Fractions. 3. Apply the results in the course to solve problems. 4. Learn about various numbers like Mersenne and Fermat	

Programme: M. Sc. (Mathematics)
Course Code: MAT-530 **Title of the Course:** DISCRETE MATHEMATICAL STRUCTURES
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites for the course:	Sets and functions	
Course Objective:	To equip students with the skills and techniques of discrete structures like graphs and trees	
Content	1. Recurrence relations, linear recurrence relations with constant co-efficients, homogeneous solutions, particular solutions, total solution, solution by method of generating functions.	6 hours
	2. Graphs, isomorphism, complement, multipartite, degree sequences, distance, eccentricity, centre, periphery, eulerian and hamiltonian graphs, algorithm for shortest path in a graph, planar graphs.	20 hours
	3. Cut-vertices, bridges, blocks, non-seperable, trees, forests, $\kappa(G), \kappa_1(G)$, branch, chord, fundamental cycle, fundamental edge cut, minimum spanning tree, kruskal's algorithm.	14 hours
	4. Transport Networks, capacity, flow, cut, Maximum flow and finding maximum flow	4 hours
	5. Vertex and edge coloring, domination number, independent domination number	16 hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings:	1. Elements of Discrete Mathematics, C L Liu, Tata McGraw Hill, Special Indian Edition 2008 2. Graphs and Digraphs, Chartrand and Lesniak, Chapman & Hall/CRC Fourth edition, 2005	
Course Outcomes:	Student will be able to 1 Solve linear recurrence relations. 2 Apply results of graph theory to solve problems modeled using graphs 3 Compile a logical argument to prove simple results involving graphs. 4 Learn about vertex and edge coloring	

Semester III&IV

Programme: M.Sc.(Mathematics)
Course Code: MAT-600 **Tittle of the Course: MATHEMATICAL MODELLING**
Number of Credits: 4
Effective from AY:2023-24

Prerequisits for the Course:	Basic knowledge of Algebra, Differential Equations, Linear Algebra, FEM	
Course Objectives:	The objectives of this course are to: • Enable students understand how mathematical models are formulated, solved and interpreted. • Make students appreciate the power and limitations of mathematics in solving practical real-life problems. • Equip students with the basic mathematical modelling skills.	
Content:		
	Unit I: Simple situations requiring mathematical modelling, techniques of mathematical modelling, classifications, characteristics and limitations of mathematical models, some simple illustrations, mathematical modelling in population dynamics, mathematical modelling of epidemics through systems of ordinary differential equations of first order mathematical models in medicine in terms of systems of ordinary differential equations.	15hours
	Unit II: Mathematical modelling through difference equations, linear growth and decay models.. Population dynamics and genetic and their applications with examples.	30hours
	Unit III: Mathematical Modelling with Graph Theoretical Approach.	15hours
Pedagogy	Lectures/Tutorials/Self study	
References/ Readings:	1. Kapur J. N. Mathematical Modelling, 2nd edition, New Age International, 2015. 2. Meerschaert, M. M. Mathematical Modelling. Academic Press, 2013. 3. Rutherford, A. Mathematical Modelling Techniques. Courier Corporation, 2012. 4. Clive,L. D. Principles of Mathematical Modelling. Elsevier, 2004. 5. Bender, E. A. An Introduction to Mathematical Modelling. Courier Corporation, 2000.	
Course Outcome:	Student will be able to	

	1. Understand concept of mathematical model and explain the series of steps involved in a mathematical modeling process. 2. Apply mathematical modeling through difference equations. 3. Understand and apply the concept of mathematical modeling through difference equations in population dynamics, genetics and probability theory. 4. Apply the concept of mathematical modeling through graph theory	

Programme: M. Sc. (Mathematics)
Course Code: MAT-601 **Title of the Course:** ALGEBRAIC TOPOLOGY
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites for the course:	Point Set Topology, Basic Group Theory	
Course Objectives:	To equip students with the skills to study Manifolds using Homotopy and to lay the foundation for a study of Homology Groups.	
Content	1 **The Fundamental group** Homotopy of paths, nulhomotopic, the fundamental group, covering spaces, path lifting, the fundamental group of the circle, retractions and fixed points, Brouwer fixed point theorem for the disc, Fundamental theorem of Algebra, antipode of a point in S^n, Borshuk Ulam theorem, Area Bisection Theorem, Deformation Retracts and homotopy type, Homotopy equivalences and homotopy inverse, Fundamental group of S^n , Fundamental groups of torus, projective plane, fundamental group of double torus is not abelian.	20 hours
	2 **The Seifert-van Kampen Theorem** Direct Sums of abelian groups, extension condition, free product of groups, free groups, commutator, commutator subgroup, generators, relations, presentation of groups, finitely presented groups, Seifret-van kampen theorem, fundamental group of a wedge of circles, adjoining a 2-cell, fundamental group of dunce cap.	16 hours
	3 **Classification of Covering Spaces** Equivalence of Covering Spaces, General lifting lemma The Universal covering space, Semi-locally simply connected, Existence of Covering Spaces.	12 hours
	4 **Classification of Surfaces** Polygonal Region, labeling, Fundamental Groups of Surfaces **Applications to group theory** Covering Spaces of a graph, The fundamental group of a graph.	12 hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/	1 Topology second Edition by James Munkres, Pearson	

Readings	Education 2 Algebraic Topology by Allen Hatcher, Cambridge University Press	
Course Outcomes	Student will be able to 1. Compute the fundamental groups of manifolds using multiple approaches. 2. Distinguish between surfaces and other manifolds using the fundamental group. 3. Formulate and appreciate the general approach of associating commutable Algebraic structures to topological objects so as distinguish between them. 4. Understand covering spaces	

Programme: M. Sc. (Mathematics)
Course Code: MAT-602 **Title of the Course:** NUMBER THEORY
Number of Credits: 4
Effective from AY: 2023-24 onwards

Prerequisites for the course:	Some basic Complex Analysis. Elementary number theory. Congruences.	
Course Objectives:	This course will serve as Prerequisites to an advanced Course in Analytical Number Theory.	
Content:	**1. Fundamental Theorem of Arithmetic.** Divisibility. Greatest common divisor. Prime numbers. The Fundamental Theorem of Arithmetic. The series of reciprocals of primes. The Euclidean algorithm.	10 hours
	2. Arithmetical functions and Dirichlet multiplication. Mobius function μ. Euler totient function **φ**. Relation connecting μ and **φ**. Product formula for **φ** (n). Dirichlet product of arithmetical functions. Dirichlet inverse and Mobius inversion formula. Mangoldt function. Multiplicative functions. Liouville function. Divisor functions. Generalized convolutions. Formal power series. Bell series. Derivative of arithmetical functions.	12 hours
	3. Averages of arithmetical functions. Big oh notation. Euler summation formula. Some elementary asymptotic formulas. Average order of d(n). Average order of σ_α(n). Average order of **φ** (n). Average order of μ(n) and Λ(n).	12 hours
	4. Some elementary theorems on distribution of prime numbers. Chebyshev's functions $\vartheta(x)$ and $\psi(x)$. Relations connecting functions $\vartheta(x)$ and $\psi(x)$.	7 hours
	5. Characters of finite abelian groups. Characters of finite abelian groups. The character group. The orthogonality relations of characters. Dirichlet character.	7 hours
	6. Partition Theory. Partitions of numbers. Generating function of p(n). Other generating functions. Theorems of Euler. Theorem of Jacobi. Special cases of Jacobi's identity.	10 hours
	7. Basic Cryptology. Caesar Cipher. Shift Cipher. Affine cipher. Hill cipher.	2 hours
Pedagogy:	lectures/ tutorials/assignments/self-study.	
References/Readings	1. T. M Apostol, *Introduction to Analuytic Number Theory*, Narosa Publishing House, 1998. 2. Thomas Koshy, *Elementary Number Theroy with Applications*, Second Edition, Elsevier India	

	Pvt. Ltd., **2005**. (Chapter 9) 3. G.H. Hardy and E.M. Wright, Introduction to theory of numbers. (Chapter XIX), Oxford University Press, sixth edition, 2008. 4. Heng Huat Chan, *Analytic Number Theory for Undergraduates*, (Monographs in Number Theory), World Scientific, **2009**. 5. I. Niven, H.S. Zuckerman and H.L. Montgomery, *An Introduction to the Theory of Numbers*, 5th edition, Wiley-India. 6. David Burton, *Elementary Number Theory*, Sixth edition, Tata McGraw-Hill Edition, 2008. 7. A. Baker, A concise introduction to theory of numbers, Cambridge University Press, 2015.	
Course Outcomes	Students will be able to 1. Learn advanced number theory, Cryptography 2. Comprehend more advanced Analytic Number Theory books. 3. Understand arithmetical functions 4. Understand partition theory	

Programme: M. Sc. (Mathematics)
Course Code: MAT-603 **Title of the Course:** LIE ALGEBRA
Number of Credits: 4
Effective from AY: 2023-24 onwards

Prerequisites for the course:	Basic Linear Algebra, basic group theory, basic analysis.	
Course Objective:	This course develops concepts in Matrix Groups and Lie algebras. It helps in understanding other concepts like Manifold, Lie groups etc.	
Content:	1. **Matrix Groups.** Matrices. Real and Complex Matrix Groups. Orthogonal Groups. Topology of Matrix Groups. Tangent space.	12 hours
	2. **Lie algebras.** Definition, Some Examples, subalgebras and Ideals. Homomorphisms. Algebras. Derivations. Structure Constants. Ideals and Homomorphisms. Constructions with Ideals. Quotient Algebras. Correspondence between Ideals. Low-Dimensional Lie Algebras.	10 hours
	3. **Solvable Lie Algebras.** Nilpotent Lie Algebras. Subalgebras of gl(V). Nilpotent Maps. Weights. The Invariance Lemma. An Application of the Invariance Lemma.	8 hours
	4. **Engel's and Lie's Theorems.**	6 hours
	5. **Some Representation Theory.** Modules for Lie Algebras. Submodules and Factor Modules. Irreducible and Indecomposable Modules. Homomorphisms. Schur's Lemma. Representations of sl(2,C). The Modules V_d . Classifying the Irreducible sl(2,**C**)-Modules.	8 hours
	6. **Cartan's Criteria**. Testing for Solvability. The Killing Form. Testing for Semisimplicity. Derivations of Semisimple Lie Algebras. The Root Space Decomposition. Cartan Subalgebras. Definition of the Root Space. Decomposition. Cartan Subalgebras as Inner-Product Spaces. Root Systems. Bases for Root Systems. Cartan Matrices and Dynkin Diagrams.	16 hours
Pedagogy:	lectures/ tutorials/assignments/self-study.	
References/Readings	1. Kristopher Tapp, *Matrix Groups for Undergraduates*, American Mathematical Society, **2005**. 2. Karin Erdmann and Mark J. Wildon, *Introduction to Lie Algebras* , Springer Undergraduate Mathematics Series, Springer-Verlag. **2006**. 3. J.E. Humphreys, *Introduction to Lie algebras and representation theory*, Graduate Text in	

	Mathematics, Springer-Verlag, 1972. 4. N. Jacobson, *Lie Algebras*, Dover Publications,1962.	
Course Outcomes	Students will be able to 1. get acquainted with Lie algebras and Matrix groups theory. 2. Comprehend Lie groups theory. 3. Understand classification of Lie algebras 4. Understand representation of finite dimensional Lie algebras	

Programme: M.Sc. (Mathematics)
Course Code: MAT-604 **Title of the Course:** GRAPHS AND NETWORKS
Number of Credits: 4
Effective from AY:2023-24

Prerequisites for the course:	**Basic set theory**	
Course Objectives:	Course deals with the basics of graph theory, basic definition of simple graphs, types of graphs, matrix representation of graphs, isomorphism in graphs, Euler & Hamiltonian graphs, trees & their properties, spanning trees, colouring of graphs, independence number and chromatic number of simple graphs, connectivity, cut-set, directed graphs, shortest paths & maximal flows in a network.	
Content:	**1. Introduction to graphs** Graphs, subgraphs, operations on graphs, degree sequences, graphic sequences, distance in graphs, walks, trails, paths, circuits, cycles, matrices and isomorphism, complement of graph, bipartite graphs, distance in graphs, digraphs and multidigraphs, Cut-vertices bridges and blocks, classes of graphs, Petersen graphs, regular graphs, Harary graphs.	19 hours
	2. Trees and connectivity Elementary properties of trees, minimal spanning trees, Prim's algorithm, Kruskal's algorithm, connectivity and edge-connectivity, connectedness of digraphs, Prüfer sequence.	8 hours
	3. Eulerian and Hamiltonian graphs Eulerian graphs and digraphs, Hamiltonian graphs and digraphs, Fleury's algorithm and Hierholzer's algorithm.	7 hours
	4. Planar graphs Euler's formula, characterizations of planar graphs, crossing number and thickness.	7 hours
	5. Graph colorings Vertex colorings, edge colorings, map colourings, Five Color theorem.	6 hours
	6. Matchings and domination in graphs Matchings and independence in graphs, vertex cover, edge cover, domination number of a graph, independence domination number of a graph.	6 hours
	7. Networks Relevance of maximum flow, Ford Fulkerson algorithm, Dijkstra's algorithm to find the shortest route.	7 hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/Readings:	1. D. B. West, Introduction to Graph Theory, Prentice Hall of India, 2006. 2. G. Chartrand and L. Lesniak, Graphs and Digraphs, Chapman & Hall/CRC, Third edition, 1996. 3. G. Agnarsson and R. Greenlaw, Graph Theory: Modeling,	

	Applications and algorithms, Pearson, 2011. 4. Gary Chartrand and Ping Zhang, Introduction to Graph Theory, Tata Mc-Graw-Hill Edition, 2006. 5. F. Harary, Graph Theory, Narosa Publishing House, 2001. 6. Gary Chartrand and O.R. Oellermann, Applied Algorithmic Graph Theory, McGraw-Hill Inc. 1993.	
Course Outcomes:	Student will be able to 1. understand relevance of graphs in different context, ranging from puzzles & games to social science/engineering/computer science. 2. solve problems 3. learn algorithms is also an essential part of graph theory. 4. know applications of Graph Theory	

Programme: M.Sc. (Mathematics)

Course Code: MAT-605 **Title of the Course:** ADVANCED GRAPH THEORY

Number of Credits: 4

Effective from AY:2023-24

Prerequisites for the course:	**Basic Graph Theory**	
Course Objectives:	This course will give a deeper insight into basic concepts in Graph Theory, so as to be able to embark into research in the field.	
Content:	1. **Review of Basic Concepts:** Graphs, Trees, minimal spanning trees, connectivity and edge-connectivity, Eulerian graphs, Hamiltonian graphs, Euler's formula, Planar graphs, Colourings, Matchings, Independence and Domination in a graph.	7 hours
	2. **Independent Sets and Cliques:** Independent Sets, Cliques, Ramsey Number and Turan's Theorem.	7 hours
	3. **Matchings, Factors and Decompositions:** Matchings & Covers, Maximum Matchings, Matchings in bipartite Graphs, Hall's Matching Condition, Min-Max Theorems, Perfect Matching, Factorizations and Decompositions.	16 hours
	4. **Labelings of Graphs:** Graceful Labeling, Harmonious Labeling, Bandwidth Labeling.	8 hours
	5. **Colourability:** Chromatic Number and Chromatic index, Brook's Theorem, Vizing's Theorem, Chromatic Polynomials.	7 hours
	6. **Connectivity and Paths:** k-Connected Graphs, k-Edge Connected Graphs, Menger's Theorem.	7 hours
	7. **Domination in Graphs:** Dominating Queens, Dominating Sets in Graphs, Applications of Dominating Sets, Bounds on the Domination Number (in terms of order, in terms of order and size).	8 hours
Pedagogy:	Lectures/ Tutorials/Assignments/Self-study	
References/Readings:	1. G. Chartrand and P. Zhang, Chromatic Graph Theory, CRC Press, 2009. 2. D. B. West, Introduction to Graph Theory, Prentice Hall of India, 2006. 3. T.W. Haynes, S.T. Hedetniemi & P.J. Slater, Fundamentals of Domination in Graphs, Marcel Dekker Inc., 1998. 4. G. Chartrand and L. Lesniak, Graphs and Digraphs, Chapman & Hall/CRC, Third edition, 1996.	
Course Outcomes:	Student will be able to 1 understand the concepts required to pursue research in Graph Theory. 2 learn labelling graphs 3 learn coloring of graphs 4 learn about domination of graphs	

Programme: M.Sc. Mathematics
Course Code: MAT-606 **Title of the Course: MEASURE THEORY -I**
Number of Credits: 04
Effective from AY:2023-24

Prerequisites for the Course:	A first course in Real Analysis	
Course Objectives:	This course gives a thorough introduction to the Lebesgue theory of integration on $\mathbb{R}$ and prepares the students to understand the concepts of abstract measure theory, a fundamental tool of advanced mathematical analysis, probability theory and applications.	
Contents	**1.Reimann-Stieltjes Integral** Weights and measures, The Riemann-Steiltjes integral, Space of integrable functions, Integrators of bounded variation, The Riemann integral. Shortcomings of Riemann integration.	14 hours
	2.Lebesgue Measure on $\mathbb{R}$ The length function and Lebesgue outer measure, Measurable sets, Sigma algebra of measurable sets, Structure of measurable sets, non-measurable sets, idea of abstract measure spaces.	10 hours
	3.Measurable Functions Measurable functions, Extended real valued functions and measurability, Sequence of measurable functions, Egorov's theorem, Approximation of measurable functions	8 hours
	4.The Lebesgue Integral Lebesgue integral of simple functions, non-negative functions and the general case. Chebyshev's inequality, monotone convergence theorem, Fatou's Lemma, Lebesgue dominated convergence theorem, Integral of infinite series of functions. Lebesgue integrability of Riemann integrable functions. Approximation of Lebesgue integrable functions by simple functions, continuous function and step functions.	16 hours
	5. The Lp spaces The L_p-spaces for $1 \leq p \leq \infty$, and their completeness. Approximation of L_p-functions by simple fuctions, continuous functions, step functions	12 hours
Pedagogy	Class room lectures and tutorials, assignments and library reference.	
References/ Readings:	1. Real Analysis, N L Carothers, Cambridge University Press, 2006. 2. Lebesgue Measure and Integration, Murray R. Spiegel Ph.D., Schaum's Outline Series, McGraw Hill Inc., 1990 3.An Introduction to Measure and Integration, Inder K Rana, Narosa, Publishing House, 2005 4. Real Analysis, H.L. Royden, Pearson Education India, 2015 5. Measure Theory and Integration, G. de Barra, New Age International, Pvt.Ltd., 2013	

Course Outcomes	Student will be able to 1. Understand Lebesgue outer measure and Lebesgue measure, existence of non-measurable sets 2. Understand the Fundamental results; the monotone convergence theorem, Dominated convergence theorem and Fatou’s lemma. 3. Understand Lebesgue integral as generalization of the Riemann integral and its behaviour with respect to sequence of functions 4. Understand Basic structure of the L_p-spaces

Programme: M.Sc. Mathematics
Course Code: MAT-607 **Title of the Course: MEASURE THEORY-II**
Number of Credits: 04
Effective from AY:2023-24

Prerequisites for the Course:	A first course in Real Analysis, Complex Analysis and Topology. A course in Lebesgue measure and integration is desirable	
Course Objectives:	This course gives a foundation in essential abstract measure theory required in varied aspects of mathematical analysis and its diverse applications	
Contents	**1.Abstract Measure and Integration** The concept of measurability, Borel sets , Measurable functions, Simple functions, Elementary properties of measures, Integration of positive functions, Monotone convergence theorem, Fatou's lemma, Integration of Complex functions, Dominated convergence Theorem, The role played by sets of measure zero, completeness of measure	14 hours
	2.Positive Borel measures Topological Preliminaries -Review of topological notions (without proof) from the theory of locally compact Hausdorff topological spaces-The Urisohn's Lemma. The Riesz representation theorem for $C_c(X)$ where X is locally compact Hausdorff, Regularity properties of Borel measures, the Lebesgue measure on $\mathbb{R}^k$, Continuity properties of measurable functions.	14 hours
	3. $\boldsymbol{L^p}$ **-spaces** Convex functions and inequalities, Jensen's inequality, The L^p -spaces and their completeness, Approximation by continuous functions- the density of $C_c(X)$ in $L^p(\mu)$.	10 hours
	4.Complex Measures Complex measures, total variation, positive and negative variation, Absolute continuity of measures, The theorem of Lebesgue-Radon-Nikodym, Consequences of the Radon-Nikodym theorem- the polar decomposition and the Hahn decomposition.	12 hours
	5. Integration on Product spaces Measurabilty on Cartesian products, product measures, The Fubini's theorem, Completion of product measures.	10 hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings:	1. Real and Complex Analysis, Walter Rudin, Third Edition, McGrow-Hill Company, 1987 2.Measure Theory and Integration, G.de Barra, Wiley Eastern Limited, 1987 3. Real Analysis, H.L. Royden, Pearson Education India, 2015 4.An Introduction to Measure and Integration, Inder K Rana, Narosa Publishing House, 2013 5.Real Analysis, Gerald B. Folland, John Wiley & Sons, 1984	

Course Outcomes	Student will be able to 1. understand and apply the concepts in Abstract measure spaces, measurable sets and measurable functions 2. understand and apply the concepts in Integrals with respect to a measure and their behaviour w.r.t. sequences of functions 3. understand and apply the concepts in Positive Borel measures, Lebesgue measure on $\mathbb{R}^k$ and regularity properties of Borel measure 4. understand and apply the concepts in Abstract L^p-spaces 5. understand and apply the concepts in Complex measures, Radon-Nikodym theorem 6. understand and apply the concepts in Product measure and integration on product spaces.

Programme: M.Sc. Mathematics
Course Code: MAT-608 **Title of the Course: FUNCTIONAL ANALYSIS-II**
Number of Credits: 4
Effective from AY:2023-24

Prerequisites for the Course:	A First Course in Real Analysis, Complex Analysis,Topology and Functional Analysis	
Course Objectives:	Having done a first course in Functional Analysis this course develops more advanced concepts in Functional Analysis which introduces the student to some important tools for the applications of Functional Analysis. Further the topics covered in the course form foundations for further readings in Functional Analysis leading to research in diverse branches of Functional Analysis and Operator Theory.	
Content:	**1.Weak and Weak* Topologies** Definitions and properties of weak topology and, weak convergence, Comparison of strong and weak convergences, Definitions and properties of weak* topology and weak*-convergence, comparison of weak and weak* convergences, The Banach- Alaoglu Theorem, Convergence of sequence of Operators -Uniform operator convergence, strong operator convergence, weak operator convergence-basic properties and the comparison of these convergences.	10 hours
	2.Spectral Theory of linear operators in normed spaces Spectral theory in finite dimensional normed spaces, matrix operators and their spectrum, Spectral theory -Basic concepts-Regular value, resolvent set, spectrum and classification of spectrum. Spectral properties of bounded linear operators-spectrum closed, non-empty, spectral radius, resolvent equation, commutativity, spectral mapping theorem for polynomials, linear independence of eigen vectors, Use of complex analysis in spectral theory	12 hours
	3.Compact linear operators on normed spaces Compact operators- definition and basic properties such as continuity, compactness criterion, operators with finite dimensional domain or range, sequence of compact operators, compact operators and weak convergence, separability of the range, adjoint of compact operators, compactness of a product of two compact operators.	12 hours
	4.Spectral properties of compact operators Eigen values countable, characteristic properties of the eigen spaces leading to the direct sum representations of the normed space as a sum of two closed subspaces in terms of a compact operator.	10 hours
	5.Operator equations involving compact linear operators Fredolhm type theorems, Fredolhm alternative, Fredolhm alternative for integral equations	10 hours

	6. Compact self-adjoint operators on Hilbert spaces and their spectrum	6 hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings:	1. Introductory Functional Analysis with Applications, Ervin Kreyszig, John Wiley & Sons, 1978. 2. Functional Analysis (Second Edition), S.Kesavan, Hindustan Book Agency, 2022 3. Functional Analysis, George Bachman and Lawrence Narici, Dover Publications,2000. 4. Functional Analysis, S.Kumaresan and D.Sukumar, Narosa Publishing House, 2020 5. Basic Operator Theory, Israyel Gohberg and Seymour Goldberg, Birkhäuser, 1981.	
Course Outcomes;	Student will be able to 1. apply the concepts of the weak topology and weak*-topology respectively on a normed space and its dual space and their comparisons with the respective norm topologies, weak and weak*-convergences of operators 2. apply the concepts of the Banaach-Aloglu theorm and the characterization of normed spaces 3. apply the concepts of basics of spectral notions of spectral theory of operators on normed spaces 4. apply the concepts of Spectral properties of compact operators 5. apply the concepts of the Fredplhm alternative	

Programme: M. Sc. (Mathematics)
Course Code: MAT-609 **Title of the Course:** SYMMETRY METHODS FOR DIFFERENTIAL EQUATIONS
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites for the Course:	Group theory, Basics of Lie Algebra, Differential equations, Partial Differential equations.	
Course Objectives:	The study of ordinary differential equations (ODEs) and partial differential equations (PDEs) is a fundamental subject area of mathematics. Differential equations (DEs) are present in almost all applications of mathematics where they provide a natural mathematical description of phenomena in the physical, natural and social sciences. Symmetry methods systematically extend well known ad-hoc techniques to construct explicit solutions for differential equations, especially for nonlinear DEs. This course is about symmetry methods (group theoretic methods) for solving DEs which is one of the most powerful methods in order to determine particular solutions to DEs.	
Content	1. **Dimensional Analysis, Modeling, and Invariance:** Introduction, Dimensional Analysis, Buckingham Pi Theorem, Application of Dimensional Analysis to DEs.	5 Hours
	2. **Lie Groups of Transformations and Infinitesimal Transformations:** Lie Group of Transformations, Infinitesimal Transformations, First Fundamental Theorem of Lie, Infinitesimal Generators, Invariant Functions, Canonical Coordinates, Invariant Surfaces, Invariant Curves, Extended Transformations (Prolongations), Multi-Parameter Lie Groups of Transformations, Lie Algebras, Solvable Lie Algebras.	10 Hours
	3. **Ordinary Differential Equations:** Invariance of an ODE, Reduction of Order Via Lie Group of Transformation and Integrating Factors, Mapping of Solutions to Other Solutions, First Order ODEs, Second and Higher Order ODEs, Invariance of ODEs Under Multi-parameter Groups, Applications to Boundary Value Problems	25 Hours
	4. **Partial Differential Equations:** Infinitesimal Criterion for the Invariance of PDEs, Invariance of Scalar PDEs, Invariant Solutions, Mapping of Solutions, Invariance of System of PDEs, Application to Boundary Value Problems.	20 Hours
Pedagogy:	Lectures/ Tutorials/Assignments/Self-study	

References/ Readings:	1. George W. Bluman and Sukeyuki Kumei, Symmetries and Differential Equations, Springer-Verlag New York, Heidelberg, Berlin, 1989. 2. G. W. Bluman and S. Anco, Symmetries and Integration Methods for Differential Equations; Springer, New York, 2002. 3. G. W. Bluman and J. Cole, Similarity Methods for Differential Equations, Springer-Verlag New York, Heidelberg, Berlin, 1974. 4. Peter J. Olver, Applications of Lie Groups to Differential Equations SpringerVerlag New York, Berlin, Heidelberg, Tokyo, 1979.	
Course Outcomes:	Students will be able to 1 Understand the concept of modeling 2 Apply the Lie group transformations and reduce order of ODEs and PDEs. 3 Solve ODE’s of higher order using symmetry methods 4 Solve nonlinear PDEs using symmetry methods	

Semester III

Programme: M.Sc.(Mathematics)
Course Code: MAT-621 Tittle of the Course: Basic MATHEMATICS FOR SOCIAL SCIENCE
Number of Credits: 4
Effective from AY:2023-24

Prerequisite for the Course:	This course is not recommended for students with Mathematics at UG level.	
Course Objectives:	The main objective of this course is to encourage students to develop a working knowledge of the basic Mathematics for social science and will present some of the ideas that form the foundation of quantitative work in the social sciences. In particular, topics from logarithm, set theory, matrix theory and calculus will be discussed with emphasis on the understanding of concepts and the development of intuition	
Content:		
	Unit I ;Binary numbers, indices, logarithm and antilogarithm, laws and properties of logarithms, simple applications of logarithm and antilogarithm, numerical problems on averages, calendar, clock, time, work and distance, mensuration, seating arrangement, sets, types of sets, Venn diagram, De Morgan's laws, problem solving using Venn diagram, relations and types of relations.	15hours
	Unit II ;Introduction of sequences, series, AP, GP and HP, relationship between AM, GM and HM. Permutations and combinations. Functions and relations. Types of functions (Polynomial function; Rational function; Logarithm function, Exponential function; Modulus function; Greatest Integer function), Graphical representation of functions.	15hours
	Unit III ; Limit and continuity, derivative as rate measure, differentiation, derivatives of implicit functions using Chain rule. Basic mathematical logic with conditional statements, tautology and contradiction.	10hours
	Unit IV ;Random experiment, sample space, events, mutually exclusive events. Independent and dependent Events, law of total probability, Bayes' Theorem. Data on various scales (nominal, ordinal, interval and ratio scale), data representation and visualization, data	20hours

	interpretation (dispersion, deviation, variance, skewness and kurtosis), percentile rank and quartile rank, correlation (Pearson and Spearman method of correlation), linear regression, applications of descriptive statistics using real time data.	
Pedagogy	Lectures/Tutorials/Self study	
References/ Readings:	Gill J. Essential Mathematics for Political and Social Research, Cambridge University Press, 2016. 2. Haeussler E., Paul R. and Wood R. Introductory Mathematical Analysis for Business, Economics, and the Life and Social Sciences, 15th edition. Prentice-Hall, 2015. 3. Goldstein L., Lay D., and Schneider D. Calculus and Its Applications, 14th Edition. Prentice Hall, 2014. 4. Hagle T. Basic Math for Social Scientists: Problems and Solutions, 1996. 5. Hagle T. Basic Math for Social Scientists: Concepts, 1996. 6. Kleppner D. and Ramsey N. Quick Calculus. Wiley, 1995. 7. Namboodiri K. Matrix Algebra: An Introduction. Sage Publications # 38, 1994.	
Course Outcome:	Student will be able to 1. Explain the fundamental concepts of indices, logarithm and antilogarithm and their role in basic Mathematics for social science. 2. Demonstrate accurate and efficient use of set theory and Venn diagram. 3. Understand and use the terms: function, relation, series arithmetic, geometric progression, Permutations and Combinations. 4. Understand the concepts and properties of limits, continuity and differentiation of a function, logical reasoning, probability and descriptive statistics	

Programme: M.Sc.(Mathematics)
Course Code: MAT-622 **Tittle of the Course: OPERATIONS RESEARCH**
Number of Credits: 4
Effective from AY:2023-24

Prerequisite for the course:	Not recommended for mathematics students	
Course Objectives:	This course is designed to introduce basic optimization techniques in order to get best results from a set of several possible solutions of different problems viz. linear programming problems, transportation problem, assignment problem and unconstrained and constrained problems etc.	
Content:		
	Unit I : Linear programming: formulation and solution of linear programming problems by graphical, simplex methods, Big-M, degeneracy, duality in linear programming, sensitivity analysis	15hours
	Unit II : Transportation problems: basic feasible solutions, optimum solution by stepping stone and modified distribution methods, unbalanced and degenerate problems, transhipment problem. Assignment problems: solution by Hungarian method, unbalanced problem, case of maximization, travelling salesman and crew assignment problems.	15hours
	Unit III : Queuing theory: basic components of a queuing system, general birth-death equations, steady-state solution of Markovian queuing models with single and multiple servers (M/M/1. M/M/C, M/M/1/k, M/M/C/k)	15hours
	Unit IV : Game theory: two persons zero sum game, game with saddle points, rule of dominance; algebraic, graphical and linear programming, concept of mixed strategy. sequencing problems: processing of n jobs through 2 machines, n jobs through 3 machines, 2 jobs through m machines, n jobs through m machines.	15hours
Pedagogy	Lectures/Tutorials/Self study	
References/ Readings:	1. Sharma, S. D. Operation Research, Kedar Nath Ram Nath Publications, 2012. 2. Swarup, K. and Gupta, P.K. Operations Research. S. Chand publisher, 2010. 3. Taha, H. A. Operation Research: An Introduction.9th edition, Pearson, 2010. 4. Gupta, P.K. and Hira, D.S. Introduction to Operations Research, S. Chand & Co. 2008. 5. Sharma, J. K., Mathematical Model in Operation Research, Tata McGraw Hill, 1989. 6. Hagle T. Basic Math for Social Scientists: Problems	

	and Solutions, 1996.	
Course Outcomes:	Student will be able to 1. Understand linear programming problems and to find their solutions by using different method. 2. Find optimal solution of transportation problems and assignment problems 3. Understand and solve different queuing models. 4. Find optimal solution of linear programming model using Game Theory. Also learn about sequencing problems.	

Programme: M.Sc.(Mathematics)
Course Code: MAT-623 Tittle of the Course: MATHEMATICS FOR FINANCIAL MANAGEMENT AND INSURANCE
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites for the Course:	Basic knowledge of, Differential Equations, Linear Algebra, Numerical Methods	
Course Objectives:	This course introduces the basic concepts of Financial Management such as Insurance and Measurement of returns under uncertainty situations. The philosophy of this course is that Time value of Money - Interest rate and discount rate play a fundamental role in Life Insurance Mathematics – Construction of Morality Tables.	
Content:		
	Unit I : Financial Management –overview. Nature and scope of financial management. Goals and main decisions of financial management. Difference between risk, Speculation and gambling. Time value of Money - Interest rate and discount rate. Present value and future value discrete case as well as continuous compounding case. Annuities and its kinds.	15hours
	Unit II : Meaning of return. Return as Internal Rate of Return (IRR). Numerical methods like Newton Raphson method to calculate IRR. Measurement of returns under uncertainty situations. Meaning of risk. Difference between risk and uncertainty. Types of risks. Measurements of risk. Calculation of security and Portfolio Risk and Return-Markowitz Model. Sharpe Single Index ModelSystematic Risk and Unsystematic Risk.	15hours
	Unit III : Taylor series and Bond Valuation. Calculation of Duration and Convexity of bonds. Insurance Fundamentals – Insurance defined. Meaning of loss. Chances of loss, Peril, Hazard, proximate cause in insurance. Costs and benefits of insurance to the society and branches of insurance-life insurance and various types of general insurance. Insurable loss exposures- feature of a loss that is ideal for insurance.	15hours
	Unit IV : Life Insurance Mathematics – Construction of Morality Tables. Computation of Premium of Life Insurance for a fixed duration and for the whole life. Determination of claims for General Insurance – Using Poisson	15hours

	Distribution and Negative Binomial Distribution – the Polya Case. Determination of the amount of Claims of General Insurance – Compound Aggregate claim model and its properties, Claims of reinsurance. Calculation of a compound claim density function F, Recursive and approximate formulae for F	
Pedagogy:	Lectures/Tutorials/Self study	
References/ Readings:	1. Ross, S. M. An Introduction to Mathematical Finance. Cambridge University Press, 2019. 2. Elliott, R. J. and Kopp, P. E. Mathematics of Financial Markets. Sprigner Verlag, New York Inc, 2018. 3. Damodaran, A. Corporate Finance - Theory and Practice. John Wiley & Sons, Inc, 2012. 4. Hull, J. C. Options, Futures, and Other Derivatives. Prentice-Hall of India Private Ltd, 2010. 5. Daykin, C. D., Pentikainen, T. and Pesonen, M. Practical Risk Theory for Actuaries. Chapman & Hall, 2008. 6. Dorfman, M. S. Introduction to Risk Management and Insurance. Prentice Hall, Englwood Cliffs, New Jersey, 1999. 7. Neftci, S. N. An Introduction to the Mathematics of Financial Derivatives. Academic Press, Inc,1991	
Course Outcomes:	Student will be able to 1. Demonstrate knowledge of the terminology related to nature, scope, goals, risks and decisions of financial management. 2. Predict various types of returns and risks in investments and take necessary protective measures for minimizing the risk. 3. Develop ability to understand, analyze and solve problems in bonds, finance and insurance. 4. Build skills for computation of premium of life insurance and claims for general insurance using probability distributions.	

Programme: M. Sc. (Mathematics)
Course Code: MAT-624 **Title of the Course:** MATHEMATICS FOR FINANCIAL MARKET
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites for the course:	Elementary Calculus, Basic Probability Theory	
Course Objectives:	At the end of this course the student will gain knowledge of basic concepts in financial mathematics	
Content	**1. Introduction: A Simple Market Model :** Basic Notions and Assumptions, No-Arbitrage Principle, One-Step Binomial Model, Risk and Return, Forward Contracts, Call and Put Options, Managing Risk with Options	6 Hours
	2. Risk-Free Assets : Time Value of Money, Money Market	6 Hours
	3. Risky Assets : Dynamics of Stock Prices, Binomial Tree Model	6 Hours
	4. Discrete Time Market Models : Stock and Money Market Models, Extended Models	6 Hours
	5. Portfolio Management : Risk, Two Securities, Several Securities, Capital Asset Pricing Model	12 Hours
	6. Forward and Futures Contracts : Forward Contracts, Futures	6 Hours
	7. Options: General Properties : Definitions, Put-Call Parity, Bounds on Option Prices, Variables Determining Option Prices, Time Value of Options	10 Hours
	8. Option Pricing : European Options in the Binomial Tree Model, American Options in the Binomial Tree Model, Black-Scholes Formula	8 Hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-Study	
References/ Readings:	1. Marek Capinski and Tomasz Zastawniak, Mathematics for Finance, An Introduction to Financial Engineering, Springer, 2003 2. Sheldon M. Ross, An Elementary Introduction to Mathematical Finance, Cambridge University Press, 2011	
Course Outcomes:	Student will be able to 1 Recall and explain concepts in simple market models, risk free assets, risky assets, dynamics of stock prices, 2 Recall portfolio management, forward contracts, futures contracts and options. 3 Prove important theorems related to topics studied. 4 Apply knowledge gained to solve basic mathematical problems in finance.	

Programme: M. Sc. (Mathematics)
Course Code: MAT-625 **Title of the Course: LATEX FOR MATHEMATICS**
Number of Credits: 2P
Effective from AY: 2023-24

Prerequisites for the Course:	Basic ability to type, Comfort with mathematical symbols and notations.	
Course Objectives:	At the end of this course the student will develop the required skill set to typeset mathematical research and produce professional mathematical documents with vector graphics. The student will also be able to effectively use macros in LATEX	
Content:	**1. LATEX Basics:** A Bit of History, Basics, LATEX input files, Input File Structure, A Typical Command Line Session, Logical Structure of your Document, Packages, The Structure of Text and Language, Files you might Encounter	8 Hours
	2. Real World LATEX: Line Breaking and PageBreaking, Ready-Made Strings, Dashes and Hyphens, Slash, Ellipsis, Ligatures, Abstract, Simple Commands,The Space Between Words, Titles, Chapters, and Sections, Cross References, Footnotes, Lists, Non-Justified Text,Quotations, Code Listings, Tables, Including Graphics and Images, Floating Bodies, Big Projects	8 Hours
	3. Typesetting Mathematical Formulae: Modern Mathematics, Single Equations, Building Blocks for Mathematical Formulae, Multiline Equations, Units, Matrices and the Like, Spacing in Math mode, Theorems and Proofs, Fiddling with math styles, Dots, More about Fractions	8 Hours
	4. Bibliographies: the bibliography environment, biblatex with biber Database files,Using biblatex,Controlling the bibliography,Citing commands, More about entries.	4 Hours
	5. Specialities: Indexing, Installing Extra Packages, LATEXand PDF, Creating Presentations	4 Hours
	6. Graphics in Your Document: Overview, Basic Usage, Curves and Shapes, Customizing Paths and Nodes, Coordinates, Reusing Pictures, Libraries	12 Hours
	7. Customising LATEX: New Commands, Environments and Packages, Fonts and Sizes, Custom Fonts with fontspec, Colours, Lengths and Spacing, The Layout of the Document, Fancy Headers	16 Hours
Pedagogy:	Practical, Hands on training, Self-study	
References/ Readings:	1. Tobias Oetiker, Marcin Serwin, Hubert Partl, Irene Hyna and Elisabeth Schlegl, The Not So Short Introduction to LATEX, 2022 2. George Gratzer, More Math Into LATEX, Springer, 2016 3. Leslie Lamport, A Documentation Preparation System LATEX User's Guide and Reference Manual, Pearson, 2006	

Course Outcomes:	Student will be able to 1. Gain the required knowledge to type professional mathematical documents 2. prepare presentations. 3. Apply graphics packages to create produce vector graphics in mathematical documents. 4. Design customized mathematical documents to suit individual needs with effective use of Fonts, Colours etc.	

Programme: MSc Mathematics
Course Code: MAT-626 **Title of the Course: PROBABILITY AND STATISTICS**
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites for the course:	Basic Mathematics	
Course Objectives:	The aim of course is to familiarize students with the fundamental concepts & techniques in Probability theory and Statistical analysis.	
Content:	**1. Data Handling:** Tabulation and frequency distribution, relative frequency distribution, cumulative frequency distribution,	03 hours
	2. Measures of central tendency & dispersion: Arithmetic mean, Median, Mode for raw data, grouped data, relationship between mean, median and mode, quartiles deciles, percentiles. Variability, range, mean deviation, coefficient of mean deviation, standard deviation, variance, coefficient of variance, skewness, Karl Pearson's coefficient, Bowley's coefficient.	07 hours
	3. Various Concepts in Probability Theory: Sample spaces, events, permutations and combinations, axioms of probability, conditional probability, independence and multiplication rule, Baye's Theorem.	05 hours
	4. Discrete Distributions: Random variables, discrete probability densities, cumulative distribution, expectation, variance and standard deviation. Binomial, Geometric and Poisson distributions.	09 hours
	5. Continuous Distributions: Continuous densities, cumulative distribution and distribution parameters, uniform, normal, standard normal, Gamma, exponential and Chi-squared distributions. Normal approximation to binomial distribution.	10 hours
	6. Descriptive Statistics and Estimation: Random sampling, sample statistics, point estimation, sampling distribution of a statistic, distribution of the sample mean and the Central Limit Theorem.	04 hours
	7. **Statistical Inference**: determining sample size, estimation of mean and proportions, Student-t distribution, confidence interval, hypothesis testing on the mean and proportion, type I, type II errors, power of the	08 hours

	test, Z-test, t-test, F-test. **8. Simple linear regression and correlation:** Linear regression analysis, model and parameter estimation by least-squares method, Properties of least square estimators, confidence interval estimation and hypothesis testing, Pearson's correlation coefficient, covariance, coefficient of determination. **9. Other tests:** ANOVA, non-parametric tests, Chi-square tests.	 08 hours 06 hours
Pedagogy:	Lectures/Tutorials/Assignments/Self-study	
References/Readings	1. Devore, J. L.: Probability & Statistics for Engineering and the Sciences, 8th edition, Cengage Learning, 2012. 2. Milton, J. S. and Arnold J. C.: Introduction to Probability and Statistics: Principles and Applications for Engineering and the Computing Sciences, 4th edition, Tata McGraw-Hill, 2007. 3. Prem S. Mann: Introductory Statistics, eighth edition, John Wiley & Sons, 2012. 4. Joseph K. Blitzstein and Jessica Hwang: Introduction to Probability, CRC Press 2014. 5. R.J. Barlow, Statistics: A Guide to the Use of Statistical Methods in the Physical Sciences, Wiley, 1989. 6. F. James, Statistical Methods in Experimental Physics, 2nd ed., World Scientific, 2006. 7. Probability and Statistics in Experimental Physics, Byron P. Roe, 2nd ed., Springer, 2001. 8. Fundamentals of Statistical and Thermal Physics, F. Reif, McGraw Hill, Inc. 1965	
Course Outcomes:	Student will be able to 1. get familiarized with basic properties of random variables, probability distributions. 2. understand basic concepts in Statistics, 3. understand how to collect, arrange, present, summarize and analyze statistical data, 4. understand to arrive at statistical inferences, apply appropriate statistical tests and interpret its results.	