M.Sc. Program from the Dept. of Mathematics

M. Sc. in Mathematics

Program Learning Objectives:	**Program Learning Outcomes:**
Program Goal 1: To learn and excel in the rigour of Mathematics	**Program Learning Outcome 1a:** The students are prepared with a mix of basic and advance mathematics courses during the program **Program Learning Outcome 1b:** A rigorous training in all basic concepts in Mathematics is provided
Program Goal 2: To be able to apply the concepts of Mathematics to problem solving	**Program Learning Outcome 2a:** Students pursue application-oriented courses in the form of electives **Program Learning Outcome 2b:** The concepts of mathematics learned are explored in courses that apply the knowledge.
Program Goal 3: To be a leader in the area where both pure mathematics and applied mathematics skills are required by offering a variety of electives	**Program Learning Outcome 3a:** Leadership skills are inculcated through learning **Program Learning Outcome 3b:** With clarity of the topics learnt, the students serve as better human resource
Program Goal 4: To prepare fundamentals of mathematics as a strong foundation to achieve goals in higher academic degrees or industries	**Program Learning Outcome 4a:** The foundation is made strong with systematics training in mathematics, which helps to pursue a higher academic degree. **Program Learning Outcome 4b:** Industry-oriented courses will help in acquiring a position in the industry.

Sl. No.	**Subject Code**	**SEMESTER I**	**L**	**T**	**P**	**C**
1.	MA4107	Computer Programming	2	0	4	4
2.	MA4108	Linear Algebra	3	1	0	4
3.	MA4109	Real Analysis	3	1	0	4
4.	MA4110	Algebra	3	1	0	4
5.	MA4111	Ordinary Differential Equations	3	1	0	4
6.	HS4111	Soft Skills for Employability	1	2	0	3
		TOTAL	**15**	**6**	**4**	**23**

Sl. No.	**Subject Code**	**SEMESTER II**	**L**	**T**	**P**	**C**
1.	MA4201	Topology	3	0	0	3
2.	MA4202	Numerical Analysis	3	0	2	4
3.	MA4203	Complex Analysis	3	1	0	4
4.	MA4204	Linear Optimization Techniques	3	0	2	4
5.	MA4205	Probability and Statistics	3	0	0	3
		TOTAL	**15**	**1**	**4**	**18**

Sl. No.	Subject Code	SEMESTER III	L	T	P	C
1.	MA5101	Measure Theory	3	0	0	3
2.	MA5102	Functional Analysis	3	0	0	3
3.	MA5103	Partial Differential Equations	3	0	0	3
4.	MA51XX/ MA61XX	DE-I	3	0	0	3
5.	XX61PQ	IDE-I	3	0	0	3
6.	MA5199	Project I	0	0	12	6
		TOTAL	**15**	**0**	**12**	**21**

Sl. No.	Subject Code	SEMESTER IV	L	T	P	C
1.	MA52XX/ MA62XX	DE-II	3	0	0	3
2.	MA52XX/ MA62XX	DE-III	3	0	0	3
3.	MA52XX/ MA62XX	DE-IV	3	0	0	3
4.	XX62PQ	IDE-II	3	0	0	3
5.	MA5299	Project II	0	0	16	8
6.	IK5201	Indian Knowledge System	2	0	0	2
		TOTAL	**14**	**0**	**16**	**22**

Total Credits : 84

ELECTIVE GROUPS

Sl. No.	Subject Code	Department Elective - I	L	T	P	C
1.	MA5104	Cryptography and Network Security	3	0	0	3
2.	MA5105	Fundamentals of Block Chain	3	0	0	3
3.	MA5106	Mathematical Finance	3	0	0	3
4.	MA6101	Advanced Graph Theory	3	0	0	3
5.	MA6102	Introduction to Algebraic D-modules	3	0	0	3
6.	MA6103	Nonlinear Optimization	2	0	2	3
7.	MA6104	Generative AI	2	0	2	3
8.	MA6105	Rings and Modules	3	0	0	3
9.	MA6106	Large Language Models (LLMs)	2	0	2	3
10.	MA6107	Number Theory	3	0	0	3
11.	MA6108	Stochastic Calculus for Finance	3	0	0	3

Sl. No.	Subject Code	Department Elective – II	L	T	P	C
1.	MA5201	Portfolio Theory and Risk Management	3	0	0	3
2.	MA6201	Randomized Algorithms	3	0	0	3
3.	MA6202	Introduction to Biomathematics	3	0	0	3
4.	MA6203	Introduction to Homological Algebra	3	0	0	3
5.	MA6204	Noncommutative Algebra	3	0	0	3
6.	MA6205	Sobolev Spaces	3	0	0	3
7.	MA6206	Wavelet Transform	3	0	0	3

Sl. No.	Subject Code	Department Elective – III	L	T	P	C
1.	MA6207	Differential Manifolds	3	0	0	3
2.	MA6208	Graph Algorithms	3	0	0	3
3.	MA6209	Numerical solutions of PDEs	2	0	2	3
4.	MA6210	Statistical Inference	3	0	0	3

Sl. No.	Subject Code	Department Elective – IV	L	T	P	C
1.	MA5202	Mathematical methods in classical mechanics	3	0	0	3
2.	MA6211	Advanced complex analysis	3	0	0	3
3.	MA6212	Algebraic Coding Theory	3	0	0	3
4.	MA5203	Discrete Mathematics	3	0	0	3
5.	MA6213	Finite Element Analysis	3	0	0	3
6.	MA6214	Introduction to Algebraic Geometry	3	0	0	3
7.	MA6215	Operators on Hilbert Spaces	3	0	0	3
8.	MA6216	Riemannian Geometry	3	0	0	3

*An upgraded version of M. Sc. 5/6 level electives need to be essentially upgraded for PhD students with additional contents comprising additional lectures / assignments / tutorials / miniproject making the total credit : 3-1-0-4 / 3-0-2-4. Such course proposals with an advanced level (6/7 level course number) are listed separately for PhD students.

Interdisciplinary Elective (IDE) Course for M. Sc. (Available to students other than Maths)

Sl. No.	Subject Code	IDE - I	L	T	P	C
1.	MA6109	Mathematical Modeling	3	0	0	3

Sl. No.	Subject Code	IDE - II	L	T	P	C
1.	MA6218	Matrix Computation	3	0	0	3

Sl. No.	Subject Code	SEMESTER I	L	T	P	C
1.	MA4107	Computer Programming	2	0	4	4
2.	MA4108	Linear Algebra	3	1	0	4
3.	MA4109	Real Analysis	3	1	0	4
4.	MA4110	Algebra	3	1	0	4
5.	MA4111	Ordinary Differential Equations	3	1	0	4
6.	HS4111	Soft Skills for Employability	1	2	0	3
		TOTAL	**15**	**6**	**4**	**23**

Course Number	MA4107 (Core)
Course Credit (L-T-P-C)	2 – 0 –4 – 4
Course Title	Computer Programming
Learning Mode	Lectures and lab
Learning Objectives	To learn fundamentals of computer programming through Python and basic algorithm designing techniques.
Course Description	This course introduces Python programming language and basic algorithm designing techniques through examples.
Course Content	Introduction to digital computers Introduction to programming- variables, assignments; expressions; input/output Conditionals and branching Functions, iteration vs recursion Introduction to data structures- Arrays/linked list, stacks, queues. Basic algorithm designing technique (through examples): divide and conquer, greedy and dynamic programming.
Learning Outcome	Students will learn Python programming language and basic algorithm designing techniques through examples. The knowledge helps them to solve many real-life applications through coding and it helps them in learning other programming languages faster.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. Luciano Ramalho, Fluent Python: Clear, Concise, and Effective Programming, O'Reilly Media, 2nd edition.
2. Michael T. Goodrich, Roberto Tamassia, and Michael H. Goldwasser, Data Structures and Algorithms in Python, John Wiley & Sons Inc.
3. Jon Kleinberg and Eva Tardos, Algorithm Design, Addison Wesley, 2005.

Reference Books:

1. Basant Agarwal and Benjamin Baka, Hands-On Data Structures and Algorithms with Python, Packt Publishing, Second edition.
2. Dusty Phillips, Python 3 object oriented programming, Packt Publishing

Course Number	MA4108 (Core)
Course Credit (L-T-P-C)	3 – 1 – 0 – 4
Course Title	Linear Algebra
Learning Mode	Lectures and Tutorials
Learning Objectives	In this subject, the students will be trained with the knowledge of mathematical tools from Linear Algebra that are essentially used in various field of Mathematics and Computing.
Course Description	Linear Algebra, as a fundamental subject for undergraduate students, provides the knowledge about the solution of system of linear equations, vector spaces, linear transformation, singular value decompositions, inner product spaces and related concepts.
Course Content	(Review of Vector spaces over fields, subspaces, bases and dimension, Systems of linear equations, matrices, rank, Gaussian elimination, Determinants) Linear transformations, representation of linear transformations by matrices, rank-nullity theorem (with proof), duality and transpose. eigenvalues and eigenvectors, characteristic polynomials, minimal polynomials, Cayley-Hamilton Theorem, triangulation, diagonalization, rational canonical form, Jordan canonical form, singular value decomposition Inner product spaces, Gram-Schmidt orthonormalization, orthogonal projections, linear functionals and adjoints, Hermitian, self-adjoint, unitary and normal operators, Spectral Theorem for normal operators, Rayleigh quotient, Min-Max Principle. Bilinear forms, symmetric and skew-symmetric bilinear forms, real quadratic forms, Sylvester's law of inertia, positive definiteness.
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand mathematical tools to solve system of linear equations. 2. Analyze the role of vector space and linear transformations. 3. Comprehend ideas of eigenvalues, eigenvectors and diagonalization. 4. Apply the concepts related to singular value decomposition to Engineering problems. 5. Develop the understanding of inner product spaces, normal operators and Bilinear forms. 6. Knowledge of this course will help to understand other courses of mathematics like algebra, operator theory, algebraic coding theory and control theory.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. K. Hoffman and R. Kunze, Linear Algebra, Pearson Education (India), 2003.PrenticeHall of India, 1991.
2. Bernard Kolman, David Hill, Elementary Linear Algebra with Applications, 9th Edition, Pearson Education, 2007.
3. S. Lang, Linear Algebra, Undergraduate Texts in Mathematics, Springer-Verlag, New York, 1989.

Reference Books:

1. M. Artin, Algebra, Prentice Hall of India, 1994.
2. H. E. Rose, Linear Algebra, Birkhauser, 2002.

Course Number	MA4109 (Core)
Course Credit (L-T-P-C)	3-1-0-4
Course Title	Real Analysis
Learning Mode	Lectures and Tutorials
Learning Objectives	Objectives of the course is let students know why it is required to define distance function on an arbitrary set. Then how all the results that are true for functions defined on real line are extended to any set with a distance of notion. Students shall be able to understand the derivative of a functions of several variables. The need of equicontinuity and Arzela Ascoli theorem will also be clear at the end of the course.
Course Description	The course deals with generalization of real line. It also deals with convergence of sequences of functions and derivative of a functions of several variables.
Course Content	Metric spaces, Zorn's lemma (Statement only), Continuous functions, Completeness, Cantor intersection theorem, Baire’s category theorem, Compactness, Finite intersection property. Functions of several variables: Differentiation, Inverse, and implicit function theorems. Sequence and Series of functions: Uniform convergence and its relation to continuity, integration and differentiation. Equicontinuity, Arzela-Ascoli Theorem. Riemann and Riemann Stieltjes Integral, Motivation to Lebesgue integration.
Learning Outcome	At the end of the course students shall be able to define and generate new metric spaces. They shall be able to compute the derivative of functions of several variables.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. W. Rudin, Principles of Mathematical Analysis, McGraw-Hill, 1976.
2. T. M. Apostol, Mathematical Analysis, Narosa Publishing House, 2002.
3. R. G. Bartle, D. R. Sherbert, Introduction to Real Analysis, John-Wiley & Sons Inc. 2011.

Reference Books:

1. G. F. Simmons, Introduction to Topology and Modern Analysis, McGraw-Hill Inc. 1983.
2. K. A. Ross, Elementary Analysis: The Theory of Calculus, Springer, 2004.

Course Number	MA4110 (Core)
Course Credit (L-T-P-C)	3 – 1 – 0 – 4
Course Title	Algebra
Learning Mode	Lectures and Tutorials
Learning Objectives	This course aims to help the students **(1)** gain a comprehensive understanding of algebraic structure; (2) well-equipped with basic concepts of Mathematics (Number Theory and Algebra) which are prerequisites to the advanced courses; (3) understanding of the advanced algebraic structures and their applications
Course Description	It gives a foundation for further studies in the other courses of mathematics of M. Sc. curriculum. Here, several examples of basic topics of groups and rings will be discussed to get a better understanding of this course. This course includes Langrange's theorem, Cayley's theorem, and Sylow's theorems for groups. Moreover, Isomorphism theorems for groups and rings will be discussed. Further, the concept of quotient fields and finite field extensions will discussed with several examples.
Course Content	(Review of Groups, subgroups, normal subgroups, permutation groups.) Cyclic groups, dihedral groups, matrix groups, Homomorphisms, quotient groups, Isomorphisms, Cayley's theorem, groups acting on sets, Sylow's theorems and applications, direct products, finitely generated abelian groups, Structure Theorem for finite abelian groups. Rings, subrings, units, ideals, homomorphism, isomorphism, quotient rings, prime and maximal ideals, fields of fractions, Euclidean domains, principal ideal domains and unique factorization domains, polynomial rings. Elementary properties of finite field extensions and roots of polynomials, finite fields.
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand, apply, and analyse the notion of groups, rings and ideals in related concepts required for advanced courses and research in Algebra. 2. Familiar with the basic properties and examples of different notions and their generalization; 3. Able to decide what properties are satisfied by the given algebraic structure and under which conditions it can be applicable.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. D. Dummit and R. Foote, Abstract Algebra, 3rd edition, Wiley, 2004.
2. J. A. Gallian, Contemporary Abstract Algebra, 4th ed., Narosa, 1999.
3. I N Herstein, Topics in Algebra, 2nd edition, Wiley, 2006

Reference Books:

1. M. Artin, Algebra, Prentice Hall of India, 1994.
2. J. B. Fraleigh, A First Course in Abstract Algebra Paperback, Addison-wesley 1967.

Course Number	MA4111 (Core)
Course Credit (L-T-P-C)	3-1-0-4
Course Title	Ordinary Differential Equations
Learning Mode	Lecture and Tutorials
Learning Objectives	To get expose to the ordinary differential equations (ODEs). To understand methods of solving ODEs. To understand the theory of solutions. To explore qualitative properties of solutions of ODEs without solution.
Course Description	This course is meant to understand both the theory of solutions as well as qualitative properties of the solutions of the ODEs.
Course Content	First Order ODE y' = f(x,y) with geometrical interpretation of solution, ODEs and direction fields, Existence and uniqueness of IVPs: Picard's and Peano's Theorems, Gronwall's inequality, continuation of solutions and maximal interval of existence, stability analysis of first order ODE. Higher order equations, existence and uniqueness of solution of IVP, Wronskian and general solution of homogeneous and non-homogeneous equations. Variable coefficients, power series method, Frobenious method, Legendre polynomials, Bessel functions, solving system of linear first order using eigenvalue- eigenvector, non-homogeneous equations, variation of parameters, stability of linear systems, Sturm's comparison and separation theorems, BVPs, Sturm Liouville BVP, eigenvalue problems, Green's function.
Learning Outcome	Students will be able to find solutions of certain class of ODEs. They will understand properties of solutions of the ODEs even when explicit solutions are not possible or feasible.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. G. Birkhoff and G. C. Rota, Ordinary Differential Equations, 4th Edition, Wiley, 2003.
2. G. F. Simmons, Differential Equations with Applications and Historical Notes, Second edition, Tata McGraw Hill, 1991.
3. S L Ross, Differential Equations, 3rd edition, Wiley, 2007

Reference Books:

1. E. A. Coddington and N. Levinson, Theory of Ordinary Differential Equations, Tata McGraw Hill, 1984.
2. S.G. Deo, V. Lakshmikantham and V. Raghavendra, Textbook of Ordinary Differential Equations, 2nd Edition, Tata McGraw Hill, 2002.

Course Code	HS4111
Course Credit	L-T-P-C: 1-2-0-3
Course Title	**Soft Skills for Professional Development**
Learning Mode	Lectures and Tutorials
Learning Objectives	**Soft Skills**. These are the traits, characteristics, habits, and skills needed to survive and thrive in the modern work world. This **soft skills** course will teach you how to develop the skills that can make the difference between a lackluster career that tops out at middle management versus one that lands you in the executive suite or wherever you define career success. This course aims to help the students **(a)** gain a comprehensive understanding of communication skills for work place interaction; **(b)** attain proficiency in written and oral language; **(c)** develop team work skills; **(d)** foster decision making; **(e)** strengthen analytical and thinking skills; **(f)** develop leadership skills; **(g)** acquire techniques for time management, problem solving and emotional intelligence.
Course Description	This academic course on soft skills aims to equip students with skills necessary for the professional world. By focusing on essential principles and providing practical experiences, students develop their soft skills. Through interactive discussions and exercises, students enhance critical thinking and adaptability in diverse contexts. Upon completion, students will excel in formal presentations, group discussions, and persuasive writing, enhancing their verbal and non-verbal proficiency.
Course Outline	**Section A: Theoretical Component** **Unit 1: Communication skills** Barriers to communication – Verbal communication (oral and written) – Non-Verbal Communication – interpersonal communication – email etiquette – power to listen – ethical considerations in communication – intercultural communication – comprehension – creative and critical writing (included in section B-below) **Unit 2: Team Building** Conflict resolution – Mediation – Accountability – Collaboration – Empathy - building rapport – cultural awareness – Dealing with people - group and teams, group formation, group decision making, types of teams and the models of team effectiveness – Negotiation techniques **Unit 3: Leadership** Leader vs Managers – Core values of leadership - leadership styles – Theories of Leadership – Leadership models - Vision and its articulation and implementation – goal setting and performance management – Ethical leadership – Power -power bases -power tactics **Unit 4: Personality Development and Stress Management** Theories of Personality development (Freud, Jung, Eysenck, Carl Rogers and Maslow), Personality frameworks such as MBTI, Big Five and personality assessment - Reasons and Remedies of Stress. **Unit 5: Thinking**

	Critical Thinking - Reasoning: Deductive and Inductive – Analytical skills – brainstorming – strategic thinking – creative thinking – Lateral Thinking – EQ and IQ **Unit 6: Problem Solving** What is a problem? Identifying a problem – data collection methods and tools – 5 Whys – drill down technique – case and effect diagram Prioritizing problem – pareto's principle Generating solutions – making decisions - Implementing solutions Evaluating solutions **Unit 7: Time Management** What is Time Management? Time Management Strategies Stumbling Blocks in Time Management Task Prioritization and Delegation Technology and Time Management **Section B: Tutorial Component** Unit I: Group Discussion Unit II: Oral presentation Unit III: Designing and Using PPTs – solo and group presentation Unit IV: Critical writing practise Unit V: Analytical writing practise

Sl. No.	Subject Code	SEMESTER II	L	T	P	C
1.	MA4201	Topology	3	0	0	3
2.	MA4202	Numerical Analysis	3	0	2	4
3.	MA4203	Complex Analysis	3	1	0	4
4.	MA4204	Linear Optimization Techniques	3	0	2	4
5.	MA4205	Probability and Statistics	3	0	0	3
		TOTAL	**15**	**1**	**4**	**18**

Course Number	MA4201 (Core)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Topology
Learning Mode	Lectures and Tutorials
Learning Objectives	The main objectives of this course is to lay a foundation for general topology. Students will learn how to generalize concepts from the realm of real numbers to arbitrary sets with some structure. The course will help students for future study in geometry or analysis.
Course Description	This course serves to lay the foundations for general topology. It begins with defining topological spaces, its basis, subspace topology, order topology, product and box topology. The core of the subject includes limit points, properties of functions on topological spaces, metric spaces, connectedness, compactness, countability and separation axioms.
Course Content	Definition and examples of topological spaces (including metric spaces), Open and closed sets, Subspaces and relative topology, Closure and interior, Accumulation points, Dense sets, Neighborhoods, Boundary, Bases and sub-bases. Construction of Topological spaces from known spaces. Product spaces, Cone and Suspension construction. Identification spaces. Neighborhood systems. Nets and Filters. Continuous functions and homeomorphism, Quotient topology, First and second countability and separability, Lindelöf spaces. The separation axioms T0, T1, T2, T3,T3_1/2 , and T4; their characterizations and basic properties. Urysohn's lemma, Urysohn's metrization theorem, Tietze's extension theorem. Compactness. Basic properties of compactness. Compactness and the finite intersection property, Local compactness, One-point compactification. Connected spaces and their basic properties. Connectedness of the real line. Components, Locally connected spaces. Tychonoff 's theorem
Learning Outcome	(1) Students will learn the concepts of general topology. (2) Students will appreciate the art of abstraction by relating the course with real analysis. (3) They will learn to extend the notions of open and closed sets, limit points, closure, connected and compact sets from the set of real numbers to general topological spaces. (4) They will learn the separation and countability axioms which will help them differentiate between the structural properties of spaces. (5) This course will enhance the research appetite of students through some deep ideas through Tychonoff theorem and the Titze extension theorem.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. M. A. Armstrong, Basic Topology, Springer, 2014.
2. J. R. Munkres, Topology, 2nd Edition, Pearson International, 2000.
3. K. D. Joshi, Introduction to General Topology, New Age International, 2000.

Reference Books:

1. G. F. Simmons, Introduction to Topology and Modern Analysis, McGraw-Hill, 1963.
2. J. L. Kelley, General Topology, Van Nostrand, 1995.

Course Number	MA4202 (Core)
Course Credit (L-T-P-C)	3 – 0 – 2 – 4
Course Title	Numerical Analysis
Learning Mode	Lectures and Labs
Learning Objectives	In this subject, the students will be trained with the knowledge of computational techniques from Numerical Analysis that are essentially used in various field of Mathematics and Computing.
Course Description	Numerical Analysis, as a fundamental subject for undergraduate students, provides the knowledge about numerical solution of system of linear equations, finite difference techniques, numerical differentiation and integration, numerical solution of ODEs and related concepts.
Course Content	Error: its sources, propagation, and analysis, Solutions of nonlinear equations: bisection method, secant method, Newton-Raphson method, fixed point iteration; Systems of linear equations: Direct methods (Gaussian elimination, LU decomposition, Cholesky factorization), Iterative methods (Gauss-Seidel, Jacobi and SOR) and their convergence for diagonally dominant coefficient matrices; Eigenvalue problems: Gerschgorin circle theorem, Jacobi, Given’s and Householder’s methods for symmetric matrices, Power method. Interpolation: Lagrange and Newton forms of interpolating polynomial, Error in polynomial interpolation of a function; Numerical differentiation and error, Forward, backward, and central difference approximations, Numerical integration: Trapezoidal and Simpson rules, Gauss Quadrature formulas, composite rules, errors in numerical integration formulae. Numerical solutions of IVP: Single step methods: Taylor series method, explicit and implicit single step methods – Euler and Runge-Kutta Methods, stability and error analysis. Numerical solutions of Boundary Value Problems (BVPs): Shooting method and finite difference method.
Learning Outcome	On successful completion of the course, students should be able to: 1. Develop the understanding of mathematical tools to solve system of linear equations. 2. Comprehend ideas of numerical differentiation and integration. 3. Apply the concepts to solve the ODEs numerically.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. K. E. Atkinson, An Introduction to Numerical Analysis, John Wiley & Sons, paperback, 1989.
2. S. D. Conte and Carl de Boor, Elementary Numerical Analysis, An Algorithmic Approach, Macgraw Hill International Editions, 1981.

References Books:

1. Richard L. Burden and J. Douglas Faires, Numerical Analysis, Cengage Learning, Inc; 9th Edition, 2010.
2. J. Stoer , R. Bulirsch, Introduction to Numerical Analysis, Springer-Verlag New York, 3rd ed. 2010.

Course Number	MA4203 (Core)
Course Credit (L-T-P-C)	3 – 1 – 0 – 4
Course Title	Complex Analysis
Learning Mode	Lectures and Tutorials
Learning Objectives	The learning objective of this course include the definition of analyticity, the Cauchy-Riemann equations and the concept of differentiability. Also to be learnt are the theorems on entire functions, residue theorem and applications and finally conformal mapping.
Course Description	We will begin with properties of complex numbers and then study the analytic function. We also study Contour integrals, Cauchy-Goursat Theorem. Further, we study uniform convergence of sequences and series, Taylor and Laurent series and their properties. Finally, we will discuss about the Residue theorem, Maximum Modulus Principle, Argument Principle, conformal mapping.
Course Content	Complex numbers and the point at infinity. Limit, continuity and differentiability of complex-valued functions. Analytic functions, Cauchy-Riemann conditions, Harmonic Conjugates, Mappings by elementary functions, Branch cut and branch points, Line and Contour integrals, Cauchy-Goursat Theorem. Uniform convergence of sequences and series, Taylor and Laurent series, Classification of singularities, Isolated singularities and residues, Zeroes and poles, Residue theorem and applications to evaluate real integrals, Maximum Modulus Principle, Argument Principle, Rouche's theorem. Riemann surfaces, Bilinear and Conformal mappings, Mobius Transformations, Schwarz-Christoffel Transformation.
Learning Outcome	After successful completion of the course the student will be able to: 1. Students will be equipped with the understanding of the fundamental concepts of complex theory and skill of contour integration to evaluate complicated real integrals via residue calculus. 2. Decide when and where a given function is analytic and be able to find it series development. 3. Describe conformal mappings between various plane regions.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. J. W. Brown and R. V. Churchill, Complex Variables and Applications, 9th Edition, 2021.
2. L. V. Ahlfors, An Introduction to the Theory of Analytic Functions of One Complex Variable, 3rd Edition 1979.

Reference Books:

1. J. B. Conway, Functions of One Complex Variable, 2nd ed., Narosa Pub. House, New Delhi, 1978.
2. T. W. Gamelin, Complex Analysis, Springer International Edition, 2001.
3. S. Ponnusamy, Foundations of Complex Analysis, Narosa Pub. House, 2005

Course Number	MA4204 (Core)
Course Credit (L-T-P-C)	3 – 0 – 2 – 4
Course Title	Linear Optimization Techniques
Learning Mode	Lectures and Labs
Learning Objectives	The objective of the course is to train student about the modeling of linear programming problems.
Course Description	Optimization technique, as a basic subject for undergraduate students, provides the initial knowledge of various models of linear programming problems and different algorithms to solve such problems.
Course Content	Linear Programming Problems: Introduction and problem formulation, concepts from geometry, geometrical aspects of LPP, convex sets, extreme points; Basic feasible solutions, graphical solutions, and linear programming in standard form. Simplex, Big M, and Two-Phase methods, revised simplex method, Special cases of LPP. Sensitivity analysis of linear programming problems. Infeasible and unbounded linear programming models, alternate optima. Transportation problems: Balanced and unbalanced transportation problems, Initial basic feasible solution of balanced transportation problems (least cost method, north-west corner rule, Vogel's approximation method), Optimal solution, modified distribution method. Assignment problems: Hungarian method. Duality theory: Dual simplex method, weak duality, and strong duality. Integer programming problems: Branch and bound method, Gomory cutting plane method for all-integer and for mixed integer LPP. Computational complexity of the simplex algorithm, Karmarkar's algorithm for LPP. Theory of games: Saddle point, linear programming formulation of matrix games, two-person zero-sum games with and without saddle-points, pure and mixed strategies, graphical method of solution of a game, solution of a game by the simplex method. Acquaintance to softwares like Python/MATLAB.
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand the terminology and basic concepts of various kinds of linear programming problems 2. Apply and differentiate the need and importance of various algorithms to solve linear programing problems 3. employ programming languages to solve linear programing problems
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. Hamdy A. Taha, Operations Research: An Introduction, Eighth edition, PHI, New Delhi (2007).
2. A. Ravindran, D.T. Phillips, J.J. Solberg, Operation Research, John Wiley and Sons, New York (2005).
3. M. S. Bazaraa, J. J. Jarvis and H. D. Sherali, Linear Programming and Network Flows, 3rd Edition, Wiley (2004).

Reference Books:

1. D. G. Luenberger, Linear and Nonlinear Programming, 2nd Edition, Kluwer, (2003).
2. E.K.P. Chong, S.H. Zak, An Introduction to Optimization, 3rd Edition, John Wiley (2008).

Course Number	MA4205 (Core)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Probability and Statistics
Learning Mode	Lectures and Tutorials
Learning Objectives	To help the students understand basic concepts in probability theory and statistics through numerous practical examples.
Course Description	This course is divided into two parts; the first part introduces basic concepts of probability theory. In the second part, using the knowledge of probability theory, different problems in classical statistics are discussed.
Course Content	Review of Counting techniques. Introduction to Probabilistic Model, Conditional probability, Bayes' rule, Total probability law, Independence of events Random variables (discrete and continuous), probability mass functions, probability density functions, Expectation, variance, moments, cumulative distribution functions, Moment generating functions. Function of random variables, Multiple random variables, joint and marginal, conditioning and independence, Derived distributions, covariance and correlation, Conditional expectation, and variance. Markov and Chebyshev inequalities, Different notions of convergence. Weak law of large number, Central limit theorem, strong law of large number Estimation: Properties, Unbiased Estimator, Minimum Variance Unbiased Estimator, Rao-Cramer Inequality and its attainment, Maximum Likelihood Estimator and its invariance property, Efficiency, Mean Square Error. Confidence Interval: Coverage Probability, Confidence level, Sample size determination, Shortest Length interval, Pivotal quantities, interval estimates for various distributions. Testing of Hypotheses: Null and Alternative Hypotheses, Test Statistic, Error Probabilities, Power Function, Level of Significance, Neyman-Pearson Lemma
Learning Outcome	Students will become familiar with principal concepts probability theory and statistics. This helps them to handle, mathematically, various practical problems arising in uncertain situations.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. Introduction to Probability, Dimitri P. Bertsekas and John N. Tsitsiklis, Athena Scientific, Second edition.
2. An Introduction to Probability and Statistics, V.K. Rohatgi and A.K.Md. Ehsanes Saleh, John Wiley, 2nd Ed, 2009.

Reference books:

1. Mathematical Statistics with applications, Kandethody M. Ramachandran, Chris P. Tsokos, Academic Press, 2009.
2. Probability and Statistics in Engineering, William W. Hines, Douglas C. Montgomery, David M. Goldsman, John Wiley & Sons, Inc, 4th Ed., 2003.
3. Statistical Inference, G. Casella and R.L. Berger, Duxbury Advanced Series,2nd Ed., 2007.

Sl. No.	Subject Code	SEMESTER III	L	T	P	C
1.	MA5101	Measure Theory	3	0	0	3
2.	MA5102	Functional Analysis	3	0	0	3
3.	MA5103	Partial Differential Equations	3	0	0	3
4.	MA51XX/ MA61XX	DE-I	3	0	0	3
5.	XX61PQ	IDE-I	3	0	0	3
6.	MA5199	Project I	0	0	12	6
		TOTAL	**15**	**0**	**12**	**21**

Course Number	MA5101 (Core)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Measure Theory
Learning Mode	Lectures and Tutorials
Learning Objectives	This course aim to train student about basics of measure theory and integration and why Riemann Integration was not enough.
Course Description	Students will be first taught about all the tools required to study the measure theory and various types of measure spaces will be discussed. Then main focus will be on Lebesgue measure and with the Lebesgue measure we shall be able to define and compute Lebesgue integration.
Course Content	Algebra, Sigma Algebra, Borel Measure, Measurable sets, Measure space, Complete measure space. The Lebesgue measure, Properties of Lebesgue measure, Uniqueness of Lebesgue Measure, Construction of non-measurable subsets. Lebesgue Integration: The integration of non-negative functions, Measurable functions, Fatou's Lemma, Integrable functions and their properties, Lebesgue's dominated convergence theorem. Absolutely continuous function, Lebesgue-Young theorem (without proof), Product of two measure spaces, Fubini's theorem. Lp-spaces, Holder's inequality, Minkowski's inequality, Completeness of Lp-spaces
Learning Outcome	Students shall be able to differentiate between Riemann Integration and Lebesgue integration and shall be able to prove complex results on measurable functions.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. Frank Jones, Lebesgue Integration On Euclidean Space, Jones and Bartlett Publishers, Inc; Revised edition, US, 2022.
2. G. de Barra, Measure Theory and Integration, John Wiley & Sons, 1981.

Reference Books:

1. J.L. Kelly, T. P. Srinivasan, Measure and Integration, Springer, 1988.
2. H. L Royden, Real Analysis, Pearson, 2007.
3. M. E. Taylor, Measure Theory and Integration, AMS, 2012.

Course Number	MA5102 (Core)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Functional Analysis
Learning Mode	Lectures and Tutorials
Learning Objectives	The objective of the course is to train student about the fundamental properties of normed spaces, Banach spaces and Hilbert Spaces.
Course Description	Functional analysis is a basic course for undergraduate student and is intended to discuss about important mathematical properties of linear transformations between Banach and Hilbert spaces and enables students to solve some functional equations.
Course Content	Metric spaces, Normed spaces, Banach spaces, Lp-spaces, Holder's inequality, Minkowski's inequality, Completion of Lp-spaces Continuity of linear maps, Dual spaces and transposes, Hahn-Banach Extension, Hahn-Banach Theorem. Uniform Boundedness Principle and its applications, Closed Graph Theorem, Open Mapping Theorem and its applications. Banach fixed point theorem Spectrum of a bounded operator, Examples of compact operators on normed spaces. Inner product spaces, Hilbert spaces, Orthonormal basis, Projection theorem and Riesz Representation Theorem.
Learning Outcome	After finishing the course, students will acquire the following abilities: 1. Recognize the fundamental properties of normed spaces, Banach spaces, Hilbert spaces and transformations between them. 2. key examples of Hilbert and Banach spaces, emphasizing their practical applications. 3. Establish connections between Functional Analysis and challenges in Partial Differential Equations, Measure Theory, and other areas of Mathematics.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. M. T. Nair, Functional Analysis: A First Course, PHI Pvt. Ltd, 2004.
2. E. M. Stein & Rami Shakarchi, Functional Analysis, Princeton University Press, 2011.
3. E. Kreyzig, Introduction to Functional Analysis with Applications, John Wiley & Sons, New York, 1978.

Reference Books:

1. J. B. Conway, A Course in Functional Analysis, 2nd ed., Springer, Berlin, 1990.
2. B. V. Limaye, Functional Analysis, 2nd ed., New Age International, New Delhi, 1996.

Course Number	MA5103 (Core)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Partial Differential Equations
Learning Mode	Lectures and Tutorials
Learning Objectives	This course will be helpful for any applied mathematicians or engineers to understand the mathematical background, analytical properties, and qualitative analysis for standard PDE models without finding its approximate solution.
Course Description	In this course the overall idea of partial differential equations will be provided in theoretical and analytical direction with their qualitative analysis.
Course Content	Introduction to PDE, Basic concepts, Linear, quasi linear & nonlinear PDEs. First order PDE- Cauchy-Kowalewski theorem, Holmgren's uniqueness theorem, Methods of characteristics. Lagrange and Charpit's methods, Monge Cone. Second order PDEs: Modeling of Heat, Wave and Laplace equations, Classification of second order PDEs (Canonical forms). Wave equation: D'Alembert's solution and Duhamel's principle for one dimensional wave equation, Uniqueness of solutions via energy method, Spherical means, Hadamard's method. Laplace equation: Mean value property, Poisson equation, Green's identity, Fundamental solutions, Poisson's formula, Maximum and minimum principles and consequences. Heat equation: Initial and/or initial-boundary value problems, Maximum and minimum principles and consequences, Uniqueness. Fourier Series and Fourier Transform and its applications to solve Heat, Wave and Poisson equations.
Learning Outcome	From this course, students will learn – how to solve simple PDEs and the analytical behavior of the solution of standard PDEs.
Assessment Method	Quiz /Assignment/ MSE /ESE

Text Books:

1. R. Haberman, Applied Partial Differential Equations, 4th Edition, Prentice Hall, 2003.
2. M. Renardy, R. C. Rogers, An Introduction to Partial Differential Equations, Springer, 2004.
3. T. Amaranath, An Elementary Course in Partial Differential Equations, Narosa Publisher, 2010

Reference Books:

1. L. Evans, Partial Differential Equations, American Mathematical Society GSM series, 2010.
2. N. Sneddon, Elements of Partial Differential Equations, Dover, 2006.
3. J. R. Buchanan, Z. Shao, A First Course in partial Differential Equations, World Scientific, 2017.

Sl. No.	Subject Code	Department Elective - I	L	T	P	C
1.	MA5104	Cryptography and Network Security	3	0	0	3
2.	MA5105	Fundamentals of Block Chain	3	0	0	3
3.	MA5106	Mathematical Finance	3	0	0	3
4.	MA6101	Advanced Graph Theory	3	0	0	3
5.	MA6102	Introduction to Algebraic D-modules	3	0	0	3
6.	MA6103	Nonlinear Optimization	2	0	2	3
7.	MA6104	Generative AI	2	0	2	3
8.	MA6105	Rings and Modules	3	0	0	3
9.	MA6106	Large Language Models (LLMs)	2	0	2	3
10.	MA6107	Number Theory	3	0	0	3
11.	MA6108	Stochastic Calculus for Finance	3	0	0	3

Course Number	MA5104 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Cryptography and Network Security
Learning Mode	Lectures
Learning Objectives	The objective of the course is to present an introduction to Cryptography, with an emphasis on how to protect information security from unauthorized users and is to understand the basics of Network vulnerability and Security Protection.
Course Description	The aim of this course is to introduce the student to the areas of cryptography and cryptanalysis. This course develops a basic understanding of the algorithms used to protect users online and to understand some of the design choices behind these algorithms.
Course Content	Security goals and attacks, Cryptography and cryptanalysis basics, Mathematics behind cryptography, Traditional and modern symmetric-key ciphers, DES, AES, Asymmetric-key ciphers, One-way function, Trapdoor one-way function, Chinese remainder theorem, RSA cryptosystem, Elgamal Cryptosystem, Diffie-Hellman key exchange algorithm, Elliptic curve cryptography, Cryptographic hash function, Message authentication, PKI, Digital signature, RSA digital signature, Security at the Network Layer: IPSec and IKE, Security at the Transport Layer: SSL and TLS, Security at the Application Layer: PGP and S/MIME
Learning Outcome	Students will be familiar with the significance of information security in the digital era. Also, they can identify various threats and vulnerabilities in networking.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Cryptography and Network Security by Behrouz A. Forouzan and Debdeep Mukhopadhyay, Second edition, Tata McGraw Hill, 2011.
2. Cryptography and Network Security Principles and practice by W. Stallings, 5/e, Pearson Education Asia, 2012.

Reference Books:

1. Cryptography: Theory and Practice by Stinson. D., third edition, Chapman & Hall/CRC, 2010.
2. Elementary Number Theory with applications by Thomas Koshy, Elsevier India, 2005.
3. Research papers

Course Number	MA5105 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Fundamentals of Block Chain
Learning Mode	Lectures
Learning Objectives	To give students the understanding of emerging abstract models for Blockchain Technology and to familiarize with the functional/operational aspects of cryptocurrency eco-system.
Course Description	This course will be on the fundamentals of Blockchain and Blockchain Technology. After covering fundamentals, we will look at some applied uses and criticisms. The best-known example of Blockchain Technology in wide use today is as the storage and transaction mechanism for the cryptocurrency Bitcoin.
Course Content	Concepts of cryptocurrency and Blockchain, Consensus Algorithms-Security of Blockchain, Blockchain Programs and Network, Concept of Blockchain parameters, Double-Spending Problem, Public Key Cryptosystem, Cryptographic Hash Functions, Digital Signatures, Bitcoin Cryptocurrency, Transactions, Mining, Consensus Mechanisms and Validation, Proof of Work (PoW), Introduction of Bitcoin Program, Ethereum Cryptocurrency, Ethereum vs. Bitcoin, Transactions, Ethereum Blocks, Proof of Stake (PoS), Security issues in Blockchain, Anonymity, Sybil Attacks, Selfish Mining, 51/49 ratio Attacks, Introduction to Smart Contracts, Framework of smart contract, Life cycle of smart contract, Challenges of Smart Contract, Case Studies as Blockchain technology based Applications
Learning Outcome	Students will be familiar with blockchain and cryptocurrency concepts. Also, they can design and demonstrate end-to-end decentralized applications.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. A. Narayanan, J. Bonneau, E. Felten, A. Miller, and S Goldfeder, “Bitcoin and Cryptocurrency Technologies”, Princeton University Press, 2016
2. Xiwei Xu, I. Weber, M. Staples, “Architecture for Blockchain Applications”, Springer, 2018.

Reference Books:

1. M. Swan, “Blockchain: Blueprint for a New Economy”, Oreilly, 2015
2. Daniel Drescher, “Blockchain Basics”, Apress.
3. Lecture Note of Prof. S. Vijayakumaran (IIT Bombay), “An Introduction to Bitcoin”
4. Lecture Note of Prof. S. Shukla (IIT Kanpur), “Introduction to Blockchain Technology and Applications”
5. Research papers

Course Number	MA5106 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Mathematical Finance
Learning Mode	Lectures
Learning Objectives	The main objective of the course is to introduce the students to the broader area of mathematical finance from a theoretical as well as computational perspective.
Course Description	Mathematical finance, as an interdisciplinary subject, which encompasses topics from financial engineering, mathematics and computational techniques.
Course Content	Financial markets and instruments, risk-free and risky assets; Interest rates, present and future values of cash flows, term structure of interest rates, spot rate, forward rate; Bonds, bond pricing, yields, duration, term structure of interest rates; Asset pricing models, no-arbitrage principle; Cox-Ross-Rubinstein binomial model, geometric Brownian motion model; Financial derivatives, Forward and futures contracts and their pricing, hedging strategies using futures, interest rate and index futures; Swaps and its valuation, interest rate swaps, currency swaps; Options, general properties of options, trading strategies involving options; Discrete time pricing of European and American derivative securities by replication; Continuous time pricing of European and American derivate securities by risk-neutral valuation; Finite difference approach to pricing European options and American options, free-boundary problem; Monte-Carlo simulation under risk neutral measure for computing financial derivative prices.
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand the fundamentals of quantitative finance. 2. Grasp the concept of time value of money and interest rates. 3. Comprehend ideas of pricing through the application of basic apply mathematical concepts. 4. Implementation of the theoretical topics through computational implementation expected in finance industry.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. M. Capinski and T. Zastawniak, Mathematics for Finance: An Introduction to Financial Engineering, 2nd Edition, Springer, 2010.
2. D. Higham, Introduction to Financial Option Valuation: Mathematics, Stochastic and Computation, Cambridge University Press, 2004.

Reference Books:

1. J.C. Hull, Options, Futures and Other Derivatives, 10th Edition, Pearson, 2018.

J. Cvitanic and F. Zapatero, Introduction to the Economics and Mathematics of Financial Markets, Prentice-Hall of India, 2007.

Course Number	MA6101 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Advanced Graph Theory
Learning Mode	Lectures
Learning Objectives	To learn various notions in basic and advanced graph theory and their applications.
Course Description	This course is meant to introduce various notions in graph theory and their application.
Course Outline	Basic definitions in graph theory, trees, connectivity, spanning trees, Eulerian and Hamiltonian graphs, matching in graphs, planar graphs, graph Coloring, Ramsay Theory: Applications, bounds on Ramsay number, Ramsay theory for integers, Graph Ramsay numbers. Extremal graph theory: Minors, Hadwiger's conjecture, Szemeredi's regularity lemma and its application Random graphs: Introduction, probabilistic method, threshold function.
Learning Outcome	Students will be accustomed to the basic graph and advanced topics in graph theory. They will be able to model different real-life problems using graph theory and also this course gives them basic foundation to do research in graph theory
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Algorithm Design By Jon Kleinberg, Éva Tardos, Pearson Education
2. The Design of Approximation Algorithms By David P. Williamson, David B. Shmoys, Cambridge University Press
3. Probability and Computing: Randomization and Probabilistic Techniques in Algorithms and Data Analysis By Michael Mitzenmacher, Eli Upfal , Cambridge University Press

Reference Books:

1. Design and Analysis of Algorithms: A Contemporary Perspective By Sandeep Sen and Amit Kumar, Cambridge University Press
2. Algorithms By Sanjoy Dasgupta, Christos H. Papadimitriou, Umesh Virkumar Vazirani, McGraw-Hill Higher Education

Course Number	MA6102 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Introduction to algebraic D-modules
Learning Mode	Lectures
Learning Objectives	The goal of this course is to provide a fundamental knowledge of Weyl algebra and its properties. It is intended that the students become familiar with the main basic techniques and results of this area and become ready for research projects.
Course Description	This course will cover the theory of Weyl algebras, ring of differential operators and Jacobian conjecture. Further, Graded rings, filtered rings, Hilbert polynomial and Bernstein inequality will be discussed.
Course Content	(Review of Rings, Ideals, Homomorphism, Isomorphism, Vector spaces, Bases, Dimensions, Linear operators, Algebras, Subalgebras.) Derivations on rings, Weyl algebras, Canonical forms, Generators and Relations, Degree of an Operator, Ideal structure, Positive characteristic, Ring of differential Operators, Jacobian Conjecture, Polynomial maps, Modules over the Weyl Algebra, D-module of an equation, Direct limit of modules. Graded rings, Filtered rings, Graded algebra, Filtered modules, Induced filtration, Noetherian modules, Good filtration, Hilbert polynomial, dimension and multiplicity, Bernstein inequality.
Learning Outcome	Upon successful completion of this course students should: 1. recognise technical terms and appreciate some of the uses of Weyl algebra. 2. Demonstrate knowledge of the advanced language of algebraic D-modules and thus get access to the wide literature that uses it. 3. Use the algebraic technique of D-modules to solve the complicated analytic problems concerning invariant distributions.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. S. C. Coutinho, A primer of algebraic D-modules, London Mathematical Society, Student Text 33, 1995.
2. J. Bernstein**,** Algebraic Theory of D-modules (Lecture notes), 2016.
3. A. Braverman and T. Chmutova, Lectures on algebraic D-modules, 2016.

Reference Books:

1. L. Rowen, Graduate algebra: noncommutative view, Graduate Studies in Mathematics, 91.
2. A. Borel, J. Coates and S. Helgason, Algebraic D-Modules (Perspectives in Mathematics), Academic Press 1987.

Course Number	MA6103 (DE)
Course Credit (L-T-P-C)	2-0-2-3
Course Title	Nonlinear Optimization
Learning Mode	Lectures and Labs
Learning Objectives	The objective of the course is to train students about the modeling and solution of nonlinear programming problems and various algorithms to solve these problems. Moreover, several optimality conditions and duality models are also discussed.
Course Description	Nonlinear Optimization, as a basic subject for Master and PhD students, provides the basic knowledge of various types of optimality conditions for constrained and unconstrained nonlinear programming problems and different algorithms to solve these problems. Moreover, generalized convexity notions and duality models will be described. With its applications in several problems arising in economics, science and engineering.
Course Content	Convex Sets and Its Properties, Support and Separation Theorems, Convex Cones and Polar Cones, Polyhedral Cones, Cone of Tangents, Cone of Attainable Directions, Cone of Feasible Directions Convex Functions**:** Definitions and Preliminary Results, Continuity and Directional Differentiability of Convex Functions, Differentiable Convex Functions and Properties Quasiconvex Function, Pseudoconvex Functions, Characterization and Properties Optimality Conditions for Unconstrained Minimization and Constrained Minimization Problems, Lagrange's Multiplier Method, Inequality Constrained Problems, Constraint Qualifications, Saddle Point Optimality Criteria, KKT conditions, Mond Weir and Wolfe Duality. Unimodal functions, Fibonacci search, Line search methods, Convergence of Generic Line Search Methods, Method of Steepest Descent, Conjugate gradient methods, Fletcher Reeves Method, Quasi-Newton Method, BFGS Method, Convergence Analysis for Quadratic functions; Interior point methods for inequality constrained optimization, Merit functions for Constrained Minimization, Logarithmic Barrier Function for Inequality Constraints, A basic Barrier-Function Algorithm. Practice with software such as Python/MATLAB
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand the terminology and basic concepts of various kinds of nonlinear programming problems 2. model several dual models related to nonlinear programming problems 3. Develop the understanding of about different solution methods and algorithms to solve nonlinear Programing problems. 4. Apply and differentiate the need for and importance of various algorithms to solve nonlinear programing problems 5. Model and solve real-life problems using optimization algorithms
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. M. S. Bazaraa, J. J. Jarvis and H. D. Sherali, E.K.P. Chong, S.H. Zak, An Introduction to Optimization, 3rd Edition, John Wiley, 2008.
2. J. Nocedal and S. Write, Numerical Optimization, Springer Science, 1999
3. E.K.P. Chong and S.H. Zak, An Introduction to Optimization, 3rd Edition, John Wiley, 2008.

Reference Books:

1. Stephan Boyd and L. Vandenberghe, Convex Optimization, Cambridge University Press, 2009.
2. O.L. Mangasarian, Nonlinear Programming, SIAM Classics in Applied Mathematics, 1969

Course Number	MA6104 (DE)
Course Credit (L-T-P-C)	2-0-2-3
Course Title	Generative AI
Learning Mode	Lectures and Labs
Learning Objectives	1. Master various generative models including Autoencoders, GANs, Transformers, and Diffusion models for creative AI applications. 2. Understand advanced concepts in Generative AI such as graph neural networks, diffusion models, and the latest architectures to address real-world challenges.
Course Description	The basic knowledge of deep learning is desirable for this course. This course will explore cutting-edge techniques in Generative AI, covering Autoencoders, GANs, Transformers, Diffusion models, and applications in graph data, alongside the latest advancements in the field.
Course Outline	Introduction to Generative AI: Autoencoder (AE), Variational AE, GAN, Types of GANs – Deep Convolutional GAN (DCGAN), Conditional GAN (cGAN), Wasserstein GAN (WGAN), Stacked GAN (StackGAN), Attention GAN, Picture to Picture GAN (Pix2Pix), Cyclic GAN. Transformer Networks: Drawbacks of Recurrent Neural Networks, Self Attention, Transformers, Bidirectional Encoder Representation from Transformer (BERT), Generative pre-trained Transformer (GPT). Diffusion models: Categories (DDPM, NCSN, SDE) of diffusion Model, Application of diffusion model in computer vision and medical imaging. Generative AI for Graph: Basics of Graph Convolutional Neural Network (GCN), Graph Embeddings, Spectral and Spatial GCNs, Graph Autoencoders, GraphGAN, Graph Diffusion Model. Some popular Architectures/concepts in Generative AI: Stable Diffusion, CLIP, DALL·E, ChatGPT, Self-supervised Learning, Knowledge Distillation, Model compression/Network Pruning, Explainable AI, etc.
Learning Outcome	1. Acquire proficiency in implementing and training diverse generative models for image, text, and graph data generation. 2. Apply state-of-the-art techniques in Generative AI to tackle complex problems in computer vision, medical image analysis, natural language processing, and graph data analysis.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Dive into Deep Learning by Aston Zhang, Zachary C. Lipton, Mu Li, and Alexander J. Smola, Cambridge University Press, 2023.
2. Deep Learning by Ian Goodfellow and Yoshua Bengio and Aaron Courville, MIT Press, 2016.

Reference Books:

1. Various research papers at prestigious venues like NIPS, ICML, ICLR, CVPR etc.

Course Number	MA6105 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Rings and Modules
Learning Mode	Lectures
Learning Objectives	Readers of this course will be well-equipped with basic concepts of Rings & Modules which are prerequisites to the courses on Fields and Galois Theory, Coding Theory, Cryptography, Homological Algebra, Noncommutative Algebra, Algebraic Geometry, and advanced courses on Analysis.
Course Description	It gives a foundation for further studies in algebra by discussing several classes of rings and modules. This course includes structure theorems for modules over PID, Artinian and Noetherian rings and modules, and their radicals. Further, the concept of Tensor product, Projective and Injective Modules are also introduced.
Course Content	Modules, submodules, quotient modules and module homomorphisms, Generation of modules, direct sums and free modules, simple modules Finitely generated modules over principal ideal domains. Ascending Chain Condition and Descending Chain Condition, Artinian and Noetherian rings and modules, Hilbert basis theorem, Primary decomposition of ideals in Noetherian rings. Radicals: Nil radical, Jacobson radical and prime radical, Localization of rings and modules. Tensor products of modules; Exact sequences, Projective, injective and flat modules.
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand, apply and analyze the notion of rings, ideals, and modules in related concepts required for advanced courses and research in Algebra. 2. Familiar with the key properties and examples of Artinian and Noetherian rings and modules and their generalization; 3. Decide whether a given ring or module, or a class of rings or modules, is Noetherian/Artinian, by applying the characterizations discussed in the course; 4. Able to use this concept for research in Information Circuits (Coding Theory, Cryptography, Image Processing, etc.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. C. Musili, Introduction to Rings and Modules, Narosa Pub. House, New Delhi, Sec. Edition, 2001.
2. J. A. Beachy, Introduction to Rings and Modules, London Math. Soc., Cam. Univ. Press, 2004.
3. D. S. Dummit and R. M. Foote, Abstract Algebra, 2nd Ed., John Wiley, 2002.

Reference Books:

1. N. Jacobson, Basic Algebra I and II, 2nd Ed., W. H. Freeman, 1985 and 1989.
2. S. Lang, Algebra, 3rd Ed., Springer (India), 2004.

Course Number	MA6106 (DE)
Course Credit (L-T-P-C)	2-0-2-3
Course Title	Large Language Models (LLMs)
Learning Mode	Lectures and Labs
Learning Objectives	1. Master neural network architectures for time series analysis and natural language processing. 2. Understand advanced techniques in language modeling for text generation and understanding.
Course Description	Explore neural networks for time series analysis, delve into advanced architectures like Transformers, BERT, and GPT, and examine emerging concepts in language models for text generation.
Course Outline	Basics of ML/DL: Classification, Regression, Training, Testing, Model selection and over/underfitting, Performance parameters, Fully Connected Neural Networks (FCNN); Time series and Recurrent Neural Networks: Time Series, NLP, FCNN and its limitation with time series analysis, RNN, LSTM, GRU, Word2vec and Glove; Architecture of Transformer Networks: Drawbacks of Recurrent Neural Networks, Self Attention, Transformers. BERT the encoder of Transformer Network: The basic idea and working of BERT, masked language modeling, Next Sentence prediction, Tokenization, Fine-tuning BERT, Tiny BERT, DistilBERT, RoBERTa, ELECTRA, T5; GPT the decoder of Transformer Network: Generalized Pre-Training modeling and its Training, ChatGPT: Exploring Its Applications and Advancements, Prompt Engineering, Llama and making DocterGPT, Challenges and upcoming big issues. Some popular models/pipelines/concepts in LLMs: Falcon, Gemini, Gemma, Lamda, Mistral, Retrieval Augmented Generation (RAG) pipeline, Hallucinations, Knowledge Graphs, Fine-tuning LLMs with LoRA and QloRA, Carbon Emissions and Large Neural Network Training, MiniLLM, Large Action Models, etc.
Learning Outcome	1. Develop skills in implementing neural networks for time series forecasting and sentiment analysis. 2. Apply state-of-the-art techniques in language modeling to generate high-quality text outputs for various applications.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE
Prerequisites	Linear algebra, Probability and Statistics

Text Books:

1. Jay Alammar, Maarten Grootendorst, Hands-On Large Language Models: Language Understanding and Generation, O'Reilly Media.
2. Denis Rothman, Transformers for Natural Language Processing: Build innovative deep neural network architectures for NLP with Python, PyTorch, TensorFlow, BERT, RoBERTa, and more, Packt.
3. Denis Rothman , Transformers for Natural Language Processing and Computer Vision: Explore Generative AI and Large Language Models with Hugging Face, ChatGPT, GPT-4V, and DALL-E3, Packt.

Course Number	MA6107 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Number Theory
Learning Mode	Lectures
Learning Objectives	Readers of this course will be well-equipped with basic concepts of numbers, their properties, and some of the standard results that are fundamental to any branch of mathematics. The course will study further properties and some advanced concept which has a lot of applications in Cryptography.
Course Description	This course introduces divisibility in integers and some knowledge of the arithmetic of congruences. In this course, we will discuss about the congruences, arithmetic functions and their applications. Further we will study two square, four square theorem and continued fractions.
Course Content	(Review: Divisibility, Basic Algebra of Infinitude of primes, discussion of the Prime Number Theorem, infinitude of primes in specific arithmetic progressions, Dirichlet's theorem (without proof).) Congruences and its properties, Structure of units modulo n, Binary and decimal representations of integers, linear congruences, Chinese remainder theorem, Fermat’s theorem, Wilson’s theorem, Fermat-Kraitchik factorization method, Number theoretic functions, Multiplicative function, Mobius inversion formula, Euler's phi function, Euler’s theorem, Properties of Phi-function (Gaus theorem), Primitive roots for primes, Composite numbers having primitive roots, Indices, Quadratic residues, Legendre symbol and their properties, Law of quadratic reciprocity, Numbers of special form, Nonlinear Diophantine equation, Pythagorean triple, Fermat's method of infinite descent, Fermat's two square theorem, Lagrange's four square theorem. Continued fractions, Rational approximations, Transcendental numbers, Transcendence of "e" and "pi", Pell's equation.
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand the importance of integers; 2. Understand other basic courses of mathematics, like Algebra, Topology, Calculus, Analysis, Geometry and Combinatorics;
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. David M. Burton, Elementary Number Theory, 6th Edition, McGrow Hill Higher Education, 2007.
2. Thomas Koshy, Elementary Number Theory with Applications, 2nd Edition, Academic Press, 2007.
3. I. Niven and H.S. Zuckerman, An Introduction to the Theory of Numbers, 5th Ed., Wiley, New York, 2008.

Reference Books:

1. W. W. Adams and L.J. Goldstein, Introduction to the Theory of Numbers, 3rd ed., Wiley Eastern, 1972.
2. A. Baker, A Concise Introduction to the Theory of Numbers, Cambridge University Press, Cambridge, 1984.

Course Number	MA6108 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Stochastic Calculus for Finance
Learning Mode	Lectures
Learning Objectives	In this subject, the students will be trained in approaches and concepts from stochastic calculus which are required to model as well as solve the problems in quantitative finance.
Course Description	This course explores the fundamentals of probability theory and various other mathematical concepts from stochastic calculus which is specifically relevant to the problems arising in mathematical finance, such as pricing of financial assets and financial derivatives.
Course Content	Probability spaces, filtrations, conditional expectations, martingales, stopping times; Markov process, Brownian motion; Stochastic differential equations; Ito process, Ito integral, Ito-Doeblin formula; Black-Scholes-Merton equation: derivation and solution; Risk-neutral valuation, risk-neutral measure, Girsanov's theorem, martingale representation theorem, fundamental theorems of asset pricing; Risk-neutral valuation of European, American and exotic derivatives; Greeks, implied volatility, volatility smile; Fixed income markets, interest rate models, pricing of fixed income securities, term structure; Forward rate models, Heath-Jarrow-Morton framework; Swaps, caps and floors and swap market models, LIBOR.
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand the fundamentals of stochastic calculus. 2. Describe the concept of probability theory used in stochastic calculus 3. Comprehend and apply stochastic calculus in financial market problems, such as risk-neutral pricing and financial derivatives.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Gopinath Kallianpur, and Rajeeva L. Karandikar, Introduction to Option Pricing Theory, Birkhäuser, 2000
2. Thomas Mikosh, Elementary Stochastic Calculus, with Finance in View, World Scientific, 1998.

References Books:

1. S. Shreve, Stochastic Calculus for Finance, Vol. I, Springer, 2004.
2. S. Shreve, Stochastic Calculus for Finance, Vol. II, Springer, 2004.

Sl. No.	Subject Code	SEMESTER IV	L	T	P	C
1.	MA52XX/ MA62XX	DE-II	3	0	0	3
2.	MA52XX/ MA62XX	DE-III	3	0	0	3
3.	MA52XX/ MA62XX	DE-IV	3	0	0	3
4.	XX62PQ	IDE-II	3	0	0	3
5.	MA5299	Project II	0	0	16	8
6.	IK5201	Indian Knowledge System	2	0	0	2
		TOTAL	**14**	**0**	**16**	**22**

Sl. No.	Subject Code	Department Elective – II	L	T	P	C
1.	MA5201	Portfolio Theory and Risk Management	3	0	0	3
2.	MA6201	Randomized Algorithms	3	0	0	3
3.	MA6202	Introduction to Biomathematics	3	0	0	3
4.	MA6203	Introduction to Homological Algebra	3	0	0	3
5.	MA6204	Noncommutative Algebra	3	0	0	3
6.	MA6205	Sobolev Spaces	3	0	0	3
7.	MA6206	Wavelet Transform	3	0	0	3

Course Number	MA5201 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Portfolio Theory and Risk Management
Learning Mode	Lectures
Learning Objectives	The goal of this course are two-folds, namely design of portfolios and the identification as well as risk management of such portfolios.
Course Description	Portfolio theory involves the usage of techniques of probability theory and statistics in the design and analysis of a financial portfolios (such as mutual funds). On the other hand, risk management involves tools from mathematics and statistics in the identification of financial risks to portfolios and the determination of the appropriate techniques to mitigate this risk.
Course Content	Return and risk of a portfolio, mean-variance portfolio theory, efficient frontier, Capital Asset Pricing Model, Arbitrage Pricing Theory; Utility theory, risk attitude of investors; Non-mean-variance portfolio theory, safety first models, semi-deviation, stochastic dominance; Bond portfolios, duration and convexity of a bond. Fundamentals of financial risk management, credit risk, market risk, operational risk, Basel and Solvency regulations; Market risk, Value-at-Risk (VaR), computation of VaR, coherent measures of risk; Credit risk, modelling correlated defaults, asset value models, term structure of default probability, credit derivatives; Operational risk, loss models, extreme value theory, parametric estimation.
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand the fundamentals of portfolio theory from asset picking to asset allocation and performance analysis of the portfolio. 2. Identification and quantification of risk of financial portfolios using mathematical and statistical tools. 3. Determination of robust techniques to mitigate the identified financial risks.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. S.P. Chakrabarty and A. Kanaujiya, Mathematical Portfolio Theory and Analysis, 1st Edition Birkshauser, 2023.
2. T. Roncalli, Handbook of Financial Risk Management, CRC Press, 2020

References Books:

1. J. C. Francis and D. Kim, Modern Portfolio Theory: Foundations, Analysis, and New Developments, 1st Edition, Wiley, 2013.

J. C. Hull, Risk Management and Financial Institutions, 4th Edition, Wiley, 2016.

Course Number	MA6201 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Randomized Algorithms
Learning Mode	Lectures
Learning Objectives	To learn different techniques used in design and analysis of randomized algorithms
Course Description	This course introduces some fundamental techniques used for design and analysis of randomized algorithms through example of different practically applicable problems. This course requires basic knowledge of discrete probability theory and algorithms as prerequisites.
Course Content	Introduction to randomized algorithms: Verifying polynomial identities, Verifying matrix multiplication, Randomized min-cut algorithm. Expectation: Linearity of expectation, Conditional expectation, Analysis of randomized quick sort, Coupon collector problem. Tail inequalities: Markov's inequality, Chebyshev's inequality, Chernoff bound, Computing median, Estimating a parameter. Balls into bins: Bucket sort, Coupon collector problem revisited, Hamiltonian cycle in random graphs. Probabilistic methods: Basic counting, Expectation arguments, Sample and Modify, Second moment method, Lovasz Local Lemma. Markov chain and Random walks: Application in 2-SAT and 3-SAT, Graph connectivity
Learning Outcome	Students will learn the fundamental techniques used in randomized algorithms and learn how to apply those techniques in different computational problems.
Assessment Method	Quiz /Assignment/ MSE / ESE

Text Books:

1. Probability and Computing by Michael Mitzenmacher, Eli Upfal , Cambridge University Press

Reference Books:

1. Randomized Algorithms by Rajeen Motwani and Prabhakar Raghavan, Cambridge University Press.
2. The Probabilistic Method by Noga Alon and Joel Spencer, Wiley.

Course Number	MA6202 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Introduction to Biomathematics
Learning Mode	Lectures
Learning Objectives	To learn application of Mathematics in Biology. To appreciate the representation of biological systems mathematically. To comprehend mathematical analysis and to correlate the outcome of mathematical system into biological system. To learn and understand the bridge between mathematical and biological worlds.
Course Description	This course is meant to expose the candidate to mathematical modeling biological systems and then apply it to various systems and analyse these models.
Course Content	**Mathematical modeling:** Role of mathematics in problem solving, Introduction to mathematical modeling and its basic concepts- system description and characterization, model formulation, validation and analysis of models, Pitfalls in modeling. **Population Dynamics:** Deterministic models in population dynamics (Discrete and Continuous), Stochastic birth-death models and analysis. **Models in ecology:** Predator-prey models (Discrete and Continuous), Spatio-temporal models- diffusion processes, Turing Instability; fisheries models- optimal harvesting and sustainability. **Models at molecular level:** HIV in vivo model, immune response models, Cancer models. **Modeling disease:** Infectious disease models, Models for non-communicable diseases (NCDs). **Models for public health:** Diseases control and interventions, Optimal control, Cost optimization. **Computational:** Parameter estimation, network models.
Learning Outcome	Students will be able to apply the mathematical knowledge on a biological system, analyse it and interpret it in terms of the biological systems.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. N. F. Britton, Essential Mathematical Biology, SUMS, Springer
2. F. Brauer and C. Castillo-Chavez, Mathematical models in population biology and epidemiology, Springer, 2012.
3. D. N. P. Murthy, N. W. Page, Ervin Y. Rodin, Mathematical modelling: a tool for problem solving in engineering, physical, biological, and social sciences, Pergamon Press, 1990.

Reference Books:

1. J. D. Murray, Mathematical Biology Volume I, 3rd Ed, 2003.
2. F. C. Hoppensteadt, Mathematical methods of population biology. Cambridge: Cambridge Univ. Press, 1982.

Course Number	MA6203 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Introduction to Homological Algebra
Learning Mode	Lectures
Learning Objectives	The objective of this course is equipping students with the methods of homological algebra and expose them to some of its very effective and historical applications in algebra.
Course Description	This course covers the basics of homological algebra. Using the tools of homological algebra, some results of commutative algebra will be discussed such as Auslander-Buchsbaum formula.
Course Content	Review of modules, submodules, quotient modules, homomorphism, kernel and image, Direct sum and direct product of modules, Free modules, universal properties of free modules and direct sums, Hom and Tensor product of modules, universal properties of tensor products, exact sequences, right exactness of tensor product, left exactness of Hom, local rings, algebras, graded rings and graded modules, polynomial rings. Localization of rings and modules, exactness of localisation, commutative properties of localisation with tensor product and Hom, Categories and functors, exact functors, injective, projective and flat modules, complexes and homology modules, resolution of a module, Derived functor: construction and uniqueness, the functors Ext and Tor, Projective, injective and global dimension, projective dimension over a local ring. Regular sequence for a module, depth of a module, Auslander-Buchsbaum formula with proof and examples.
Learning Outcome	Students will learn the methods of homological algebra systematically. They will appreciate it as an extension of their knowledge from Linear algebra. They will also be prepared to take a research project in related topics.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Balwant Singh: Basic Commutative Algebra, World Scientific Publishing Company (2011).
2. M. F. Atiyah and I. G. MacDonald: Introduction to commutative Algebra, Addison-Wesley Series in Mathematics, Westview Press (1994).
3. David Eisenbud : Commutative Algebra with a view towards Algebraic Geometry, Springer-Verlag New York (1995).

Reference Books:

1. Charles A. Weibel: An introduction to Homological Algebra, (Series Title: Cambridge Studies in Advanced Mathematics), Cambridge University Press (1995).
2. Joseph Rotman : An introduction to Homological Algebra, (Series Title: Universitext), Springer, Second edition (2009).

Course Number	MA6204 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Non-commutative Algebra
Learning Mode	Lectures
Learning Objectives	The goal of this course is to provide a fundamental knowledge of non-commutative algebra. It is intended that the students become familiar with the main basic techniques and results of this area and become ready for research projects.
Course Description	This course will cover theory of non-commutative algebra. It will begin with matrix rings, tensor products of matrix algebras and cover important result such as Wedderburn structure theorem. Further, simple rings, primitive rings derivations, involutions and density theorem will be discussed.
Course Content	Matrix Rings and PLIDs, Tensor Products of Matrix Algebras, Ring constructions using Regular Representation. Basic notions for Non-commutative Rings, Structure of Hom (M, N), Semisimple Modules & Rings, Wedderburn Structure Theorem, Simple Rings, Rings with Involution. The Jacobson Radical and its properties. Prime and Semiprime rings, Essential ideals in prime rings, Maximal Right of Ring of Quotients, The Two sided and Symmetric Rings of Quotients, The extended Centroid, Derivations and (Anti) automorphisms. Primitive Rings and Ideals, Rings of Quotients, Density Theorems, Primitive Rings with Nonzero Socle.
Learning Outcome	After completion of this course student will: 1) become fluent working with rings. 2) be able to understand some proofs of non-commutative algebra. 3) be able to appreciate powerful structure theorems, and be familiar with examples of non-commutative rings arising from various parts of mathematics.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. L. Rowen, Graduate algebra: noncommutative view, Graduate Studies in Mathematics, 91.
2. K. I. Beidar, W. S. Martindale, A. V. Mikhalev, Rings with Generalized Identities, Monographs and Textbooks in Pure and Applied Mathematics, 196, Marcel Dekker, Inc., New York, 1996.
3. T. Y. Lam, A first course in noncommutative rings, GTM, Springer.

Reference Books:

1. B. Farb, R. Dennis, Noncommutative algebra, GTM, Springer-Verlag.
2. J. Golan and T. Head, Modules and the structure of rings: A primer, Pure and applied mathematics

Course Number	MA6205 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Sobolev Spaces
Learning Mode	Lectures
Learning Objectives	The Sobolev spaces serve as a theoretical framework for studying solutions to partial differential equations.
Course Description	This course deals with Sobolev Spaces and some basic properties of them and simple application on PDEs.
Course Content	**Distribution and Fourier Transform** Revision / introduction to theory of distributions and Fourier Transform **Sobolev Spaces** The Spaces $W^{l,p}_{\infty}(\Omega)$ and $W^{l,p}(\Omega)$, their simple characteristic properties, density theorems, Min and Max of $W^{l,p}$ Functions, The space $H_m(R^n)$ and its Properties, Density results. Dual Spaces, Fractional Order Sobolev Spaces, Poincare theorem, Stampaccia Theorem, Trace spaces and Trace Theory. **Imbedding Theorem** Sobolev Lemma, Continuous and compact imbedding of Sobolev spaces into Lebesgue Spaces, Rellich Weighted Spaces **Applications to elliptic PDE** Abstract Variational problems, Lax-Milgram lemma, weak solutions and well posedness with examples, regularity result, maximum principles, eigenvalue problems.
Learning Outcome	Students should be able to realize the importance of Sobolev spaces and should be able to define them and shall be able to prove existence of weak solutions for a class of PDEs.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Kesavan S.: Topics in Functional Analysis and Applications. New Age International Private Limited, January 2015.
2. Pathak R. S.: A Course in Distribution Theory and Applications. Narosa publishing House, 2001.

Reference Books:

1. Renardy M. and Rogers R.C., An Introduction to Partial Differential Equations. Springer, 2004.
2. Lieb and Loss, Analysis: Second Edition, American Mathematical Society, 2001.

Course Number	MA6206 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Wavelets Transform
Learning Mode	Lectures
Learning Objectives	Learn about Fourier Transform, its draw back and extension of concepts of Fourier to Wavelets.
Course Description	Details of various transforms will be discussed that is required to understand Wavelet transform. Definition of Wavelets, Wavelet Basis, Multiresolution Analyses will be discussed throughout the course. At the end we shall learn how to solve ODEs and PDEs with help of Wavelets.
Course Content	Fourier Transforms, Poisson's Summation Formula, The Shannon Sampling Theorem, Heisenberg's Uncertainty Principle, The Gabor Transform, The Zak Transform, The Wigner-Ville Distribution, Ambiguity Functions. Wavelet Transforms, Continuous Wavelet Transforms, Basic Properties, The Discrete Wavelet Transforms, Orthonormal Wavelets, Multiresolution Analysis and Construction of Wavelets, Properties of Scaling Functions and Orthonormal Wavelet Bases, Construction of Orthonormal Wavelets, Daubechies' Wavelets, Mallat's Theorem, Wavelet Expansions and Parseval's Formula. Application: Solutions of ODEs and PDEs by using wavelets.
Learning Outcome	On successful completion of the course, students should be able to: 1. Differentiate between advantages and disadvantage of Fourier and Wavelets transform. 2. They shall be able to construct orthonormal basis of $L^2(R)$. 3. They shall be able to solve some ODEs and PDEs using Wavelets.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Lokenath Debnath, Wavelet Transforms and Their Applications, Springer Science+Business, Media, New York, 2002.
2. María Cristina Pereyra, Lesley A. Ward, Harmonic Analysis: From Fourier to Wavelets, AMS Book, Student Mathematical Library, IAS/Park City Mathematical Subseries, Volume 63.

Reference Books:

1. C. K. Chui, An Introduction to Wavelets, Academic Press, 1992.

Daubechies, Ten Lectures on Wavelets, SIAM Publication, Philadepphia, 1992.

Sl. No.	Subject Code	Department Elective – III	L	T	P	C
1.	MA6207	Differential Manifolds	3	0	0	3
2.	MA6208	Graph Algorithms	3	0	0	3
3.	MA6209	Numerical solutions of PDEs	2	0	2	3
4.	MA6210	Statistical Inference	3	0	0	3

Course Number	MA6207 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Differential Manifolds
Learning Mode	Lectures
Learning Objectives	Same as Learning Outcome
Course Description	It is a basic introductory course in the theory of smooth manifolds.
Course Content	The derivative, continuously differentiable functions, the inverse function theorem, the implicit function theorem. Topological manifolds, partitions of unity, imbedding and immersions, manifolds with boundary, submanifolds. Tangent vectors and differentials, Sard's theorem and regular values, Local properties of immersions and submersions. Vector fields and flows, tangent bundles, Embeddings in Euclidean spaces, smooth maps and their differentials. Smooth manifolds, smooth manifolds with boundary, smooth submanifolds, construction of smooth functions, classical Lie groups.
Learning Outcome	At the end of this course, students should be able to: -compute the atlases of several important examples of smooth manifolds. -compute the derivatives of smooth functions defined on smooth manifolds.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. J. M. Lee, Manifolds and Differential Geometry, AMS, GSM, 2014.
2. G. E. Bredon, Topology and Geometry, Springer-verlag, 1993.
3. A. Kosinski, Differential Manifolds, Academic Press, 1992.

Reference Books:

1. J. R. Munkres, Analysis on Manifolds, Addison-Wesley Publishing Company, 1991.
2. M. Spivak, A Comprehensive Introduction to Differential Geometry I, Publish or Perish, 1979.

Course Number	MA6208 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Graph Algorithms
Learning Mode	Lectures
Learning Objectives	To learn various notions in graph theory and their application in real life situation and to learn different algorithms to solve optimization problems in graph theory.
Course Description	This course is meant to introduce various notions in graph theory and their application.
Course Outline	(Review of Basic definitions in graph theory, Trees, Connectivity, Spanning trees, Shortest Path Problems, Eulerian and Hamiltonian graphs, Planar graphs, Graph Coloring) Graph searching algorithm: Breadth first search (BFS), Depth first search (DFS) and their applications. Algorithms for spanning tree: Kruskal's algorithm, Prim's algorithm Algorithms for shortest path: Dijkstra's algorithm, Bellman-Ford algorithm, Floyd-Warshall algorithm Matching, Konig Theorem, Algorithm to find maximum matching in bipartite graphs, Hall's theorem, Matching in non-bipartite graph: Edmond's blossom algorithm. Network flow, Max flow-min cut theorem, Ford-Fulkerson algorithm. Graph coloring, Greedy coloring technique, Variations of graph coloring Independent set, Clique, Dominating set and corresponding optimization problems. Probabilistic methods, Alteration technique, Applications of linearity of expectation and conditional expectation in graph theory. Notion of the class P, NP and NP-complete with examples
Learning Outcome	Students will be accustomed to the basic graph algorithms. Using graph theory, they will be able to model different real-life problems. Also, implementing the algorithms taught in the course, they can even solve those real-life problems.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Introduction to Graph Theory by D. B. West, Pearson Prentice Hall.
2. Graph Theory by Reinhard Diestel, Graduate Texts in Mathematics, Springer, 5th Edition.
3. Graph Algorithms by Shimon Even, Cambridge University Press.

Reference Books:

1. Algorithm Design by J. Kleinberg and Eva Tardos, Pearson Education
2. Introduction to Algorithms by T. H. Cormen, C. E. Leiserson, R. L. Rivest and C. Stein, Prentice Hall India.

Course Number	MA6209 (DE)
Course Credit (L-T-P-C)	2-0-2-3
Course Title	Numerical solutions of PDEs
Learning Mode	Lectures and Labs
Learning Objectives	In this subject, the students will be trained with the knowledge of Computing of the approximate solutions of partial differential equations.
Course Description	This course involves difference equations to solve differential equations by algorithms
Course Content	Introduction to Finite differences: Mesh points (uniform/nonuniform), Finite-difference approximations of integrals and derivatives, Order of convergence. Linear Transport Equation, Upwind Scheme, Central scheme, Midpoint Scheme, Lax- Wendroff and Lax-Friedrich schemes, CFL condition, Lax-Richtmyer equivalence theorem, Diffusion, Dissipation, Dispersion. Introduction to Von- Neumann stability analysis and Matrix analysis. General Parabolic Equation (1D & 2D): Initial and boundary value problems (Dirichlet and Neumann), Explicit and implicit methods (Backward Euler and Crank-Nicolson schemes) with consistency and stability, Discrete maximum principle, ADI methods for two dimensional heat equation including Method of Lines. General Elliptic Equation (1D & 2D): Finite difference scheme for initial and boundary value problems, Discrete maximum principle, Peaceman-Rachford algorithm (ADI) for linear systems. Wave Equation (1D & 2D): Explicit schemes and their stability analysis, Implementation of boundary conditions. Exposure on writing computational algorithm.
Learning Outcome	From this course, students will learn – how to solve partial differential equations and their convergence analysis
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. J. C. Strikwerda, Finite Difference Schemes and Partial Differential Equations, SIAM, 2004.
2. W. Morton and D. F. Mayers, Numerical Solution of Partial Differential Equations, Cambridge University Press, 2nd Edn., 2005.
3. Zhilin Li, Zhonghua Qiao, Tao Tang, Numerical Solution of Differential Equations, Cambridge University Press, 2017.

Reference Books:

1. Mark S. Gockenbach, Partial Differential Equations: Analytical and Numerical Methods, 2nd Edition, SIAM.
2. R. M. M. Mattheij, S. W. Rienstra, J. H. M. T. T. Boonkkamp, Partial Differential Equations: Modeling, Analysis, Computation, SIAM, 2005.

Course Number	MA6210 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Statistical Inference
Learning Mode	Lectures
Learning Objectives	Students will learn basic concepts of statistics which are significantly important in statistical analysis. One of the main goals of this course is to build background in theoretical statistics.
Course Description	Various estimation methods will be discussed and their error behavior will be studied. Some of important hypothesis testing problems will also be discussed.
Course Outline	Sampling distributions, Basic Concepts of estimation problems, Order statistics and their distributions, Sufficiency, Factorization method, minimal sufficient statistic, exponential families, unbiased estimators and properties, mean square error, Rao-Blackwell Theorem, Lehmann-Scheffe Theorem, Method of moments estimators, Maximum likelihood estimation and invariance property, Consistent estimators, Fisher information, Cramer-Rao inequality, confidence intervals, pivotal quantities, Examples of interval estimation. Tests of hypotheses, simple and composite hypotheses, critical regions, Type I and II errors, Power of a test, significance probabilities, size of a test, monotone likelihood ratio property and examples, Neyman-Pearson Lemma, uniformly most powerful tests, likelihood ratio tests, chi-square tests.
Learning Outcome	From this course students will be able to learn basics of theoretical statistics. They will learn various inference methods and will understand their comparative behavior.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. R. L. Berger and G. Casella, Statistical Inference, Duxbury Advanced Series, Second Edition, 2007.
2. A. M. Mood, F. A. Graybill and D. C. Boes, Introduction to the Theory of Statistics, Tata McGraw-Hill, 2009.

Reference Book:

V. K. Rohatgi & A. K. Md. E. Saleh, An Introduction to Probability and Statistics. John-Wiley, Second Edition, 2009.

Sl. No.	Subject Code	Department Elective – IV	L	T	P	C
1.	MA5202	Mathematical methods in classical mechanics	3	0	0	3
2.	MA6211	Advanced complex analysis	3	0	0	3
3.	MA6212	Algebraic Coding Theory	3	0	0	3
4.	MA5203	Discrete Mathematics	3	0	0	3
5.	MA6213	Finite Element Analysis	3	0	0	3
6.	MA6214	Introduction to Algebraic Geometry	3	0	0	3
7.	MA6215	Operators on Hilbert Spaces	3	0	0	3
8.	MA6216	Riemannian Geometry	3	0	0	3

Course Number	MA5202 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Mathematical methods in classical mechanics
Learning Mode	Lectures
Learning Objectives	The students would learn the singularity theorems of Hawking and Penrose, the positive mass theorem, and the theorems on black hole uniqueness and black hole thermodynamics.
Course Description	This course is an introduction to classical mechanics from a mathematical viewpoint.
Course Content	Lagrangian Mechanics: Lagrange's. equations, Legendre transformations, Hamilton's equations, Liouville's theorem, Holonomic constraints, Lagrangian dynamical systems, Noether's Theorem, D'Alembert's principle; Hamiltonian mechanics: Differential forms, Symplectic structures on manifolds, Hamiltonian phase flows and their integral invariants, Lie algebra of vector fields and Hamiltonian functions, symplectic geometry, The integral invariant of Poincare and Cartan, Huygens Principle, The Hamilton-Jacobi method, Generating functions, Integrable systems.
Learning Outcome	The students would learn the singularity theorems of Hawking and Penrose, the positive mass theorem, and the theorems on black hole uniqueness and black hole thermodynamics.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. V. I. Arnold, Mathematical methods of Classical Mechanics, 2nd edition, GTM 60, Springer, 2010.

Reference Books:

B.A. Dubrovin, A.T. Fomenko, S. P. Novikov, Modern Geometry- Methods and Applications (Part1), 2nd edition, GTM 93, Springer.

Course Number	MA6211 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Advanced complex analysis
Learning Mode	Lectures
Learning Objectives	Same as learning outcome
Course Description	This is an advanced course on complex analysis. In this course we will study some global properties of analytic functions and discuss some important examples of meromorphic functions.
Course Content	Conformal mappings, the Maximum principle of analytic functions; a general form of Cauchy's theorem, Harmonic functions; Mean-value property, Schwarz's reflection principle, Weierstrass factorization theorem, The Gamma function, Stirling's formula; Hadamard's theorem, Normal families, The Riemann mapping theorem, Harnack's principle, The Dirichlet problem, Elliptic functions and their properties, the Weierstrass-**P** function, global properties of analytic functions; analytic continuation, Picard's theorem.
Learning Outcome	At the end of this course, students should be able to: - compute factorization of a general analytic function (which may have infinitely many factors). - Understand important properties of some special complex analytic functions, which find their application in analytic number theory and geometry.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Complex Variables and Applications: James Ward Brown and Ruel V. Churchill, 8th Edition, McGraw Hills.
2. Complex Analysis: Lars V Ahlfors, McGraw Hill Education; Third edition (July 2017)
3. Complex Analysis: Elias M. Stein and Rami Shakarchi, Princeton University Press (23 May 2003)

Reference Books:

1. Joseph L. Taylor, Complex Variables - American Mathematical Society, 2011.
2. Edward C. Titchmarsh, The Theory of Functions, Oxford University Press; 2 edition, 1976.

Course Number	MA6212 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Algebraic Coding Theory
Learning Mode	Lectures
Learning Objectives	Readers of this course will be well-equipped with the application of the basics of mathematics, specially, Algebra, Number Theory and Probability Theory in Information Theory.
Course Description	It gives a foundation for further studies in information communications. This course includes different codes such as binary codes, Hamming codes, linear codes (cyclic codes in detail), and nonlinear codes, with different bounds by using mathematical tools, which are essential to understand an information communication system.
Course Content	Polynomial rings over fields, Extension of fields, Computation in GF(q), n-th roots of unity, Vector space over finite fields. Error Detection, correction and decoding. Linear block codes: Hamming weight, Generator and Parity-check matrix Encoding and Decoding of linear codes, Bounds: Sphere-covering bound, Gilbert-Varshamov bound, Hamming bound, Singleton bound, Plotkin bound. Hamming codes, Simplex codes, Golay codes, First and Second order Reed-Muller codes. Nonlinear codes: Hadamard codes, Preparata codes, Kerdock codes, Nordstorm-Robinson code, Weight distribution of codes. The structure of cyclic codes, Roots of Cyclic Codes, Decoding of cyclic codes, Burst-error-correcting codes, Constacyclic and quasi-cyclic codes, skew cyclic codes, Quadratic residue codes, BCH codes, RS codes, GRS codes. Generalized BCH codes. Self-dual codes and invariant theory, Covering radius problem, Convolutional codes, LDPC codes, Turbo codes.
Learning Outcome	On successful completion of the course, students should be able to: 1. Understand the primary information communication circuits; 2. Able to understand the importance of better codes in communication channels; 3. Help to develop some MDS, and better new codes using the concept of number theory and algebra; 4. Capable of analyzing the capacity of a code based on studied bounds and results.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Raymond Hill, A First Course in Coding Theory (Oxford Applied Mathematics and Computing Science Series), Clarendon Press, 1986.
2. Ron Roth, Introduction to Coding Theory, Cambridge University Press, 2006.

Reference Books:

1. J. H. van Lint, Introduction to Coding Theory, Springer, 1999.
2. M. Shi, A. Alahmadi and P. Sole, Codes and Rings: Theory and Practice. Netherlands: Elsevier Science, 2017.
3. San Ling and Chaoping Xing, Coding Theory: A First Course. Cambridge University Press, 2004.

Course Number	MA5203 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Discrete Mathematics
Learning Mode	Lectures
Learning Objectives	To learn formal mathematical way of writing through mathematical logic and different counting techniques through examples
Course Description	This course is meant to introduce different counting techniques. It also covers introductory graph theory and Boolean algebra.
Course Outline	Mathematical Logic and Proofs: Propositional logic and equivalences, Predicate and Quantifiers, Introduction to Proofs, Proof methods Sets, Relations and Functions: Relations and their properties, Closure of Relations, Order Relations, Equivalence relations, POSets, Mobius function of POSets, Lattices, Distributive lattices. Counting Techniques: Permutations and Combinations, Binomial coefficients, Pigeonhole principle, Double counting, Principle of Inclusion-Exclusion, Recurrence relations and its solution, Divide and Conquer, Generating functions. Graph Theory: Basic definitions, Trees, Connectivity, Spanning trees, Shortest Path Problems, Eulerian and Hamiltonian graphs, Planar graphs, Graph Coloring Boolean Algebra: Boolean functions, Logic gates, Simplification of Boolean Functions, Boolean Circuits
Learning Outcome	Students will be accustomed with the formal mathematical way of writing. They will also be able to apply counting techniques to different problems. Using graph theory, they will be able to model different real-life problems as well.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Discrete Mathematics and Its Applications by K. H. Rosen, Tata McGraw-Hill
2. Basic Techniques of Combinatorial Theory by D. I. A. Cohen, John Wiley & Sons
3. Introduction to Graph Theory by D. B. West, Pearson Prentice Hall

Reference Books:

1. A Walk Through Combinatorics by Miklos Bona, 4th Edition, World Scientific
2. Invitation to Discrete Mathematics by J. Matousek and J. Nesetril, Oxford University Press

Course Number	MA6213 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Finite Element Analysis
Learning Mode	Lectures
Learning Objectives	In this subject, the students will be trained with the knowledge of mathematical analysis for Finite Element and corresponding computational techniques for solving ODE/PDEs by this approach.
Course Description	Finite Element Analysis is an interdisciplinary subject, focuses on relations between fundamentals of Mathematics and numerical approaches for solving PDEs arising in Engineering modeling.
Course Content	Introduction to Integrable functions and Sobolev Spaces, Piecewise linear basis functions, Polynomial approximations and interpolation errors. Poincare inequality. Variational formulation for elliptic boundary value problems in one and two dimensions. Galerkin orthogonality, Cea's Lemma. Construction of finite element spaces and triangular finite elements. Aubin-Nitsche duality argument; non-conforming elements; computation of finite element solutions and their convergence analysis. Parabolic initial and boundary value problems: Semi-discrete and fully discrete (forward and backward Euler in time) schemes, Convergence analysis. Stiffness matrix. Algorithms and computational experiments by MATLAB.
Learning Outcome	On successful completion of the course, students should be able to: 1. Know the basic parts of finite element approach 2. Error and convergence analysis of the finite element method mathematically 3. Write algorithms for solving one and two dimensional ODE/PDEs by using finite element approach 4. Know on how to solve applied models by using finite element approach
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. E. Suli and D. F. Mayers, An Introduction to Numerical Analysis, Cambridge Univ. Press, 2003.
2. S. C. Brenner and R. Scott, The Mathematical Theory of Finite Element Methods, Springer, 2008.
3. E. Suli, Lecture Notes on Finite Element Methods for Partial Differential Equations, University of Oxford, 2020.

Reference Books:

1. C. Johnson, Numerical solutions of Partial Differential Equations by Finite Element Methods, Cambridge Univ. Press, 2009.
2. Philippe G. Ciarlet, The Finite Element Method for Elliptic Problems, SIAM, 2002

Course Number	MA6214 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Introduction to Algebraic Geometry
Learning Mode	Lectures
Learning Objectives	To expose students with the theoretical aspects of curves and prepare a foundation for learning algebraic geometry.
Course Description	This course covers the classical theory of algebraic curves from the point of view of algebraic geometry.
Course Content	Review of ideals and modules, operations with ideals, quotient modules and exact sequences, free modules, Affine space and algebraic sets, ideal of a set of points, The Hilbert basis theorem, irreducible components of algebraic sets, Affine Varieties, Hilbert's Nullstellensatz, coordinate rings, polynomial maps, coordinate changes, rational functions and local rings, local properties of plane curves, tangent lines, intersection number, Divisors on Curves, Degree of a principal divisor, Projective algebraic varieties, projective plane curves, linear systems, Bezout's theorem, Max Noether's fundamental theorem, Zariski topology, varieties, morphism of varieties, rational maps,
Learning Outcome	Students will learn the basic ideas of algebraic geometry such as coordinate ring, function field, affine and projective varieties etc. They will be prepared to take an advance course on algebraic geometry.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Willima Fulton : Algebraic Curves, An Introduction to Algebraic Geometry, Addison-Wesley Publishing Company, Advanced Book Program, 1989
2. S S Abhyankar: Algebraic Geometry For Scientists And Engineers, AMS, 1990
3. David Eisenbud : Commutative Algebra with a view towards Algebraic Geometry, Springer-Verlag New York (1995).

Reference Books:

1. Justin R Smith: Introduction to Algebraic Geometry, Createspace Independent Pub, Dover reprint, 2014
2. M F Atiyah & I G MacDonald, Introduction to Commutative Algebra, Addison Wesley Publishing Company, 1994

Course Number	MA6215 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Operators on Hilbert Spaces
Learning Mode	Lectures
Learning Objectives	The objective of the course is to train student about the properties of operators on Hilbert Spaces.
Course Description	The course is intended to discuss about important mathematical properties of linear transformations between Hilbert spaces to enable students to solve functional equations.
Course Outline	Adjoints of bounded operators on a Hilbert space, Normal, self-adjoint and unitary operators, their spectra and numerical ranges. Compact operators on Hilbert spaces, Spectral theorem for compact self-adjoint operators, Application to Sturm-Liouville Problems.
Learning Outcome	After finishing the course, students will acquire the ability to recognize the fundamental properties of Hilbert spaces and transformations between them.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. J. B. Conway, A Course in Functional Analysis, 2nd ed., Springer, Berlin, 1990.
2. C. Goffman and G. Pedrick, First Course in Functional Analysis, Prentice Hall, 1974.
3. I. Gohberg and S. Goldberg, Basic Operator Theory, Birkhauser, 1981.
4. E. Kreyzig, Introduction to Functional Analysis with Applications, John Wiley & Sons, New York, 1978.
5. B. V. Limaye, Functional Analysis, 2nd ed., New Age International, New Delhi, 1996.
6. M. T. Nair, Functional Analysis: A First Course, PHI Pvt. Ltd, 2004.

Course Number	MA6216 (DE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Riemannian Geometry
Learning Mode	Lectures
Learning Objectives	Same as Learning outcome
Course Description	It is a basic introduction to the theory of Riemannian manifolds. This course is fundamental for understanding Einstein theory of General relativity.
Course Content	Riemannian manifolds, Levi-Civita connection, Geodesics; minimising properties of geodesics, Hopf-Rinow theorem, Curvature; sectional curvature, Ricci curvature, scalar curvature, tensors, Jacobi fields, first and second fundamental forms, Hadamard theorem, fundamental group of manifolds of negative curvature, cut locus, injectivity radius, The Sphere theorem.
Learning Outcome	At the end of this course, students should be able to: -compute the curvature of several important examples of Riemannian manifolds of higher dimension. -compute the geodesics on a given Riemannian manifold.
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. Manfredo P. do Carmo, Riemannian Geometry, Birkhauser (1992)
2. Peter Petersen, Riemannian Geometry, GTM, vol-171, 2nd edition, Springer (2006)

Reference Books:

1. S. Kumaresan, Riemannian Geometry-concepts, examples, and techniques, Techno world (2020)
2. Barrett O. Neill, Semi-Riemannian Geometry with applications to relativity, Academic Press (1983)

Interdisciplinary Elective (IDE) Course for M. Sc. (Available to students other than Maths)

Sl. No.	Subject Code	IDE - I	L	T	P	C
1.	MA6109	Mathematical Modeling	3	0	0	3

Course Number	MA6109 (IDE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Mathematical Modeling
Learning Mode	Lectures
Learning Objectives	To understand the importance of mathematics as tool in different areas. To understand the relation of physical world and its corresponding representation into mathematical terms. To understand systematic process of modeling a system. To expose students to the differential equations and their qualitative behavior and application in mathematical modeling. To learn through some of the examples of mathematical models in different areas.
Course Description	This course is meant to expose the candidate to basic philosophy of mathematical modeling and then apply it to various systems and analyse these models.
Course Content	Stability of scaler nonlinear differential equations; Linear and nonlinear stability of system of differential equations; Lyapunov Stability, Examples. Introduction to modeling; Elementary mathematical models and General modeling ideas; General utility of Mathematical models, Role of mathematics in problem solving; Concepts of mathematical modeling; System approach; formulation, Analyses of models; Pitfalls in modeling. Illustrations of models with their analysis in Population dynamics, Traffic Flow, Social interactions, Viral infections, Epidemics, Finance, Economics, Management, etc. (The choice and nature of models selected may be changed with mutual interest of lecturer and students.) Introduction to probabilistic models and their analysis. Introduction to stochastic differential equations and application in modeling.
Learning Outcome	Students will be able to apply the mathematical knowledge on a physical system and obtain a mathematical model, analyse it and interpret it in terms of the physical world
Assessment Method	Quiz /Assignment/ Project / MSE / ESE

Text Books:

1. D. N. P. Murthy, N. W. Page, Ervin Y. Rodin, Mathematical modelling: a tool for problem solving in engineering, physical, biological, and social sciences, Pergamon Press, 1990.
2. W. E. Boyce and R.C. DiPrima, Elementary Equations and Boundary Value Problems, 7th Edition, Wiley, 2001.

Reference Books:

1. J. D. Murray, Mathematical Biology, Vol I, 3rd Ed, Springer, 2003.
2. Wei-Bin Zhang, Differential equations, bifurcations, and chaos in economics, Series on Advances in Mathematics for Applied Sciences, Vol 68, World Scientific, 2005.
3. M. Kot, Elements of Mathematical Ecology, Cambridge University Press, 2012.

Sl. No.	**Subject Code**	**IDE - II**	**L**	**T**	**P**	**C**
1.	MA6218	Matrix Computation	3	0	0	3

Course Number	MA6218 (IDE)
Course Credit (L-T-P-C)	3-0-0-3
Course Title	Matrix Computation
Learning Mode	Lectures
Learning Objectives	The major objective of this course is to answer the fundamental question of choice of suitable matrix computation method for solving a system of linear equations. The students will also explore the parallel implementation of the various methods discussed.
Course Description	This course provides the knowledge of various numerical techniques to solve linear equations, implementation of these methods, the architecture of parallel computers. The course also provides information to gain proficiency in utilizing MPI, OpenMP and HPC kernels for efficient computation.
Course Outline	Introduction to Direct Methods: Direct Methods for solving linear systems and Application to BVP, Discritization of PDE's. (06 Lectures) Sparse Matrices: Introduction to sparse matrices, Storage Schemes, Permutations and Reorderings, Sparse Direct Solution Methods.(06 Lectures) Basic iterative methods: Iterative method for solving linear systems: Jacobi, Gauss – Seidel and SOR and their convergence, projection method: general projection method, steepest descent, MR Iteration, RNSD method (6 Lectures) Krylov subspace methods: Introduction to Krylov subspace, Arnoldi's method, GMRES method, Conjugate gradient algorithm, Lanczos Algorithm, Block KrylovMethods (6 Lectures) Preconditioners: Introduction to preconditioners, ILU preconditioner,preconditioned CG. (6 Lectures) Parallel implementation: Architecture of parallel computers, introduction to MPI &openMP, HPC kernels (BLAS, multicore and GPU computing)(6 Lectures) Introduction to domain decomposition and multigrid methods (6 Lectures)
Learning Outcome	Upon completion of this course, the students should be able to 1. Apply various Matrix factorization methods to solve system of linear equations 2. Understand different storage schemes and pick the right one for efficient computation.
Assessment Method	Quiz /Assignment/ MSE / ESE

Text Books:

1. Yousef Saad; Iterative Methods for Sparse Linear Systems; SIAM 2003
2. C.W. Ueberrhuber; Numerical Computation : Methods, Software and Analysis; Springer-Verlag, Berlin, 1997.
3. P. Wesseling; An Introduction to Multigrid Methods; John Wiley & Sons 1992.
4. A. Grama, A. Gupta, G. Karypis, V Kumar; Introduction to Parallel Computing; Pearson Education Limited 2003