

**Department of Mathematics**  
**Curriculum and Syllabi for M.Sc. in Mathematics**  
*With effect from 2019 entry batch*

**PO Statements:**

1. Inculcate critical thinking and comprehensive problem solving ability to carry out scientific investigation, without being biased with preconceived notions.
2. Students should be able to analyze the problems, formulate and hypothesis, evaluate and validate results, and draw reasonable conclusions thereof.
3. Graduates should be able to update their advanced knowledge on topics in pure and applied mathematics.
4. Graduates of the program will develop the knowledge of a wide range of mathematical techniques and application of mathematical methods/tools in scientific and engineering domains.
5. Enhancing ability to write and present their creative skills and innovative thinking through assignments and project works.
6. Enabling graduate students to pursue the research or careers in industry in mathematical sciences and allied fields.

**Course Structure**

**Semester I**

S.N.	Code	Subject	L	T	P	Credits
1	MA 5101	Real Analysis	3	1	0	4
2	MA 5102	Linear Algebra	3	1	0	4
3	MA 5103	Mathematical Methods	3	1	0	4
4	MA 5104	Classical Mechanics	3	1	0	4
5	MA 5105	Computer Programming & Data Structures	3	0	2	4
6	EAA	Extra Academic Activities (Yoga)	0	0	2	0
<b>Total contact hours/credits</b>			<b>15</b>	<b>4</b>	<b>4</b>	<b>20</b>

**Semester II**

S.N.	Code	Subject	L	T	P	Credits
1	MA 5116	Abstract Algebra	3	0	0	3
2	MA 5117	Ordinary Differential Equations	3	1	0	4
3	MA 5118	Topology	3	0	0	3
4	MA 5119	Probability and Statistics	3	0	0	3
5	MA 5120	Complex Analysis	3	1	0	4
<b>Total contact hours/credits</b>			<b>15</b>	<b>2</b>	<b>0</b>	<b>17</b>

**Semester III**

S.N.	Code	Subject	L	T	P	Credits
1	MA 6101	Functional Analysis	3	1	0	4
2	MA 6102	Partial Differential Equations	3	1	0	4
3	MA 6103	Optimization Techniques	3	1	0	4
4	MA 6104	Numerical Analysis	3	0	2	4
5	MA 6105	Seminar	0	0	2	1
<b>Total contact hours/credits</b>			<b>12</b>	<b>3</b>	<b>4</b>	<b>17</b>

**Semester IV**

S.N.	Code	Subject	L	T	P	Credits
1	MA 6116	Discrete Mathematical Structure	3	0	0	3
2	MA 61XX	Elective	3	0	0	3
3	MA 6199	Project & Dissertation	-	-	-	10
<b>Total contact hours/credits</b>			<b>6</b>	<b>0</b>	<b>0</b>	<b>16</b>

**List of Elective Courses**

S.N.	Code	Subject	<i>Prerequisites, if any</i>
1.	MA 6131	Fluid Dynamics	-
2.	MA 6132	Rings and Modules	MA1516
3.	MA 6133	Measure Theory and Integration	MA1501
4.	MA 6134	Mathematical Modelling	MA 1517, MA1602
5.	MA 6135	Fuzzy Sets Theory	-
6.	MA 6136	Graph Theory and Applications	-
7.	MA 6137	Modelling and Simulation	MA1519
8.	MA 6138	Advanced Operations Research	MA1519
9.	MA 6139	Computational Fluid Dynamics	MA1604
10.	MA 6140	Fuzzy Sets, Fuzzy Logic and Applications	-
11.	MA 6141	Soft Computing Techniques	MA1505, MA1603
12.	MA 6142	Spectral element method	MA1601, MA1604
13.	MA 6143	Finite Element Method	MA1601, MA1604

## Detailed Syllabi

<b>MA 5101</b>	<b>Real Analysis</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. First Semester (Core)	3	1	0	4

**Real number system:** Ordered sets, Real field, Completeness property, Archimedean property, Denseness of rational and irrationals, Countable and uncountable sets.

**Metric Spaces:** Open sets, Closed sets, Compact sets, Perfect sets, Connected sets, Baire's Category theorem.

**Numerical sequences and Series:** Sequences, Series, Power series, Absolute convergence, Rearrangements.

**Continuity:** Limits of functions, Continuous functions, Continuity and compactness, Continuity and connectedness, Discontinuities, Monotonic functions.

**Differentiation:** Derivative of a real function, Mean Value Theorems, Continuity of Derivatives, L'Hospital's Rule, Taylor's Theorem.

**Riemann-Stieltjes Integral:** Definition and existence of the Integral, Properties of the integral, Differentiation and Integration.

**Sequences and Series of functions:** Uniform convergence, Uniform convergence and continuity, Uniform convergence and integration, Uniform convergence and differentiation. Equicontinuity, Ascoli's Theorem.

**Functions of several variables:** Differentiation, Inverse and Implicit function theorems.

### **Text Books/ References:**

1. Rudin, W.: Principles of Mathematical Analysis, 3<sup>rd</sup> Ed., Tata McGraw Hill, 1976.
2. Carothers, N. L.: Real analysis, Cambridge University Press, 2000.
3. Apostol, T.M.: Mathematical Analysis, 2<sup>nd</sup> Ed., Narosa Book Distributors Pvt. Ltd., 2002.
4. Tao, T.: Analysis I, Vol.1, Hindustan Book Agency, 2006.
5. Tao, T.: Analysis II, Vol. 2, Hindustan Book Agency, 2006.

### **COs:**

1. Covers theoretical needs of Measure Theory and Integration, Functional Analysis, Differential equations and other branches of Mathematics.
2. Understands the concepts of Continuity, Differentiability, Integration, Sequences and Series of functions, etc.
3. Learns the applications of the concepts of Sequences and Series of functions to the problems arising in ODEs and PDEs, Functional Analysis, Fourier analysis, etc.
4. Learns to use the concepts of Metric spaces in order to understand some concepts in Complex Analysis, Functional Analysis and other branches of Mathematics.
5. Understands the concepts of Inverse and Implicit function theorems and their applications.

<b>MA 5102</b>	<b>Linear Algebra</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. First Semester (Core)	3	1	0	4

Vector spaces, Subspaces, Linear sum & Direct sum of subspaces, Quotient space, Basis & Dimension, Ordered basis & Coordinates.

Linear transformations, Algebra of linear transformations, Isomorphism, Rank & Nullity of a linear transformation, Singular, Non-singular & Invertible linear transformations / operators.

Matrix of a Linear transformation/Linear operator, Change of basis, Rank & nullity of a Matrix, Similar Matrices, System of linear equations & their consistency, Eigen values and Eigen vectors of a Linear operator/ Square matrix, Algebraic & Geometric Multiplicity of Eigen values, Cayley-Hamilton theorem, Diagonalizability, Minimal polynomial.

Linear functional and Dual space, Dual basis, Second dual space, Annihilators, Transpose of a linear Transformation.

Invariant subspaces, Direct sum decomposition, Invariant direct sums, and Primary decomposition theorem. Bilinear forms and its matrix representation, Quadratic forms, Hermitian forms, Cyclic subspaces, Cyclic decomposition, Rational forms & Jordan canonical forms.

Inner product spaces, Orthonormal basis, Gram-Schmidt Orthogonalization process, Adjoint operators, Orthogonal and Unitary operators / matrices, Normal operator.

#### **Text Books/ References:**

1. Hoffman, K. and Kunze, R: Linear Algebra, Prentice Hall of India, 2005.
2. Artin, M.: Algebra, Prentice Hall of India, 2005.
3. Herstein, I.N.: Topics in Algebra, John-Wiley, 1999.
4. Halmos, P.R.: Finite Dimensional Vector Spaces, Springer Verlag, New York, 1987.
5. Lipschutz, S.: Theory and Problems of Linear Algebra, McGraw Hill, New York, 1991.
6. Singh, S.: Linear Algebra, Vikas Publishing House, 1998.
7. Strang, G.: Linear Algebra and Its applications, Nelson Engineering, 4th Edition, 2007.

#### **COs:**

1. Use of axioms for abstract vector spaces to discuss examples of real /abstract vector spaces and subspaces, and also the existence of a basis of any vector space.
2. Interpret existence and uniqueness of solutions and also solve systems of linear algebraic equations using Gauss-elimination method reducing to echelon form.
3. Understand the relationship between a linear transformation and its matrix representation and also the kernel and image of a linear transformation in terms of nullity and rank of the matrix.
4. Use Eigen spaces of matrices to diagonalize a matrix, explain the significance of eigenvectors and eigenvalues and also use eigenvectors to represent a linear transformation with respect to a particularly nice basis.
5. Accustomed with the Gram-Schmidt orthogonalization process and various types of linear operators and also have an insight into the amicability of Linear Algebra concepts to model, solve, and analyse real-world situations.

<b>MA 5103</b>	<b>Mathematical Methods</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. First Semester (Core)	3	1	0	4

**Integral Transforms:** Laplace Transform, Laplace Transform & Inverse Laplace transform with application to the solution of differential equations.

**Fourier Transform:** Fourier Integral Transform, Application of Fourier Transform to ordinary and partial differential equations in initial and boundary value problems.

**Z-transform:** Definition and properties, Z-transform of some standard functions, initial and final value theorems, convolution theorem, Inverse Z-transforms and applications.

**Linear Integral Equations:** Linear integral equation of the first and second kind of Fredholm and Volterra type, Solutions with separable kernels, Characteristic numbers and Eigen functions, resolvent kernel.

**Calculus of Variation:** Variation of a functional, Euler-Lagrange equation, Necessary and sufficient conditions for extrema, Direct method in variational problems, Rayleigh -Ritz method.

**Text Books/ References:**

1. Poularikas, A. D.: The Laplace Transforms and Applications, CRC Press, 1996.
2. Hildebrand, F.B.: Methods of Applied Mathematics, Dover publication, 1972.
3. Krasnov, M.L., Makarenko, G.I. and Kiselev, A.I.: Problems and Exercises in Calculus of Variations, Mir Publishers, 1975.
4. Kanwal, R.P.: Linear Integral Equations, Academic Press, New York, 1998.
5. Kanwal, R.P. and Sneddon, I.N.: Fourier Transforms, Dover publication, 2010.
6. Gupta, A.S.: Calculus of variation with applications, Prentice Hall of India, 2004.
7. Spiegel, M.R.: Theory and Problems of Laplace transforms, Schaum's series, 2011.
8. Bender, C. M. and Orszag, S. A.: Advanced Mathematical Methods for Scientists and Engineers, McGraw-Hill, 1978.
9. Raisinghania, M. D.: Integral equations and boundary value problems, S. Chand Company Ltd., 2007.

**COs:**

1. Familiar with the basic concepts of Laplace transforms, Fourier transforms, Fourier sine and cosine transforms and Z-transforms.
2. Ability to solve initial value problems using Laplace transform.
3. Capability to solve boundary value problems using Fourier transform.
4. Ability to solve difference equations with initial conditions using Z-transforms.
5. Potentiality to solve certain linear integral equations and variation of functional problems.

<b>MA 5104</b>	<b>Classical Mechanics</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. First Semester (Core)	3	1	0	4

**Rigid Body Mechanics:** Two-dimensional motion of rigid bodies, equations of motion referred to rotating axes, Euler's dynamical equation of motion, Motion of a rigid body about an axis, theory of small oscillation.

**Space Mechanics:** Equation of motion of a particle moving in space, path of a particle moving in space, acceleration of a particle in terms of polar coordinates and cylindrical coordinates,

**Continuum Mechanics:** Molecular diffusion, conservation of mass, material derivatives, equation of continuity, motion, principle of angular momentum, conservation of energy.

**Mechanics of Deformation:** External forces and internal forces, stress, strain, principal stresses & strains, relation between stress and strain, deformation, stress components, strain components, stress invariant, strain invariant, body force, gravity force, initial stress, incremental stress and incremental strain, equilibrium equations for the stress field in two dimensions and three dimensions.

**Lagrangian Mechanics:** Generalized coordinates, constraints of motion, degrees of freedom, holonomic system, principle of virtual work, generalized force, Lagrange's equations from D'Alembert's principle, compound pendulum, spherical pendulum.

**Hamiltonian Mechanics:** Elements of calculus of variations, Euler-Lagrange's equation, generalized momentum, conjugate momentum, Hamilton's canonical equations of motion, Hamilton's principle and principle of least action, Poisson's Brackets, Hamilton-Jacobi theory.

**Text Books/ References:**

1. Goldstein, H., Poole, C., and Safko, J.: Classical Mechanics, Pearson Education, 2008.
2. Corben, H. C. and Stehle, P.: Classical Mechanics, 2<sup>nd</sup> Ed., Dover Publications, 1977.
3. Malvern, L.E: Introduction to the Mechanics of a Continuous Medium, Prentice Hall, 1977.
4. Loney, S.L.: Dynamics of a Particle, Macmillan India Ltd., 1972.
5. Rana, N. C. and Joag, P.S.: Classical Mechanics, Tata McGraw-Hill, 1991.
6. Biot, M.A.: Mechanics of Incremental Deformation, John Wiley & Sons. Inc., 1965.

**COs:**

1. Have a deep understanding of Newton's laws.
2. Be able to solve the Newton equations for simple configurations using various methods.
3. Learn how to represent the equations of motion for complicated mechanical systems using the Lagrangian and Hamiltonian formulations of classical mechanics.
4. Be familiar with topics of current interest in classical mechanics.
5. Have made progress on a research project in the areas of mechanics.

<b>MA 5105</b>	<b>Computer Programming and Data Structure</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
M.Sc. First Semester (Core)		3	0	2	4

**Computer Programming in C/C++:** Control statement and Loops, Functions, Arrays, Subroutines, Character Strings, Structures, Pointer data type and its applications.

**Data Structure:** Introduction to data types, Data structures, linear and Multi-dimensional Arrays, Pointers, Linked Lists, Stacks, Queues, Complexity algorithms, Singly linked lists, Doubled linked lists, Circular linked lists, Application of Linked Lists, Introduction to complexity of algorithm, Non-linear data Structure, Graphs, Various representation of graphs, Trees: binary trees, red-black trees, AVL tree, B tree, B+ tree, Spanning tree.

**Shorting Algorithms:** Bubble sort, Selection sort, Insertion sort, Shell sort, Quick sort, Heap sort, Radix sort, Searching Algorithms: Linear Search, Binary Search, Hashing.

#### **Text Books/ References:**

1. Balagurusamy, E.: Programming In ANSI C, McGraw Hill Education, 7<sup>th</sup> Edition, 2016.
2. Hubbard, J.R.: Schaum's Outline of Programming with C++, The McGraw Hill company Inc., 2<sup>nd</sup> edition, 2000.
3. Kernighan, B. W. and Ritchie, D.M.: The C Programming Language, Pearson, 2<sup>nd</sup> edition, 2015.
4. Tremblay, J.P. and Sorenson, P.: An Introduction to Data Structures with Applications, McGraw Hill, 1985.
5. Horowitz, E. and Sahni, S.: Fundamentals of data structures, Galgotia Publications, 2008.
6. Stroustrup, B.: The C++ Programming Language, Kindle Edition, 4<sup>th</sup> Edition, 2013.
7. Kanetkar, Y.: Understanding Pointers in C & C++, 5<sup>th</sup> edition, BPB Publications, 2018.
8. Sinha, P.K.: Computer Fundamentals concept, 6<sup>th</sup> edition, BPB Publication, 2003.
9. Kernighan, B.W. and Ritchie, D.M.: The C Programming language, Pearson Education, 2015.
10. Kanetkar, Y., Let us C, 3rd edition, BPB Publication, 2007.
11. Padmanabham, P., C & Data structures, B.S. Publications, 2012.

#### **COs:**

1. Ability to write computer programme independently for a specified objective.
2. Skill to identify the problems on linear and non-linear data structure and applying different approaches to solve them.
3. Articulate the need to develop algorithms and designing programme by using sophisticated programming skills.
4. Capability to handle different shorting algorithms.
5. Apply various sorting, searching and hashing techniques and their performance comparison.

<b>MA 5116</b>	<b>Abstract Algebra</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Second Semester (Core)	3	0	0	3

**Group:** Groups, Subgroups, Normal subgroups, Quotient groups, Homomorphism & Homomorphism theorems, Cyclic groups, Permutation groups, Cayley's theorem, Class equation, Sylow's theorem & their applications.

**Series of Subgroups:** Subnormal & Normal series of subgroups, Composition series, Butterfly theorem, Jordan-Holder theorem, Derived Series, Solvable group, Direct product(sum) of a finite set of groups & their simple properties, Decomposition theorem, Chain conditions, Artinian and Noetherian groups.

**Rings, Ideals and Fields:** Rings, Ideals, Prime, Principle & maximal Ideals, Quotient Rings, Ring Homomorphism, Principal ideal domains, Euclidean Rings and Euclidean domains, Unique Factorization Domain, Field Extensions, Degree of extension, Algebraic, Transcendental, Separable and Normal extension of a field, Galoi's Field.

**Partially Ordered Algebraic Systems:** Partially ordered sets (Posets), Lattices, Complete Modular, Distributive and Boolean Lattices and their simple properties, Pogroups, Subgroups & Factor groups of Pogroup, Homomorphism & Isomorphism of Pogroup.

**Text Books/ References:**

1. Fuchs, L.: Partially Ordered Algebraic Systems, Dover Publication, Inc., 2011
2. Singh, S. and Zameeruddin, Q.: Modern Algebra, Vikas Publishing, 2006.
3. Gratzner, G.: Genral Lattice Theory, Academic Press, 1978.
4. Gallian, J. A.: Contemporary Abstract Algebra, Narosa Publisihng House, 1998.
5. Khanna, V. K. and Bhambri, S. K.: A course in Abstract Algebra, Vikas Publishing, 2017.
6. Hall, M.: The Theory of Groups, The Macmillan Co., New York, 1959.
7. Herstein, I.N.: Topics in Algebra, New Age International Publishers, 2006.

**COs:**

1. Students will have a working knowledge of important mathematical concepts in abstract algebra such as group, subgroup, normal groups, quotients groups and permutation groups.
2. Understand the concepts of Sylow's theorem and their applications.
3. Demonstrate the concepts of Subnormal & Normal series of subgroups, Jordan-Holder theorem.
4. Provide information on ideals and Quotient rings, Field of Quotient of an integral domain, Extension fields and Roots of polynomials.
5. Provide information on Posets and different types of lattices.

<b>MA 5117</b>	<b>Ordinary Differential Equations</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Second Semester (Core)	3	1	0	4

**First order ODEs:** Initial value problems (IVPs), Successive Approximation, Existence and Uniqueness of solutions of IVPs for first order ODEs, Picard's theorem, Peano's Existence theorem, Continuation and Dependence on Initial Conditions, Existence of solutions in the large interval, Singularities of ODEs, Ordinary and Singular Points, Series Solutions, Power Series solution, Frobenius method, Solutions of Legendre, Bessel, Hypergeometric equations.

**Higher order ODEs:** Linear dependence and Wronskian, Solution of Homogeneous and Non-homogeneous linear ODEs with constant and variable coefficients, Variation of parameters, Systems of first order ODEs. Oscillations of Second order equations, Fundamental results, Strum's Comparison theorem, Elementary Linear Oscillations, Comparison theorem of Hille-Wintner.

**Boundary Value Problems:** Basic definitions, Orthogonal and Orthonormal set of Functions, Gram-Schmidt process of Ortho-normalization, Self adjoint eigenvalue problems, Strum-Liouville problem, Green's functions.

**Stability Theory:** Basic definitions, Elementary critical points, Critical points of nonlinear systems, Linear systems with constant coefficients, Stability of quasi-linear systems, autonomous systems, Lyapunov function.

**Text Books/References:**

1. Coddington, E.A.: An introduction to Ordinary Differential Equations, Prentice Hall of India, New Delhi, 1991.
2. Deo, S.G. Lakshmikantham Y. and Raghavendra, V.: Text Book of Ordinary Differential Equation, 2<sup>nd</sup> Edition, Tata McGraw-Hill, New Delhi, 1997.
3. Simmons G.F. and Robertson, J.S.: Differential Equations with Applications and Historical Notes, 2<sup>nd</sup> Edition, Tata McGraw-Hill, 2003.
4. Ross, S.L.: Differential Equations, 3<sup>rd</sup> Edition, Wiley, 2007.
5. Rao, M.R.: Ordinary Differential Equations: Theory and Applications. Affiliated East-West Press Private Limited, New Delhi, 1980.
6. Birkhoff, G. and Rota, G.C.: Ordinary Differential Equations, 4<sup>th</sup> Edition, John-Wiley & Sons, 1989.

**COs:**

1. Identify the initial and boundary value problems.
2. Use the existence theorem for initial value problems to determine uniqueness of solutions.
3. Determine the power series solutions about ordinary and singular points.
4. Illustrate the complete solution of a differential equation with constant coefficients by variation of parameters.
5. Expand the knowledge to find the stability criteria whenever solution is difficult to find it.
6. Understand and solve the Strum-Liouville and Green's function problems.

<b>MA 5118</b>	<b>Topology</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Second Semester (Core)	3	0	0	3

Topological spaces, open sets, closed sets, basis for a topology, sub-basis, order topology, product topology, subspace topology, limit point, continuous function, Homeomorphism, Metric space and its topology, Quotient topology, Nets, Topology and convergence of nets.

Connected spaces, Connected subspaces of the real line, Components and local connectedness, Compact spaces, Heine-Borel Theorem, Local -compactness.

Countability axioms, separation axioms, regular and normal spaces, Urysohn's Lemma, Urysohn Metrization Theorem, Tietze Extension Theorem, Tychonoff Theorem, Completely regular spaces, Stone -Czech compactification.

**Text Books/ References:**

1. Munkres, J.R.: Topology, 2nd Ed., Pearson Education India, 2001.
2. Joshi, K.D.: Introduction to General Topology, New Age International, New Delhi, 2000.
3. Kelley, J.L.: General Topology, Van Nostrand, 1955.
4. Simmons, G.F.: Introduction to Topology and modern Analysis, International Student ed., 1963.
5. Willard, S.: General Topology, Addison Wesley, Reading Mass., 1970.
6. Lipschutz, S.: Theory and problems of General Topology, McGraw-Hill, 1965.

**COs:**

1. Abstract reasoning of topological spaces and continuity along with their properties.
2. Understanding concepts like subspace, product and quotient topologies and how their definitions are related to continuous functions, connection between metric spaces and topological spaces.
3. To work with various notions of compactness and know the relations with other topological and metric properties, and be familiar with various compactification constructions.
4. Knowledge of countability and separation properties of a topological space.

<b>MA 5119</b>	<b>Probability and Statistics</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Second Semester (Core)	3	0	0	3

**Introduction:** Review on basic concepts of probability, conditional probability and Bayes' theorem, Central Limit theorem, Random variable (both discrete and continuous), Probability distribution, Mathematical expectation (including sum and product), Moment generating function (MGF), Special Probability Distributions: Binomial, Normal, Chi-square, Student's *t*, Poisson, Hyper-geometric, Beta, Gamma, Exponential with their simple properties and applications, Moments from MGF.

**Bivariate Random Variable:** Joint, Marginal and Conditional probability distributions with applications.

**Correlation and Regression:** Basic concept of correlation and regression, linear regression, method of least square, Correlation and regression analysis (with mathematical derivation) and applications in each case, multiple linear regression.

**Sampling Distribution:** Basic definitions, Sampling distribution of means, Variance and proportions (t-, F- and  $\chi^2$ -distribution).

**Estimation and Testing of Hypothesis:** Point estimations, interval estimation, Confidence interval, Critical value, Level of significance, testing of hypothesis for large and small samples, t-test, F-test and  $\chi^2$ -test, test of goodness of fit.

**Text Books / References:**

1. Feller, W.: An Introduction to Probability Theory and its Applications, Willey-Eastern, 1993.
2. Rohatgi, V.K.: An Introduction to probability theory and mathematical statistics, Wiley Eastern Publisher Ltd., New Delhi, 1984.
3. Ramana, B.V.: Higher Engineering Mathematics, Tata McGraw Hill Educ. Pvt. Ltd., 2012.
4. Freund, John, E.: Mathematical Statistics with Applications, Pearson Education, 2004.
5. Mood, A.M. and Graybill, F.A.: Introduction to the theory of Statistics, Mc-Graw-Hill, 1974.
6. Gnedenko, B.: The theory of Probability, MIR, Moscow, 1988.
7. Chakravarty, I.M.: Hand Book of Methods of Applied Statistics, Vol-I, Willey, 1967.
8. Kapoor, J. N. and Saxena, H.C.: Mathematical Statistics, S. Chand & Company Ltd., 2007.

**COs:**

1. Development of analytic skill to solve the mathematical problems in Probability.
2. Articulate the concepts of different probability distributions and applications.
3. Familiarization with MGF and Expectation in a probability distribution.
4. Proficiency in the basic concept and problem solving ability in Correlation and Regression of 2-D random variables.

<b>MA 5120</b>	<b>Complex Analysis</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Second Semester (Core)	3	1	0	4

Algebra of Complex Numbers, The Complex Plane, Polynomials, Transcendental functions such as Exponential, Trigonometric and Hyperbolic Functions, Complex Valued Function, Limit, Continuity, Differentiability, Cauchy-Riemann Equations (Cartesian & Polar), Analytic Functions, Entire Function, Harmonic Functions, Harmonic Conjugate.

Contour integral, Simply Connected Domain, Cauchy's Theorem, Cauchy Goursat's Theorem, Cauchy's Integral Formula, Cauchy's Estimate, Liouville's Theorem, Fundamental Theorem of Algebra, Morera's Theorem, Power Series, Taylor's Series, Laurent Series.

Singularities, Types of Singularities, Zeros of Holomorphic functions, Picard's Theorem, Casorati-Weierstrass Theorem, Residues, Cauchy Residue Theorem, Evaluation of Real Integrals, Argument Principle, Rouché's Theorem.

Conformal Maps, Bilinear Transformation, Riemann Sphere, Open Mapping Theorem, Riemann mapping theorem Maximum Modulus Principle, Schwarz's Lemma, Homotopy, Winding Number, Runge's Theorem, Poisson's Formula, Schwarz Reflection Principle, Analytic Continuation.

**Text Books/ References:**

1. Brown, J.W. and Churchill, R.V.: Complex Variables and Applications, McGraw Hill, 9<sup>th</sup> Edition, 2013.
2. Saff, E.B. and Snider, A.D.: Fundamentals of Complex Analysis with Applications to Engineering and Science, Pearson, 3<sup>rd</sup> Edition, 2003.
3. Ahlfors, L.V.: Complex Analysis, McGraw Hill, 3<sup>rd</sup> Edition, 2013.
4. Conway, J.B.: Functions of Complex Variable, Narosa Publishers, 2<sup>nd</sup> Edition, 2000.

**COs:**

1. Understand the basic concepts of complex analysis.
2. Apply the methods of complex analysis to evaluate definite integrals and infinite series.
3. Acquire the skill of contour integration to evaluate complicated real integrals via residue calculus.

<b>MA 6101</b>	<b>Functional Analysis</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Third Semester (Core)	3	1	0	4

**Normed linear spaces:** Normed linear spaces, Incomplete normed linear spaces, Completion of normed linear spaces, Banach spaces, Properties of Banach spaces, Schauder Basis and Separability, Heine-Borel theorem and Riesz lemma.

**Operators on normed linear spaces:** Bounded linear operators, Examples of bounded and unbounded linear operators, Operator norm, Dual spaces, Closed operators, Hahn-Banach theorem and its applications, Uniform boundedness principle, Closed graph theorem, Bounded inverse theorem, Open mapping theorem, Reflexivity and weak convergence.

**Hilbert spaces:** Inner product spaces, Orthonormal set, Gram-Schmidt ortho-normalization, Orthonormal basis, Bessel's inequality, Separable Hilbert spaces. Projection and Riesz representation theorem, Orthonormal complements, Orthogonal projections, Projection theorem, Riesz representation theorem.

**Bounded operators on Hilbert spaces:** Adjoint, Normal, Unitary, Self adjoint operators, Compact operators, Eigenvalues, Eigenvectors, Banach algebras.

**Spectral theorem:** Spectral theorem for compact self adjoint operators, Statement of spectral theorem for bounded self adjoint operators.

**Text Books/ References:**

1. Limaye, B. V.: Functional Analysis, 2nd Ed., New Age International Publishers, 1996.
2. Kreyszig, E.: Introductory Functional Analysis with Applications, John Wiley & Sons, 1978.
3. Conway, J. B.: Functional Analysis, 2nd Ed., Springer-Verlag, 1990.
4. Rudin, W.: Functional Analysis, Tata McGraw Hill, 1974.
5. Gohberg, I. and Goldberg, S.: Basic Operator Theory, Birkhäuser, 1980.
6. Nair, M.T.: Functional Analysis: A First Course, PHI Learning Private Limited, 2002.

**COs:**

1. Covers theoretical needs of partial differential equations, optimization, approximation theory and other branches of Mathematics.
2. Learns the concepts of the main theorems: Hahn-Banach theorem, uniform boundedness principle, closed graph theorem and open mapping theorem.
3. Learns the applications of the spectral analysis in the theory of integral equations and Sturm-Liouville problems.
4. Learns to apply the theory of Banach spaces and Hilbert spaces in order to get the approximate solutions of partial differential equations.
5. Learns to solve the certain problems arising in partial differential equations, optimization, mathematical analysis and other branches of Mathematics.

<b>MA 6102</b>	<b>Partial Differential Equations</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Third Semester (Core)	3	1	0	4
<i>Prerequisite(s): MA 1501, MA 1517.</i>					

**Introduction:** Classification of partial differential equations and examples, Formulation of PDEs.

**First Order Equations:** Cauchy problems, Method of characteristics, Monge cone, Lagrange's method, Charpits method, Special types of non-linear equations.

**Second Order Equations:** Preliminaries, General solution of higher order PDEs with constant coefficients, Classification of second order PDEs, Characteristics, Canonical forms, Separation of variables method for Wave, Laplace, Heat equations, Green's functions for elliptic, parabolic and hyperbolic equations.

**Hyperbolic Equation:** Well-posedness of Cauchy problems for wave equation in  $\mathbb{R}^n$ , D'Alembert solution, Spherical means, Initial-boundary value problems on bounded domains and well-posedness, Existence and Uniqueness of solutions, Non-homogeneous equations and Duhamel principle.

**Elliptic Equation:** Fundamental solutions, Existence and uniqueness of solutions, Boundary Value Problems, Mean value property and its consequences, Maximum principles, Poisson's formula.

**Parabolic Equation:** Fundamental solution, Initial and Boundary Value Problems, Maximum principle, Existence and Uniqueness of solutions.

**Text Books/ References:**

1. Rao, K. S.: Introduction to Partial differential Equations, 3<sup>rd</sup> Edition, PHI, 2011.
2. Evans, L.C.: Partial Differential Equations, Graduate Studies in Mathematics, Vol. 19, AMS, 1999.
3. John, F.: Partial Differential Equations, Springer, 1982.
4. Strauss, W.: Partial Differential Equations: An introduction, Wiley, 2008.
5. Sneddon, I. N.: Elements of Partial Differential Equations, Mc-Graw-Hill, 1988.
6. Owen, Mc.: Partial Differential Equations: Methods and Applications, 2<sup>nd</sup> Edition, Pearson, 2003.

**COs:**

1. Apply PDEs techniques to predict the behavior of certain phenomena.
2. Solve real life problems by identifying them appropriately from the perspective of PDEs.
3. Apply specific methodologies, techniques and resources to conduct research and produce innovative results in the area of specialization.
4. Use appropriate methods to study phenomena modelled with PDEs.
5. Identify real phenomena as models of PDEs.

<b>MA 6103</b>	<b>Optimization Techniques</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Third Semester (Core)	3	1	0	4

**Review of Linear Programming Problems (LPP):** Simplex method, Dual Simplex method, two phase method, revised simplex method, transportation and assignment problems.

**Game theory:** Pure & mixed strategies, Rectangular game, Two person zero sum game, Games with saddle points and without saddle points, Graphical method for  $2 \times n$  and  $m \times 2$  games.

**Job Sequencing Problems:** Introduction of job sequencing problems, processing of  $n$  jobs through two machines.

**Sensitivity Analysis and Parametric Programming:** Introduction to post optimality analysis, variation in the cost vector, variation in the requirement vector, changes in the co-efficient matrix, addition and subtraction of a variable, addition and subtraction of a constant, parametric linear programming.

**Integer Programming:** Introduction, Gomory’s method for all integer and mixed integer programming, Branch and Bound Technique.

**Dynamic programming:** Single stage and multi-stage programming, Bellman dynamic programming approach, Forward and backward process, Applications of dynamic programming.

**Nonlinear Programming:** Introduction and formulation of Non-Linear Programming Problem (NLPP), Different types of NLPP, Method of Lagrange multipliers, Karush-Kuhn-Tucker theory,

**Convex optimization:** Convex programming, quadratic programming, geometric programming.

**Stochastic Programming:** Introduction, chance constraint programming and two stage programming.

**Goal Programming:** Introduction, formulation of linear goal programming problem, graphical goal attainment method.

**Text Books/ References:**

1. Hiller, F.S. and Lieberman, G.J.: Introduction to Operations, Research, MGH Int. Ed., 1990.
2. Hadley, G.: Linear Programming, Narosa Publishing House, New Delhi, 2002.
3. Taha, H.A.: Operations Research - An Introduction, Pearson Education, 2010.
4. Swarup, Kanti, Gupta, P.K. and Man Mohan: Operations Research, S. Chand & Sons, 2017.
5. Kambo, N.S.: Mathematical Programming Techniques, Affiliated East-West Press, 2008.
6. Rao, S.S.: Optimization Theory and Applications, Wiley Eastern Ltd, 2005.
7. Luenberger, D.G. and Ye, Yinyu: Linear and Nonlinear Programming, Springer, 2008.

**COs:**

1. Understand the need and origin of the optimization methods.
2. Get a broad picture of the various applications of optimization methods used in engineering.
3. Able to apply the mathematical results and numerical techniques of optimization theory to engineering problems.

<b>MA 6104</b>	<b>Numerical Analysis</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Third Semester (Core)	3	0	2	4

Root Finding Problems for Transcendental and Polynomial Equations, Real and Complex Roots-Generalized Newton’s method, Muller’s method and other methods, Analysis of error, Stability and convergence.

**Spline Interpolation:** Types of spline functions and piecewise interpolation, Cubic splines, Interpolation with cubic splines, end conditions, error analysis of cubic spline.

**Solution of linear systems:** Solution of tri-diagonal system (Band matrix), Numerical solution of Eigen value problems, Ill conditioned system.

**Numerical Differentiation and Integration:** Numerical differentiation, Errors in differentiation, Newton-Cotes Integration formula, Trapezoidal, Simpson's (1/3 & 3/8), Boole's & Weddle's rules, Euler-Maclaurin formula, Gaussian quadrature.

**Numerical Solution of ODE:** Picard's method, Taylor's series method, Euler's and Modified Euler's method, Runge-Kutta methods, Milne's predictor-corrector method, Single step and multistep method for BVP, Shooting method.

**Numerical Solution of PDE:** Finite difference approximations for PDE, Solution of PDE (BVP) by Crank-Nicolson method (ADI method), Numerical solution of Laplace equation, Poisson equation, one dimensional wave equation, Dirichlet's problem and Neumann problem by ADI method.

The following list of programs by using FORTRAN/MATLAB language to be covered in practical classes.

1. Forward/Backward Interpolation Formula.
2. Iterative method: Fixed point iteration, Newton-Raphson method.
3. Inverse of a square matrix.
4. Higher order derivatives by using finite difference methods.
5. Integration by Trapezoidal rule.
6. Integration by Simpson's 1/3 rule.
7. Integration by Simpson's 3/8 rule.
8. Integration by Weddle's rule.
9. Solution of ODE (IVP) by Euler's method.
10. Solution of ODE (IVP) by fourth order Runge-Kutta method.
11. Solution of ODE (IVP) by Milne's predictor-corrector method.
12. Solution of PDE (BVP) by Crank-Nicolson method.
13. Solution of Laplace equation.
14. Solution of Poisson equation.
15. Solution of one dimensional Wave equation.

**Text Books/ References:**

1. Smith, G.D.: Numerical Solution of Partial Differential Equations: Finite Difference Methods Oxford University Press, Third edition, 1986.
2. Jain, M.K., Iyengar, S. R. K. and Jain, R. K.: Numerical Methods for Engineers and Scientists, New Age International publishers, 2008.
3. Forsythe, G.E. and Wasow, W.R.: Finite Difference methods for partial Differential equations, John Wiley and Sons, 1960.
4. Gerald, C.F. and Wheatley, P.O.: Applied Numerical Analysis, Pearson Education Inc., 2004.

5. Conte, S. D. and Boor, C.D.: Elementary Numerical Analysis an Algorithmic Approach, McGraw-Hill Book Company, 1980.
6. Hildebrand, F.B.: Introduction to Numerical Analysis, Dover Publications Inc., 1987.

**COs:**

1. Ability to solve the real and complex roots of polynomials and transcendental equations.
2. Skill to develop the interpolating polynomials using different interpolation.
3. Capability to find the numerical solution of the ordinary and partial differential equations with different boundary conditions.
4. Ability to implement the different methods for calculating integration.
5. Capability to develop different algorithm for solving the ODEs.

<b>MA 6116</b>	<b>Discrete Mathematical Structure</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Fourth Semester (Core)	3	0	0	3

**Logic and Proofs:** propositional logic, valid, satisfiable and unsatisfiable formulas, predicates and quantifiers, rules of inference, direct and indirect proofs, proof by contradiction, contrapositive proofs, etc.

**Size of a Set:** Cardinality of a set, Schroeder-Bernstein theorem, Finite and infinite sets, power set theorem, Cantor's diagonal argument.

**Induction and Recursion:** Mathematical Induction (strong), Recursive definitions and structural induction, Recursive Algorithms.

**Introduction to counting:** Basic counting techniques, inclusion and exclusion, pigeon-hole principle, generalized permutation and combination, Generating Permutations and Combinations, Introduction to recurrence relation and solution of linear recurrence relation, generating function.

**Relations:** Relations, properties and applications, Computer representations of relations, Operations on relations, The connectivity relations, Equivalence relations, Partial orderings.

**Graphs and Trees:** Computer representation of graphs, Paths, Cycles and Circuits, Eulerian and Hamiltonian graphs, Planner graphs, Graph Colouring, Spanning trees, Binary trees, Binary search trees.

**Boolean Algebra:** Boolean Functions, Logic Gates, Minimization of Circuits.

**Text Books/ References:**

1. Koshy, T.: Discrete Mathematics with Applications, Academic Press, 2004.
2. Rosen, K.H.: Discrete Mathematics and Its Applications, Tata McGraw-Hill, 7<sup>th</sup> edition, 2011.
3. Liu, C. L.: Elements of Discrete Mathematics, Tata McGraw-Hill, 1985.

4. Mott, J. L., Kandel, A. and Baker, T. P.: Discrete Mathematics for Computer Scientists and Mathematicians, Prentice Hall India, 1986.

**COs:**

1. Write an argument using logical notation and determine if the argument is valid or not.
2. Solve problems using different proof techniques.
3. Enumerate objects, perform combinatorics and solve counting problems using recurrence relations and generating functions.
4. Determine properties of relations and perform various operations on relations.
5. Solve problems using graphs and trees.
6. Apply Boolean algebra to circuits.

<b>MA 6131</b>	<b>Fluid Dynamics</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Fourth Semester (Elective)	3	0	0	3

**General orthogonal curvilinear coordinates:** Arc length in orthogonal coordinates, gradient in orthogonal coordinates, divergence in orthogonal coordinates, Laplacian in orthogonal coordinates, curl of a vector function in orthogonal coordinates.

**Kinematics of fluids in motion:** Real fluids and ideal fluids, velocity of a fluid at a point, streamlines and path lines- steady and unsteady flows, the velocity potential, the vorticity vector, local and particle rates of change, the equation of continuity, acceleration of a fluid, conditions at a rigid boundary, general analysis of fluid motion.

**Equation of motion of a fluid:** Pressure at a point in a fluid at rest, pressure at a point in a moving fluid, conditions at a boundary of two inviscid immiscible fluids, Euler’s equations of motion, Bernoulli’s equation, discussion of the case of steady motion under conservative body forces.

**Viscous flow:** Stress components in a real fluid, relations between Cartesian components of stress, translational motion of fluid element, the rate of strain quadric and principal stresses, some further properties of the rate of strain quadric, stress analysis in fluid motion, relations between stress and rate of strain, the coefficient of viscosity and laminar flow, the Navier-Stokes equations of motion of a viscous fluid, some solvable problems in viscous flow- steady motion between parallel planes, steady flow through tube of uniform circular cross-section, steady flow between concentric rotating cylinders.

**Text Books/ References:**

1. Chorlton, F.: Textbook of fluid dynamics, Van Nostrand, 2004.
2. Batchelor, G.H.: An Introduction to fluid dynamics, Cambridge University Press, 2002.
3. Raisinghania, M. D.: Fluid Dynamics, S. Chand Publishing, 2018.

**COs:**

1. Familiar with the basic concepts of fluid dynamics and governing equations of motion of inviscid or viscous fluid.
2. Ability to solve the governing equations for some steady viscous flow problems.

<b>MA 6132</b>	<b>Rings and Modules</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Fourth Semester (Elective)	3	0	0	3
<i>Prerequisite(s): MA 1516</i>					

**Rings and Fields:** Brief review of rings and ideals, Nilpotent element, Idempotent element, Boolean rings, Divisors, units and associates, Principle Ideal Domain, Euclidean Domain. Unique Factorization Domain, Chain conditions, Noetherian and Artinian Rings, Nilradical and Jacobson radical, Operations on Ideals, Reducible and irreducible polynomials, Roots of polynomials, Polynomial Rings and Irreducibility criteria.

**Modules:** Basic Definition and examples, Submodules, Quotient modules, Module Homomorphisms, Fundamental Theorem of module homomorphism, Direct sums and free modules, Finitely generated modules, Torsion free and Torsion modules, Free modules, A module as the direct sum of a free and a torsion module, Direct sums and direct products of modules, External and Internal direct sums, Noetherian and Artinian modules.

**Text Books/ References:**

1. Musili, C.: Introduction to Rings and Modules, Narosa Publishing House, 2010.
2. Hartley, B. and Hauvkes, T. O.: Rings, Modules and Linear Algebra, Chapman and Hall Ltd., 1970.
3. Allenly, R. B.: Rings, Fields and Groups, Butterworth Heinemann, 1991.
4. Singh S. and Zameeruddin, Q.: Modern Algebra, Vikas Publishing, 2006.
5. Gallian, A.: Contemporary Abstract Algebra, Narosa Publishng House, 1998.
6. Rose, J.: A Course on Rings Theory, Cambridge University Press, 1978.

**COs:**

1. Students will have knowledge of fundamental properties of rings and modules with examples. In particular, students will be familiar with the key properties and examples of Noetherian and Artinian rings and modules.
2. Students will be able to decide whether a given ring or module is Noetherian/ Artinian by applying the characterizations discussed in the course.
3. Identify the concept of Nilpotent element, Idempotent element, Boolean rings.

4. Understand the concepts of Principal Ideal Domain, Euclidean Domain and Unique Factorization Domain.
5. Demonstrate the concepts of Nil-radical and Jacobson radical, Polynomial Rings, Irreducibility criteria, Finitely generated modules, Torsion free and Torsion modules, Free modules.

<b>MA 6133</b>	<b>Measure Theory and Integration</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
M.Sc. Fourth Semester (Elective)		3	0	0	3
<i>Prerequisite(s): MA 1501</i>					

**Lebesgue measure:** Introduction, Outer measure, Measurable sets and Lebesgue measure, Regularity properties, a non-measurable set, Measurable functions, Simple functions, Egoroff's theorem, Lusin's theorem.

**Lebesgue Integral:** Lebesgue integral of a bounded function over a set of finite measure, Bounded convergence theorem, Integral of a non-negative function, Fatou's Lemma, Monotone convergence theorem, General Lebesgue integral, Lebesgue convergence theorem, Convergence in measure.

**Differentiation and Integration:** Differentiation of monotone functions, Functions of bounded variation, Differentiation of an integral, Absolutely Continuity, Change of variable formula.

**General measure and Integration theory:** Measure spaces, Measurable functions, Integration, General convergence theorems, Signed measures, Hahn-Decomposition theorem, The Radon-Nikodym theorem. The  $L^p$  spaces, The Hölder's inequality and Minkowski's inequality, Completeness of  $L^p$ , Approximation in  $L^p$ .

**Measure and Integration in Product space:** Measurability in a product space, The product measure and Fubini's theorem.

**Text Books/ References:**

1. de Barra, G.: Measure theory and Integration, New Age International Publishers, 2000.
2. Royden, H.L.: Real Analysis, 2<sup>nd</sup> Ed., the Macmillan Company, 1968.
3. Halmos, P.R.: Measure Theory, Springer-Verlag, 1974.
4. Bauer, H.: Measure and Integration Theory, Walter de Gruyter, 2001.
5. Rudin, W.: Principles of Mathematical Analysis, 3<sup>rd</sup> Ed., Tata McGraw Hill, 1976.

**COs:**

1. Covers the theoretical needs of Probability and Statistics, Functional Analysis, Partial differential equations and other branches of Mathematics.
2. Learns the concepts of Lebesgue measure, Measurable sets, Measurable functions, Lebesgue Integration and their properties.

3. Learns the difference between Riemann integration and Lebesgue Integration.
4. Understands the applications of  $L^p$  spaces to the problems arising in partial differential equations.
5. Learns the applications of Lebesgue integration and convergence theorems to the problems arising in partial differential equations.
6. Change the order of integration in order to evaluate integrals.

<b>MA 6134</b>	<b>Mathematical Modelling</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
M.Sc. Fourth Semester (Elective)		3	0	0	3
<i>Prerequisite(s): MA 1517, MA 1602.</i>					

**Introduction:** Basic idea of model, mathematical model and mathematical modelling, Simple situations requiring mathematical modeling, Techniques of mathematical modeling, Classifications, Characteristics and limitations of mathematical models, Some simple illustrations.

**Mathematical modeling through difference equations:** Basic theory of linear difference equations with constant coefficients, Mathematical models in Economics, Finance, Population dynamic, and Genetics.

**Mathematical modeling through first order ODEs:** Linear growth and decay models, Logistic model, Radio-active decay and Carbon dating model, Compartment model, Mathematical model for diffusion of Glucose, Medicine in the blood stream.

**Mathematical modeling through systems of ODEs of the first order:** Mathematical model in Economics and Finance, Mathematical model of drug distribution in human body, Compartment model, Medicine.

**Mathematical modeling through second order ODEs:** Mathematical model for Planetary motion, Circular motion, Motion of satellites.

**Mathematical modeling through PDEs:** Situations giving rise to PDEs models, Equation of continuity in fluid dynamics, heat flow.

**Text Books/ References:**

1. Kapur, J.N.: Mathematical Modeling, 2<sup>nd</sup> Edition, New Age International Private Limited, 2015.
2. Kapur, J.N.: Mathematical Models in Biology and Medicine, Affiliated East-West Pvt. Limited, 2010.
3. Giordano, F.R., Fox, W.P., Horton S.B., and Weir, M.D.: A First Course in Mathematical Modelling, 4<sup>th</sup> Edition, Cengage Learning, 2008.
4. Meyer, W.J.: Concepts of Mathematical Modelling, Dover Publications, 2004.
5. Charlton, F.: Ordinary Differential and Difference Equations: Theory and applications, Nostrand Publication, 1965.

**COs:**

1. Learn the basic principles, procedure and limitations of mathematical modelling.
2. Understand the theory and characteristics of difference equations to develop the mathematical model.
3. Develop the skills and knowledge to analyze the dynamical, physical, and planetary motion problems through differential equations.

<b>MA 6135</b>	<b>Fuzzy Sets Theory</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Fourth Semester (Elective)	3	0	0	3

**Fuzzy Sets:** Crisp Sets. Fuzzy sets versus Crisp sets,  $\alpha$  - cuts and properties, representation of fuzzy sets, extension principle of fuzzy sets.

**Operations on Fuzzy Sets:** Fuzzy complement, fuzzy union, fuzzy intersection, combinations of operations, general aggregation operations.

**Fuzzy Arithmetic:** Fuzzy numbers, Linguistic variables, arithmetic operations on intervals, arithmetic operations on fuzzy numbers, lattice of fuzzy numbers, fuzzy equations.

**Fuzzy Relations:** Crisp relation and fuzzy relation, cardinality, operations, properties, fuzzy Cartesian product and composition, fuzzy tolerance and equivalence relations, value assignments, forms of composition operation.

**Text Books/ References:**

1. Klir G.J. and Yuan, B.: Fuzzy sets and Fuzzy logic: Theory and Applications, Prentice Hall of India, 1997.
2. Ross, T.J.: Fuzzy Logic with Engineering Applications, McGraw Hill, 1997.
3. Zimmerman, H.J.: Fuzzy Set theory and its Applications, Kluwer Academic Publishers, 4<sup>th</sup> Edn., 2001.
4. Klir, G.J. and Folger, T.A.: Fuzzy sets, Uncertainty and Information, Prentice Hall of India, 1988.

**COs:**

1. Familiar with the basic methods and applications of fuzzy set theory.
2. Solve problems based on fuzzy sets, fuzzy relations and fuzzy arithmetic.

<b>MA 6136</b>	<b>Graph theory and Applications</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Fourth Semester (Elective)	3	0	0	3

**Introduction to Graphs:** Graphs, graph as models, incidence and degree of a vertex, isolated and pendent vertex, null graph, simple graph, digraph, operations on graphs, graph isomorphism, weighted graph, special graphs, matrix representation of a graph (Both for digraphs and undirected graphs).

**Trees and Connectivity:** Walks, paths and circuits, connected and disconnected graphs, Euler and Hamiltonian graphs with their properties, Applications: Chinese postman problem, Travelling salesman problem. Rooted tree, binary tree, height of a binary tree, centre, radius and diameter of a tree, distance between two trees, spanning tree, fundamental circuits, finding all spanning trees of a graph, spanning tree of a weighted graph, minimum spanning trees, Prims and Kruskal's algorithms, DFS, BFS algorithm, shortest path algorithms, cut-sets, fundamental circuits, connectivity and separability, network flows: max-flow min-cut theorem.

**Planner Graphs:** Planner graph, Kuratowski's two graphs; detection of planarity, algorithm to check the planarity, dual of a planner graph.

**Coloring, Covering and Partitioning:** Vertex coloring, chromatic number, chromatic partitioning, chromatic polynomial, clique, edge coloring, map coloring (four color conjecture), Matching, Covering.

**Advanced Topics:** Perfect graphs, Matroids, Ramsay theory, Applications of graph theory.

#### **Text Books/ References:**

1. Narsingh Deo: Graph Theory with Applications to Engineering and Computer Science, Prentice-Hall, 2004.
2. Frank Harary: Graph Theory, Narosa Publishing House, 2001.
3. Bondy, J.A. and Murty, U.S.R.: Graph Theory and Applications, (Freely downloadable from Bondy's website), 2007.
4. Ahuja, R., Magnanti, T. and Orlin, J.: Network Flows: Theory, Algorithms, and Applications, Prentice-Hall, 2011.
5. Clark, J. and Holton, D.A.: A first look at Graph Theory, Allied publication ltd, New Delhi, 1991.

#### **COs:**

1. Illustrate basic ideas on graphs, circuits, cut sets, network flows, planar graphs and its applicability.
2. Illustrate about chromatic characteristics and directed graph.
3. Acquaint with the different algorithms networking optimization problem.
4. Identifying coloring, covering and partitioning problems and the process to solve them.
5. Inculcate independent thinking on practical graph theoretic real life problems.
6. Provide independent thinking of possible research ideas in real life situations.

<b>MA 6137</b>	<b>Modelling and Simulation</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
M.Sc. Fourth Semester (Elective)		3	0	0	3
<i>Pre-requisite: MA 1519</i>					

**System Model:** Definition of a System, system concept, examples of systems and components types of system, continuous & discrete systems, concept of model and model building, model classification and representation.

**Simple ODE, PDE and Difference Equation Models:** Concept of different models governed by ODE, PDE and difference equations, initial value problems and boundary value problems.

**Models of Operations Research:** Different OR - models: sequencing models, birth-death process, queuing models, Haris EOQ graph, deterministic EOQ models.

**Uncertainty Modeling:** Uncertainty in modeling: input data, conceptualization, parameterization and representation of the model. types of uncertainty in modeling - probabilistic modeling and possibilistic modeling.

**System Simulation:** Introduction to simulation, brief history of simulation, computational aspects of simulating a system, classification of simulation, difficulties in simulation, advantages and disadvantages of simulation techniques,

**Probability Concepts in Simulation:** Stochastic variables, discrete and continuous probability functions, numerical evaluation of continuous probability functions, continuous uniformly distributed random numbers,

**Random Numbers and Stochastic Simulation:** Concept of random numbers, continuous uniformly distributed random numbers, properties of random numbers, random number generation in stochastic simulation, generation of pseudo random numbers, Random number generators – linear congruential generator, mid square method, multiplicative congruential generator, rejection method.

**Monte-Carlo Simulation:** Introduction to Monte-Carlo simulation, algorithm of Monte-Carlo simulation technique, advantages and limitations of Monte-Carlo simulation techniques.

**MATLAB and Simulation Software:** Concept of using different simulation software, MATLAB as a simulation tool, SIMUL8 as a powerful simulation tool, Monte-Carlo software, General Purpose Simulation System (GPSS).

**Text Books/ References:**

1. Gordon, Geoffrey: System Simulation, Prentice Hall of India, 1987.
2. Deo, Narshingh: System Simulation with Digital Computer, Prentice Hall of India, 2004.
3. Zeigler, Bernard, P., Praehofer, Herbert and Kim, Tag: Theory of Modeling and Simulation, Academic Press, 2000.
4. Law, A.M. and Kelton, W.D.: Simulation Modeling and Analysis, McGraw-Hill, New York, 1991

5. Rubinstein, R.Y.: Simulation and the Monte-Carlo Method, John Wiley & Sons, New-York, 1981
6. Taha, H.A.: Operations Research, An Introduction to Operations Research, PHI New Delhi, 2008.

**COs:**

1. Able to transform the physical behavior of a system into a mathematical model.
2. Able to transform mathematical models into a efficient algorithm for simulation purpose.
3. Understand the mathematical tools that are needed to solve the problems of modeling and simulation.
4. Understand the uses of the results of the models in real life situation.

<b>MA 6138</b>	<b>Advanced Operations Research</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Fourth Semester (Elective)	3	0	0	3
<i>Pre-requisite: MA 1519</i>					

**Inventory Theory:** Introduction to Inventory theory, Economic parameters associated with inventories, EOQ graph, deterministic inventory problems without shortages, deterministic inventory problems with shortages, EOQ problems with price breaks, multi items deterministic problems, inventory problems with uncertain demand.

**Queuing Theory:** Introduction to queuing system, objectives and characteristics of queuing system, probability distributions in queuing system (Birth-Death Process), queue disciplines, Kendall's notation (a/b/c): (d/e/f); classification of queuing models, Poisson queuing system, Non-Poisson queuing system.

**Network Theory–Project management:** Introduction to network scheduling, basic components of network, network construction, Fulkerson's rule, forward pass calculation, backward pass calculation, slack time, determination of critical path, PERT analysis, Estimation of activity time, cost analysis, project cost, crashing of activities.

**Reliability Theory:** Elements of Reliability theory, failure rate, extreme value distribution, analysis of stochastically failing equipments including the reliability function, reliability and growth model, System reliability, Fault tree analysis. Failure time modeling, Estimation and Testing in reliability

**Replacement Theory:** Introduction, failure mechanism of items, replacement of deteriorating items, replacement of sudden failure items, failure trees.

**Coding and Information Theory:** Introduction, measure of information, entropy function, entropy as a measure of uncertainty, properties of entropy function, communication system, channel probabilities, conditional entropies, mutual information, encoding and decoding.

**Text Books/ References:**

1. Hiller, F. S. and Lieberman, G. J.: Introduction to Operations Research, MGH, 2010.
2. Taha, H.A.: Operations Research, An Introduction to Operations Research, PHI New Delhi, 2008.
3. Ravindran, A., Phillips, D. T. and Solberg, J.: Operations Research- Principles and Practice, John Wiley & Sons, 2005.
4. Wagner, H: Principles of Operations Research, PHI, 1982.
5. Cooper, R.B.: Introduction to Queuing Theory, North Holland, 1981.
6. Swarup, Kanti, Gupta, P.K. and Man Mohan: Operations Research- An Introduction, S. Chand & Company, New Delhi, 1977.
7. Barlo, Richard E., and Proschan, Frank: Statistical Theory of Reliability and Life Testing, Holt, Rinehart and Winston Inc, 1975.

**COs:**

1. Able to identify and develop operational research models from the verbal description of the real system.
2. Understand the mathematical tools that are needed to solve the problems of operations research.
3. Learn about various decision making processes.
4. Able to use mathematical software to solve the proposed models of operations research.
5. Have made progress on a research project in the areas of operations research.

<b>MA 6139</b>	<b>Computational Fluid Dynamics</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Fourth Semester (Elective)	3	0	0	3
<i>Prerequisite(s): MA 1604</i>					

Governing equations of fluid dynamics, Introduction to finite difference discretization, Explicit and Implicit schemes, Truncation error, consistency, convergence and stability analysis, Thomas algorithm, ADI method for 2-D heat conduction problem, Multigrid method, Upwind scheme, CFL stability condition.

Preliminary concepts, Flux computation across quadrilateral cells, Conservation principles of fluid dynamics, Basic equations of viscous and inviscid flow, Basic equations in conservative form, Associated typical boundary conditions for Euler and Navier-Stokes equations, Grid generation using elliptic partial differential equations, Incompressible viscous flow field computation: Stream function vorticity formulation, staggered grid, SIMPLE algorithm.

**Text Books/ References:**

1. Versteeg, H.K. and Malalasekera, W.: An Introduction to Computational Fluid Dynamics, 2<sup>nd</sup> Edition, Pearson Education Limited, 2007.

2. Fletcher, C.A.J.: Computational Techniques for Fluid Dynamics, Vol-I and Vol-II, Springer, 1988.
3. Andersson, J.D.: Computational Fluid Dynamics, McGraw-Hill, Inc., 1995.
4. Schlichting, H. and Gersten, K.: Boundary Layer Theory, Springer, 2000.
5. Niyogi, P., Chakraborty, S.K., and Laha, M.K.: Introduction to computational fluid Dynamics, Pearson Education, Delhi, 2005.
6. Patankar, S.V.: Numerical Heat Transfer and Fluid Flow, Taylor & Francis, 1980.
7. Hoffman, K.A., Chiang, S.T.: Computational Fluid Dynamics, Volume I, 4<sup>th</sup> Edition, Engineering Education System, Wichita, USA.

**COs:**

1. Familiar with the basic governing equations of fluid flow and heat transfer problems.
2. Apply different numerical techniques to solve problems in fluid flow and heat transfer.
3. Ability to understand the importance of stability in explicit and implicit scheme.

<b>MA 6140</b>	<b>Fuzzy Sets, Fuzzy Logic and Applications</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
	M.Sc. Fourth Semester (Elective)	3	0	0	3

Basic concepts of fuzzy sets, Properties of Membership Functions.

**Fuzzification and Defuzzification:** Features and various forms of membership functions, Fuzzification,  $\alpha$ -cuts for fuzzy relations, Defuzzification to crisp sets and scalars.

**Fuzzy Logic and Fuzzy Systems:** Classic and fuzzy logic, approximate reasoning, natural language, linguistic hedges, fuzzy rule based systems, graphical technique of inference.

**Extension Principle:** Functions of fuzzy sets, extension principle, fuzzy mapping, vertex method and DSW algorithm.

**Fuzzy Measures:** Belief and plausibility, probability measures, possibility and necessity measures, possibility distribution.

**Fuzzy Optimization:** One dimensional fuzzy optimization, fuzzy concept variables and casual relations, fuzzy cognitive maps, agent based models.

**Fuzzy Decision Making:** Fuzzy ordering, nontransitive ranking, decision making in fuzzy environment.

**Text Books/ References:**

1. Klir, G.J. and Yuan, B.: Fuzzy sets and Fuzzy logic: Theory and Applications, PHI, 1997.
2. Ross, T.J.: Fuzzy Logic with Engineering Applications, McGraw Hill, 1997.

3. Zimmerman, H.J.: Fuzzy Set theory and its Applications, Kluwer Academic Publishers, 4<sup>th</sup> Edn., 2001.
4. Klir, G. J. and Folger, T. A.: Fuzzy sets, Uncertainty and Information, PHI, 1988.
5. Nguyen, H.T. and Walker, E.A.: First Course in Fuzzy Logic, Chapman & Hall, 2<sup>nd</sup> Edn., 1999.
6. Mendel, J.M.: Uncertain Rule, Based Fuzzy Logic Systems; Intro and New Directions, PHPTR, 2000.
7. Ross, T. J.: Fuzzy Logic with Engineering Applications, McGraw Hill, 1997.
8. Buckley, J. J. and Eslami, E.: An Introduction to Fuzzy logic and Fuzzy sets, Springer, 2002.

**COs:**

1. Understand the basic concepts of fuzzy set, fuzzy logic and its application in real life models which cannot be described with classical mathematical models.
2. Able to apply concepts of fuzzy sets and fuzzy logic in solving real life problems.

<b>MA 6141</b>	<b>Soft Computing Techniques</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
M.Sc. Fourth Semester (Elective)		3	0	0	3
<i>Pre-requisite: MA 1505, MA 1603.</i>					

**Introduction to Soft Computing:** Soft computing constituents, Characteristics of Neuro computing and Soft computing; Difference between soft computing and hard computing.

**Neural Networks:** Basics of Neural Networks (Introduction to Neural Networks, Biological Neural Networks, McCulloch Pitt model), Supervised learning algorithms (Perceptron for single and multi-layer, linear separability, Delta learning rule, Back propagation algorithm), Unsupervised learning algorithms (Hebbian learning, Winner take all, self-organizing maps, learning vector quantization).

**Fuzzy Set Theory:** Classical sets and Fuzzy sets, classical relations and Fuzzy relations, Properties of membership function, Fuzzy extension principle, Fuzzy Systems: fuzzification and defuzzification.

**Single Objective Optimization:** Derivative based optimization techniques (Steepest Descent, Newton method); Derivative free optimization techniques (GA, PSO, DE, ACO, ABC).

**Multi-objective Optimization:** Basic Concepts, Pareto optimal front, Evolutionary approaches for MOEA.

**Text Books/ References:**

1. Kumar, S.: Neural Networks, Tata McGraw Hill publication, 2012.
2. Deb, K.: Multi-Objective Optimization using Evolutionary Algorithms, Wiley Publication, 2001.
3. Deb, K.: Optimization for Engineering Design: Algorithms and Examples, PHI, 2012.

4. Timothy, J. Ross.: Fuzzy Logic with Engineering Applications, Wiley Publication, 2004.
5. Rajsekarand, S. and Vijayalakshmi Pai, G.A.: Neural Networks, Fuzzy Logic and Genetic Algorithm: Synthesis and Applications, Prentice Hall of India, 2013.
6. Padhy, N. P.: Artificial Intelligence and Intelligent Systems, Oxford University Press, 2005.
7. Haykin, S.: Neural Networks, Prentice Hall of India, 1998.

**COs:**

1. Familiarization about different soft computing techniques and their applications.
2. Articulate the need of Neural network and Fuzzy set theory concepts
3. Skill development to model a real life problem to apply soft computing techniques.
4. Interpret the Single and multi-objective optimization problems as a platform to solve by evolutionary optimization approaches
5. Ability to identify and select a suitable Soft Computing technology to solve different complex problems in optimization

<b>MA 6142</b>	<b>Spectral Element Method</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
M.Sc. Fourth Semester (Elective)		3	0	0	3
<i>Pre-requisite: MA 1601, MA 1604.</i>					

**Introduction:** Historical Background, Weighted Residual Methods, Some Examples of Spectral Methods.

**Polynomial Approximation:** The Fourier System, Continuous and Discrete Fourier Expansion, Differentiation, Fourier Approximation, Inverse Inequalities, Orthogonal Projection, Interpolation, The Gibbs Phenomenon, Orthogonal Polynomials and Related Approximation Results, Gauss-Type Quadrature, Interpolation and Discrete Polynomial Transforms, Differentiation in the Physical Space and in the Frequency Space.

**Basic Approaches to Constructing Spectral Methods:** Strong and Weak Formulations of Differential Equations, Spectral Approximation of the Burgers Equation (Fourier Galerkin, Fourier Collocation, Chebyshev Tau, Chebyshev Collocation, Legendre G-NI), Convolution Sums, Transform Methods and Pseudo-spectral Methods, Aliasing Removal, Matrix Construction.

**Algebraic Systems and Solution Techniques:** Preconditioning, Fundamentals of Iterative Methods for Spectral Discretization, Low-Order Preconditioning of Model Spectral Operators in One Dimension and Several Dimensions, Spectral Multigrid Methods.

**Theory of Stability and Convergence:** Conditions for Stability and Convergence, The Error Equation

**Text Books/ References:**

1. Canuto, C., Hussaini, M. Y., Quarteroni, A. T. and Zang, A.: Spectral Methods Fundamentals in Single Domains, 1<sup>st</sup> Edition, Springer, 2006.
2. Shen, J., Tang, Tao and Wang, Li-Lian: Spectral Methods Algorithms Analysis and Applications, Springer, 2011.
3. Kopriva, David: Implementing Spectral Methods for Partial Differential Equations, Algorithms for Scientists and Engineers, Springer, 2009.
4. Trefethen, L. N.: Spectral Methods in MATLAB, SIAM, Philadelphia, 2000.
5. Karniadakis, George Em. and Sherwin, Spencer J.: Spectral hp-element methods for CFD, Oxford University Press, 2013.
6. Deville, M. O., Fischer, P. F. and Mund, E. H.: High-Order Methods for Incompressible Fluid Flow, Cambridge University Press, 2002.
7. Guo, Ben-Yu and Kuo, Pen-Yu: Spectral methods and their applications, World Scientific Publishing Company, 1998.
8. Gottlieb, David and Orszag, Steven A.: Numerical Analysis of Spectral Methods: Theory and Applications, SIAM, 1987.

**COs:**

1. Gain concepts behind variational methods and weighted residual methods in SEM.
2. Identify the application and characteristics of SEM.
3. Apply spectral element methods to structural, thermal, dynamic problems, where high accuracy is required
4. Develop the knowledge and skills needed to effectively evaluate spectral element methods.

<b>MA 6143</b>	<b>Finite Element Method</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
M.Sc. Fourth Semester (Elective)		3	0	0	3
<i>Pre-requisite: MA 1601, MA 1604.</i>					

Basic concepts of finite element method(FEM), weak formulation of boundary value problem (BVP), Ritz method, weighted residual method, Laz-Milgram theorem, piecewise polynomial approximation in function spaces, Galerkin orthogonality and Cea's lemma, Aubin-Nitsche duality argument, construction of a finite element space, polynomial approximation theory in Sobolev spaces, Bramble-Hilbert lemma, partial discretization and time dependent problems, discretization error, applications to elliptic, parabolic and hyperbolic equations, error estimates, variational crimes, a posteriori error analysis, reliability, adaptivity, solving FEM problems on computers.

**Text Books/ References:**

1. Branner, Susane C. and Scott, L. R.: The Mathematical Theory of Finite Element Methods, 3<sup>rd</sup> Edition, Springer, 2007.

2. Reddy, J. N.: An Introduction to the Finite Element Method, McGraw-Hill, 4<sup>th</sup> Edition, 2018.
3. Zienkiewicz, O. C.: Taylor, R. L. and Zhu, J. Z.: The Finite Element Method, 7<sup>th</sup> Edition, Elsevier India, 2014.
4. Oden, J.T. and Reddy, J. N.: An Introduction to the Mathematical Theory of Finite Elements, Dover Publications Inc., 2010.
5. Logan, D.L.: A First Course in the Finite Element Method, CL Engineering; 5<sup>th</sup> edition, 2011.
6. Bathe, Klaus-Jurgen: Finite Element Procedures, 2<sup>nd</sup> Edition, PHI Learning Pvt. Ltd., 1996.

**COs:**

1. Gain concepts behind variational methods and weighted residual methods in FEM.
2. Identify the application and characteristics of FEA elements such as bars, beams, plane and isoperimetric elements, and 3-D element.
3. Develop element characteristic equation procedure and generation of global stiffness equation will be applied.
4. Apply suitable boundary conditions to a global structural equation, and reduce it to a solvable form.
5. Identify how the finite element method expands beyond the structural domain, for problems involving dynamics, heat transfer, and fluid flow.