Central University of Punjab

M.Sc. MATHEMATICS

Batch 2022

Department of Mathematics and Statistics
School of Basic Sciences

M.Sc. (Mathematics) Programme

Graduate Attributes:

Students will be able to develop a broad understanding of recent mathematical theories, tools and techniques. Students will apply different mathematical techniques in various fields and will independently plan and carry out research in pure and applied mathematics. They will compete at regional/national/international level for research/jobs in the area of mathematics.

M.Sc. Mathematics (Semester-I)

Course Code	Course Title	Course Type	Credit Hours			Course Credits
			L	T	P	
MAT.506	Real Analysis	Core	3	0	0	3
MAT.508	Linear Algebra	Core	3	0	0	3
MAT.509	Ordinary Differential Equation	Core	3	0	0	3
MAT.511	Number Theory	Core	3	0	0	3
MAT.525	Differential Geometry	Core	3	0	0	3
MAT.527	Differential Geometry (Practical)	Skill based	0	0	2	1
MAT. 530	Topology	Core	3	0	0	3
MAT.568	Basics of Latex (Practical)	Skill based	0	0	2	1
Interdisciplinary Elective -(Choose any one course offered by other Departments)						
XYZ	Interdisciplinary Elective	IDC	2	0	0	2
Total			**20**	**0**	**4**	**22**

Interdisciplinary courses offered by Department of Mathematics and Statistics
(For the students of other Departments)

MAT.510	Basic Mathematics	IDC	2	0	0	2
MAT.529	Numerical Methods					

M.Sc. Mathematics (Semester-II)

Course Code	Course Title	Course Type	Credit Hours			Course Credits
			L	T	P	
MAT.526	Complex Analysis	Core	3	0	0	3
MAT.531	Abstract Algebra	Core	3	0	0	3
MAT.552	Calculus of Variation and Integral equations	Core	3	0	0	3
MAT.555	Differential Manifolds	Core	3	0	0	3
MAT.536	Basics of Mathematics Software	Skill based	0	0	2	1
MAT.561	Partial Differential Equations	Core	3	0	0	3
MAT.562	Measure Theory	Core	3	0	0	3
MAT.563	Partial Differential Equations (Practical)	Skill based	0	0	2	1
Discipline Elective Course (Opt any one of the following)						
MAT.512	Mathematical Statistics	DE				
MAT.532	Mathematical Modeling					
STA.511	Operations Research		3	0	0	3
Value added Course (opt any one course offered by other departments)						
XYZ	Value Added Course	VAC (Value based)	2	0	0	2
Total			**23**	**0**	**4**	**25**

Value added courses offered by Department of Mathematics and Statistics (For PG students of other Departments)

MAT.515	Vector and Tensor Analysis	VAC (Value Based)	2	0	0	2
MAT.528	Linear Programming					
MAT.534	Mathematical Methods					

M.Sc. Mathematics (Semester-III)

Course Code	Course Title	Course Type	Credit Hours			Course Credits
			L	T	P	
MAT.502	Research Methodology	Compulsory Foundation	4	0	0	4
MAT.571	Functional Analysis	Core	3	0	0	3
Discipline Elective Course (Opt any one of the following)						
MAT.556	Advanced Complex Analysis	DE	3	0	0	3
MAT.557	Advanced Partial Differential Equations					
MAT.558	Algebraic Topology					
MAT.572	Riemannian Geometry					
Discipline Elective Course (Opt any one of the following)						
MAT.560	Discrete Differential Geometry	DE	3	0	0	3
MAT.564	Category Theory					
MAT.565	Dynamical Systems					
MAT.566	Advanced Numerical Analysis					

MAT.569	Introduction to Cryptography					
MAT.567	Review of Mathematical Concepts (DEC)	Compulsory Foundation	2	0	0	2
STA.563	Entrepreneurship	Compulsory Foundation	1	0	0	1
MAT.600	Dissertation-Part I	Skill based	0	0	8	4
Total			**16**	**0**	**8**	**20**

M.Sc. Mathematics (Semester IV)

Course Code	Course Title	Course Type	Credit Hours			Course Credits
			L	T	P	
MAT.601	Dissertation-Part II	Skill Based	0	0	40	20

Total Credits for the course: 87

Evaluation Criteria for Core, Discipline Elective, Compulsory Foundation, VAC and IDC
A. Internal Assessment: [25 Marks]
B. Mid Semester Test: Based on Subjective Type Questions [25 Marks]
C. End Semester Exam: Based on 70% Subjective Type Questions and 30% Objective Type Questions [50 Marks]

Evaluation Criteria for Discipline Enrichment Course (DEC):
A. Surprise Tests [weighted 15%]
B. Assignments [weighted 10%]
C. Mid Semester Test: Based on Objective Type Questions [weighted 25%]

B. End Semester Exam: Based on Objective Type Questions [weighted 50%]

Evaluation Criteria for Entrepreneurship Course:

A. Mid Semester Test: Based on Objective Type Questions [25 Marks]

B. End Semester Exam: Based on Objective Type Questions [25 Marks]

Evaluation Criteria for Dissertation:

  A. Third semester (Based on proposal)
    a) Dissertation proposal and presentation: Supervisor [50 marks]
    b) Dissertation proposal and presentation: HoD and Senior most faculty [50 marks]

  B. Fourth semester (Based on Dissertation)
    c) Continuous assessment, report, presentations, viva voce: Supervisor [50 marks]
    d) Continuous assessment, report, presentations, viva voce: HoD, Senior most faculty, and External expert [50 marks]

Evaluation Criteria for Practical Courses

A. Practical file: [15 Marks]

B. Practical Exam: [75 Marks]

C. Viva-Voce Examination: [10 Marks]

Instructions regarding MOOC courses:

MOOCs may take up 40% of the total credits (excluding dissertation credits). MOOC may be taken in lieu of any course but content of that course should match a minimum 70%. Mapping is to be done by the respective department and students may be informed accordingly.

Instructions for Dissertation work:

Students will have an option to carry out dissertation work in industry, national institutes or Universities in the top 100 NIRF ranking. Group dissertation may be opted, with a group consisting of a maximum of four students. These students may work using a single approach or multidisciplinary approach. Research projects can be taken up in collaboration with industry or in a group from within the discipline or across the discipline.

Course Title: Real Analysis

Course Code: MAT.506

Course type: Core

Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1: Apply the knowledge of set theory and metric spaces with properties.
CLO2: Illustrate various properties of compact sets and connected sets.
CLO3: Explain concepts of convergent sequences and continuity in metric spaces.
CLO4: Apply the knowledge of Riemann Stieltjes Integrals.
CLO5: Discuss the problem of interchange of limit processes for sequences of functions and pointwise/Uniform convergence of sequence of functions.

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	**Metric spaces:** Definition and examples, Open and closed sets, Compact sets, Elementary properties of compact sets, k- cells, Compactness of k-cells, Compact subsets of Euclidean space $\Re^k$, Bolzano Weierstrass theorem, Heine Borel theorem, Perfect sets, Cantor set, Separated sets, Connected sets in a metric space, Connected subsets of real line. **Activity:** Students will solve some problems which will be based on concepts of compact sets and connected sets	CLO1 CL02
II	**Sequences in Metric spaces:** Convergent sequences,	CLO3

11 Hours	Subsequences, Cauchy sequences, Complete metric space with examples, Cantor's intersection theorem (Statement only), Category of a set and Baire's category theorem. Banach contraction principle. **Activity:** Students will solve some problems which will be based on application of sequences, category theorem and Banach contraction theorem.	
III 12 Hours	**Continuity:** Limits of functions (in Metric spaces), Continuous functions, Continuity and compactness, Continuity and connectedness, Discontinuities, Uniform continuity. **Riemann Stieltje's Integral:** Definition and existence of Riemann Stieltje's integral, Properties of integral. Integration and Differentiation. Fundamental Theorem of Calculus, 1st and 2nd Mean Value Theorems of Riemann Stieltje's integral. **Activity:** Students will do examples/exercises related to continuity and its characterizations. Students will explore how Riemann Stieltje's integral is a generalization of Riemann integral.	CLO4
IV 10 Hours	**Sequences and series of functions:** Problem of interchange of limit processes for sequences of functions, Uniform convergence, Uniform convergence and continuity, Uniform convergence and integration, Uniform convergence and differentiation. **Activity:** Students will explore how uniform convergence is related to integration and differentiation.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. T. M. Apostol, *Mathematical Analysis*, Addition –Wesley, USA, 1981.
2. R. G. Bartle, *The Elements of Real Analysis*, John Willey and Sons, New York, 1976.
3. A. Kumar and S. Kumaresan, *A Basic Course in Real Analysis*, Narosa, Publishing House, New Delhi, 2014.
4. W. Rudin, *Principles of Mathematical Analysis,* 3rd Edition, McGraw Hill, Kogakusha, International student Edition, 1976.
5. E. C. Titchmarsh, *The Theory of functions,* Oxford University Press, Oxford, 2002.

Course Title: Linear Algebra

Course Code: MAT.508

Course Type: Core

Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1 Review the basic notions in linear algebra that are often used in mathematics and other sciences

CLO2 Define Vector spaces, Subspaces and related results.

CLO3 Define linear transformations and characteristic polynomials with examples.

CLO4 Illustrate various properties of canonical forms.

CLO5 Study of Inner product spaces

CLO6 Explain concepts of the Gram-Schmidt orthogonalization process.

Unit I 12	Vector spaces, Subspaces: Definition and Examples, Linear dependence and independence, Basis and dimensions,	CLO1

Hours	Coordinates, Linear transformations, Algebra of linear transformations, Isomorphism, Matrix representation of a linear transformation **Activity:** Students will construct different vector spaces like a set of all continuous functions, set of all polynomials. They will define Linear transformation on these spaces.	
Unit II 12 Hours	Change of basis, Rank and nullity of a linear transformation. Linear functionals, Dual spaces, Transpose of a linear transformation. Annihilating Polynomials: Characteristic polynomial and minimal polynomial of a linear transformation, Characteristic values and Characteristic vectors of a linear transformation, Cayley Hamilton theorem. **Activity:** Students will explore the geometrical and physical meaning of Characteristic values and characteristics vectors.	CLO2
Unit III 12 Hours	Diagonalizing matrices, Diagonalizing real symmetric matrices, Characteristic polynomials and minimal polynomials of block matrices, Canonical forms: Jordan canonical forms, rational canonical forms. Quotient spaces, Bilinear forms, Symmetric and skew- Symmetric bilinear forms, Sylvester's theorem, quadratic forms, Hermitian forms. **Activity:** Students will solve the problems related to applications of canonical forms of matrices.	CLO3
Unit IV 09 Hours	Inner product spaces. Norms and distances, Orthonormal basis, Orthogonality, Schwarz inequality, The Gram-Schmidt orthogonalization process.Orthogonal and positive definite matrices. **Activity:** Students will explore the application of defining norm and the inner product on vector spaces.	CLO4 CLO5 CLO6

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. J. Gilbert and L. Gilbert, *Linear Algebra and Matrix Theory,* Cengage Learning, 2004.
2. K. Hoffman and R. Kunze: *Linear Algebra,* 2nd Edition, Pearson Education (Asia) Pvt. Ltd/ Prentice Hall of India, 2004.
3. V. Bist and V. Sahai, *Linear Algebra,* Narosa, Delhi, 2002.

4. S Lang, Linear Algebra, Undergraduate texts in mathematics, Springer, 1989.

Course Title: Ordinary Differential Equations	**L**	**T**	**P**	**Credits**
Course Code: MAT.509	3	0	0	3

Course Type: Core

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1. Define Initial, Boundary value problems and related results.
CLO2. Review the basic concepts of ordinary differential equations.
CLO3. Study of applications of Green's function in solving boundary value problems.
CLO4. Explain concepts of the two Dimensional Autonomous Systems.

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	**Existence and Uniqueness of Initial Value**	CLO1

	Problems: Picard's and Peano's Theorems, Gronwall's inequality, continuation of solutions and maximal interval of existence, continuous dependence. **Activity:** Students will try to find the applications of existence and uniqueness theorem of initial value problems	
II 11 Hours	**Higher Order Linear Equations and linear Systems:** fundamental solutions, Wronskian, variation of constants, matrix exponential solution, behaviour of solutions. **Activity:** Students will explore the use of Wronskian for checking the behaviour of solutions higher order linear equations and linear Systems	CLO2
III 12 Hours	Boundary Value Problems: Green's function and its applications to boundary value problems, Sturm-Liouville boundary value problem, Eigenvalues and Eigenfunctions. **Activity:** Students will solve some boundary value problems using the Green's function.	CLO3
IV 10 Hours	Two Dimensional Autonomous Systems and Phase Space Analysis: critical points, proper and improper nodes, spiral points and saddle points. **Activity:** Students will check the behavior of some dynamical systems by finding their critical points and checking their stability.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.
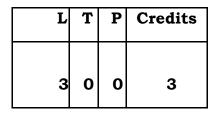

Suggested Readings:

1. E. A. Coddington and N. Levinson, *Theory of ordinary differential equations*. McGraw-Hill Book Company, Inc., New York-Toronto-London, 1955.
2. E. B. Williams and C. DiPrima Richard, *Elementary Differential Equations and Boundary Value Problems*, 8th Edition, John Wiley and Sons, New York, 2005.
3. G. F. Simmons and S. G. Krantz, *Differential Equations; Theory, Techniques and Practice*, Tata McGraw Hills, 2007.
4. L. Perko, *Differential Equations and Dynamical Systems*, Springer, 2001.
5. M. Hirsch, S. Smale and R. Deveney, Differential Equations, Dynamical Systems and Introduction to Chaos, Academic Press, 2004
6. S. L. Ross, *Differential Equations*, 3rd Edition, Wiley, 1984.

7. M. Rama Mohana Rao, Ordinary Differential Equations: Theory and Applications. Affiliated East-West Press Pvt. Ltd., New Delhi, 1980.

Course Title: Number Theory	L	T	P	Credits
Course Code: MAT.511				
Course Type: Core	3	0	0	3
Total Hours: 45				

Learning outcomes:

The students will be able to

CLO1: Apply the concept of divisibility of integers and congruences.
CLO2: Discuss various important properties and results of number theory.
CLO3: Develop the knowledge of number theoretic functions and explore their usage in various important results.
CLO4: Explain the representation of an integer as a sum of two or four squares.
CLO5: Explore the applications of quadratic residues and quadratic non-residues and the basics of Diophantine equations.

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	**Introduction to Number Theory:** Divisibility of Integers, Greatest common divisor, Euclidean algorithm. The theorem of arithmetic, Congruences, Residue classes and reduced residue classes. **Activity:** Students will work on different examples related to divisibility of integers, residue and reduced residue classes with applications.	CLO1 CL02
II	Chinese remainder theorem, Fermat's little theorem, Wilson's theorem, Euler's theorem.	CLO3

11 Hours	Arithmetic functions $\sigma(n)$, $d(n)$, $\tau(n)$, $\mu(n)$, Order of an integer modulo n, primitive roots for primes. **Activity:** Students will explore the use of number theoretic functions based on Chinese remainder theorem, Fermat's little theorem etc.	
III 12 Hours	**Quadratic Residues**: The theory of indices, Quadratic residues, Product of quadratic residues and quadratic non-residues, Euler's criterion, The Legendre symbol and its properties, Gauss's lemma, Quadratic reciprocity law, Jacobi symbol and its properties. **Activity:** Students will explore the concept of Legendre symbol and its applications to find the solution of quadratic congruences.	CLO4
IV 10 Hours	**Diophantine equations:** Representation of an integer as a sum of two and four squares, Diophantine equations $ax + by = c$, $x^2+y^2=z^2$ and its application to $x^4+y^4=z^2$. **Activity:** Students learn the basic of Diophantine equations and will find the integers which can or cannot be written as a sum of two and four squares.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. W. W. Adams and L. J. Goldstein, *Introduction to Number Theory*, Prentice Hall Inc., 1976.
2. T. M. Apostol, *Introduction to Analytic Number Theory*, Springer Verlag, 1976.
3. D. M. Burton, *Elementary Number Theory*, Tata McGraw-Hill, 7th Edition, New Delhi, 2012.

4. H. Davenport, *The Higher Arithmetic: An Introduction to the Theory of Numbers*, Cambridge University Press; 8 edition, 2008.
5. G. H. Hardy and E. M. Wright, *An Introduction to the Theory of Number*, Oxford Univ. Press, U.K., 2008.
6. I. Niven, S. Zuckerman, and H. L. Montgomery, *Introduction to Number Theory*, Wiley Eastern, 1991.

Course Title: Differential Geometry

Course Code: MAT.525

Course type: Core

Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1: Learn the basic concepts of plane and space curves.
CLO2: Understand the theory of surfaces in $\square^3$.
CLO3: Define the first and second fundamental forms.
CLO4: Illustrate various properties of curvature.
CLO5: Explain the theory of geodesics and relation between geometry and topology.

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	Curves in plane and space: Parameterized curves, Tangent vector, Arc length, Reparametrization, Regular curves, Curvature and torsion of smooth curves, Frenet-Serret formulae, Arbitrary speed curves, Frenet approximation of a space curve, Isometries of R^3, The Tangent Map of an Isometry, Orientation, Congruence of curves.	CLO1

	Activity: To find curvature and torsion of some important plane and space curves and study global properties of curves.	
II 11 Hours	**Surfaces in space:** Definition and examples, Smooth surfaces, Smooth maps, Tangents and derivatives, Normal and orientability. Examples of surfaces: Level surfaces, generalized cylinder and generalized cone, Ruled surfaces, Surface of revolution, Compact surfaces. First fundamental form, Isometries of surfaces, Conformal mapping of surfaces, Equiareal maps and theorem of Archimedes. **Activity:** To find the first fundamental form and surface area of some important surfaces.	CLO2
III 11 Hours	Second fundamental form, Gauss and Weingarten maps, Normal and geodesic curvatures, Meusnier's theorem, Parallel transport and covariant derivative, Gaussian and mean curvatures, Principal curvatures, Euler's theorem, Surfaces of constant Gaussian curvature, Flat surfaces, Surfaces of constant mean curvature, Gaussian curvature of compact surfaces. **Activity:** To find a second fundamental form, principal curvatures and Gaussian curvature of some important surfaces.	CLO3
IV 11 Hours	Geodesics: Definition and basic properties, Geodesic equations, Geodesics on a surfaces of revolution, Clairaut's theorem, Geodesics as shortest paths, Geodesic coordinates, Gauss and Codazzi-Mainardi equations,Gauss' Remarkable Theorem, Compact surfaces of constant Gaussian curvature. **Activity:** To find geodesics, geodesic equations and compact surfaces of constant Gaussian curvature.	CLO4 CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. C. Baer, *Elementary Differential Geometry*, Cambridge University Press, 2001.
2. M. P. Do Carmo, *Differential Geometry of Curves and Surfaces*, Revised and Updated Second Edition, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 2016.
3. A. Gray, E. Abbena, and S. Salamon, *Modern Differential Geometry of Curves and Surfaces with Mathematica*, Third edition, CRC Press, 2006.
4. R. S. Millman & G. D. Parkar, *Elements of Differential Geometry*, Englewood Cliffs, N.J. : Prentice Hall, 1977.
5. B. O' Neill, *Elementary Differential Geometry*, Revised Second Edition, Academic Press, 2006.
6. A. Pressley, *Elementary Differential Geometry*, Second Edition, Undergraduate Mathematics Series, Springer-Verlag London Ltd., 2010.
7. T. J. Willmore, *An Introduction to Differential Geometry*, First Edition, Dover Publications, Inc., Mineola, New York, 2012.

Course Title: Differential Geometry (Practical)

L	T	P	Credits
0	0	2	1

Course Code: MAT.527

Course Type: Skill based

Total Hours: 30

Laboratory work:

Students will use software MATHEMATICA/MATLAB for performing following activities

1. Plotting of plane curves. Computing the length and curvature of plane curves.

2. To determine velocity, speed and acceleration of parameterized curves.

3. Plotting of some special curves and their curvature, plotting of level curves.

4. To define and construct evolutes, involutes and parallel curves.

5. Graph of unit speed plane curve with assigned curvature function.

6. Translating, rotating and reflection of curves.

7. Constructing tangent, normal and binormal vectors and visualizing resulting Frenet frame for a space curve.

8. Plotting and computing curvature and torsion of space curves.

9. Plotting of space curves with assigned curvature and torsion.

10. Investigation of surface patches and associated normal vectors.

11. Visualization of nonorientable surfaces and the Gauss map.

12. Computation of the first fundamental form of various surfaces.

13. Computing the shape operator and various curvatures.

14. Modeling of surfaces formed from straight lines defined in one way or another by a space curve.

15. Construction of surfaces of revolution, obtained by starting from a plane curve.

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. C. Baer, *Elementary Differential Geometry*, Cambridge University Press, 2001.
2. M. P. Do Carmo, *Differential Geometry of Curves and Surfaces*, Revised and Updated Second Edition, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 2016.
3. A. Gray, E. Abbena, and S. Salamon, *Modern Differential Geometry of Curves and Surfaces with Mathematica*, Third edition, CRC Press, 2006.

4. R. S. Millman & G. D. Parkar, *Elements of Differential Geometry*, Englewood Cliffs, N.J. : Prentice Hall, 1977.

	L	T	P	Credits
Course Title: Topology	3	0	0	3

Course Title: Topology

Course Code: MAT.530

Course type: Core

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1: Describe Topological spaces with examples and related concepts in detail.
CLO2: Explain continuous functions in topology and its characterizations.
CLO3: Understand various topological properties with examples.
CLO4: Explain the concept of Compact spaces and its consequences.
CLO5: Discuss various separation axioms with their usage to prove many important results in topology.

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	Topological spaces: Open sets, Closed sets, Neighborhoods, Bases, Sub bases, Limit points, Closures, Interiors, Continuous functions, Homeomorphisms. Examples of topological spaces: Subspace topology, Product topology, Metric topology. **Activity:** Students will work with some new topological spaces and continuous functions defined on them. They will try to find spaces which are Homeomorphic or not.	CLO1 CL02
II 12 Hours	Quotient Topology: Construction of cylinder, Cone, Mobius band and Torus. Connected spaces, Connected subspaces of the real line, Components and path components, Local connectedness. **Activity:** Students will work on how various topological surfaces are constructed. They will also work on various examples of connected and disconnected spaces and its applications to detect when two topological spaces are not homeomorphic.	CLO3
III 11 Hours	Compact spaces, Sequentially compact spaces, Heine-Borel theorem, Compact subspaces of the real line, Limit point compactness, Local–compactness and one point compactification. **Activity:** Students will explore other important topological properties with examples and applications which will again help to determine non-homeomorphic topological spaces.	CLO4

IV 10 Hours	Separation axioms: Hausdorff spaces, Regularity, Complete regularity, Normality, Urysohn lemma, Urysohn Metrization Theorem, Tietze Extension theorem and Tychnoff theorem (Statements only). **Activity:** Students will try to find applications of different separation axioms along with its importance to find new results in topology.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. M. A. Armstrong, *Basic Topology*, Paperback Edition, Springer, 2004.
2. James Dugundji, *Topology,* Universal Book Stall, New Delhi, 1990.
3. J. L. Kelley, *General Topology*, GTM, First Edition, Springer, 1975.
4. S. Kumaresan, *Topology of Metric Spaces,* second edition, Narosa Publishing House New Delhi, 2015.
5. J. R. Munkres, *Topology,* Second Edition, Pearson India Education services Pvt. Ltd., 2015.
6. G. F. Simmons, *Introduction to Topology & Modern Analysis*, McGraw Hill, Auckland, 1963.

Course Title: Basics of LateX (Practical)

Code: MAT.568

Total Hours: 30

Course Type: Skill based

L	T	P	Credits
0	0	2	1

Laboratory work:

Students will use software(s) TeXmaker/ Overleaf etc., for performing following activities:

1. Installation of the LaTeX software in Windows and Linux and understanding LaTeX compilation and LaTeX editors.
2. Basic syntax used in LaTeX.
3. Writing mathematical equations, Matrices, Tables, Inclusion of graphics into LaTeX file.
4. Page configurations**:** Title, Abstract, Keywords, Chapter, Sections and Subsections.
5. References and their citations.
6. Labeling of equations, Table of contents, List of figures.
7. Use of Packages**:** amsmath, amssymb, amsthm, amsfonts, graphic.
8. Use of document classes**:** Article, Report, Book, Beamer.
9. Applications of LaTeX in writing reports, books, research papers and thesis.

Transaction mode: Lecture/Demonstration/ Co Operative learning/ programming / Practical/ Group discussion/Team teaching/Experimentation/Tutorial/Problem solving/Self-learning.

Suggested Readings:

1 D. F. Griffiths and D. J. Higham, *Learning LaTeX,* 2nd Edition, Philadelphia, Pennsylvania, SIAM, 1997.

2 L. Lamport. LATEX: A Document Preparation System, User's Guide and Reference Manual. 2nd Edition, Addison Wesley, New York, 1994.

M. Goossens, F. M. Michel, and S. Alexander, The LaTeX companion, 2nd Edition, Addison-Wesley, 1994.

	L	T	P	Credits
Course Title: Basic Mathematics	2	0	0	2

Course Code: MAT.510

Course Type: IDC

Total Hours: 30

Learning outcomes:

The students will be able to

CLO1: Define sets and functions with related concepts.

CLO2: Define the concept of functions and relations.

CLO3: Relate the concept of Arithmetic progression and Geometric progression and their sum.

CLO4: Explain the description of algebraic properties of complex numbers.

CLO5: Explore the theory of Matrices and Determinants.

Units/ Hours	Contents	Mapping with CLO
I 08 Hours	**Sets**: Basic Definitions, subsets, power set, set operations. Ordered pairs, Cartesian product of sets. **Functions and Relations:** Definition of relation, domain, co-domain and range of a relation. Binary relations, equivalence relations, partition. Function as a special kind of relation from one set to another. Domain, co-domain and range of a function. Composition, inverse. Real valued function of the real variable, constant, identity, Polynomial, rational, Functions. **Activity:** Students will try to find the applications of functions and relations.	CLO1 CL02
II 07 Hours	Sequence and series, Arithmetic Progression (A.P), Arithmetic Mean (A.M), Geometric Progression (G.P), general term of a G.P, sum of n terms of a G.P. Arithmetic and Geometric series, infinite G.P. and its sum. Geometric mean (G .M), relation between A.M and G.M. **Activity:** Students will solve some problems related to these sequences and series.	CLO3

III 08 Hours	Need for complex numbers, especially $\sqrt{-1}$, to be motivated by inability to solve every Quadratic equation. Brief description of algebraic properties of complex numbers. Argand plane and polar representation of complex numbers, Statement of Fundamental Theorem of Algebra, n^{th} roots of unity. **Activity:** Students will solve some problems related to the complex number.	CLO4
IV 07 Hours	Matrices and types of matrices, Operations on Matrices, Determinants of Matrix and Properties of Determinants, Minors and Cofactor and Adjoint of a square matrix, Singular and non-singular Matrices, Inverse of a Matrix, Eigen-values and Eigenvectors, Cayley Hamilton theorem. **Activity:** Students will solve some problems related to the matrices and determinants of a matrix.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Reading:

1. E. Kreyszig, *Advanced Engineering Mathematics*, 9th edition, John Wiley & Sons, Inc., 2006.
2. E. Kreyszig, *Advanced Engineering Mathematics*, 9th edition, John Wiley & Sons, Inc., 2006.
3. G. B. Thomas and R. L. Finney, *Calculus and Analytic Geometry*, 11th edition, Pearson India, 2015.
4. P. K. Jain, *Mathematics: Text book for class XI*, NCERT, 2006.
1. R. K. Jainand S.R.K. Iyengar, *Advanced Engineering Mathematics*, 8th Edition, Narosa Publications, 2002.

Course Title: Numerical Methods	L	T	P	Credits
Course Code: MAT.529	2	0	0	2

Course Title: Numerical Methods

Course Code: MAT.529

Course Type: IDC

Total Hours: 30

Learning outcomes:

The students will be able to

CLO1. Explain the basic concept of errors.
CLO2. Review the basic concepts of various numerical techniques for a variety of mathematical problems occurring in science and engineering.
CLO3. Review the numerical techniques for interpolation and approximations with examples.
CLO4. Explain the concept of numerical solutions of differential equations.

Units/ Hours	Contents	Mapping with CLO
I 7 Hours	**Error Analysis:** Relative error, Truncation error, Roundoff error, Order of approximation, Order of convergence, Propagation. **Activity:** Students will explore the use of error analysis and rounding in some daily life problems like measuring.	CLO1
II 8 Hours	**Roots of Nonlinear Equations:** Bisection method, Secant method, Newton Raphson method, Convergence and order of convergence. **Activity:** Students will explore the use of these methods in solving some real life problems.	CLO2

III 8 Hours	**Linear Systems of Equations:** Gauss elimination and Gauss-Seidel methods. **Interpolation**: Lagrange's Method, Newton's polynomials. **Activity:** Students will explore the use of these methods in solving some real life problems.	CLO3
IV 7 Hours	**Solution of Differential Equations:** Euler's method, Heun's method, Taylor series method, RungeKutta method. **Activity:** Students will explore the use of these methods in solving some scientific problems.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Reading:

1. C. F. Gerald and P. O. Wheatly,*Applied Numerical Analysis*, 7th Edition, Pearson LPE, 2009. *Computation*, 6th Edition, New Age International, New Delhi, 2015.

2. J. I. Buchaman and P. R. Turner, *Numerical Methods and Analysis,* Prentice-Hall, 1988.
3. K. Atkinson, *An Introduction to Numerical Analysis,* 2nd Edition, John Wiley & Sons, 2012.

4. M. K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering*

5. R. S. Gupta, *Elements of Numerical Analysis*, 2nd Edition, Cambridge University Press, 2015.

6. S. S. Sastry, *Introduction Methods of Numerical Analysis*, 4th Edition, Prentice-Hall, 2005.

M. Sc. Mathematics

Semester-II

Course Title: Complex Analysis	L	T	P	Credits
Course Code: MAT.526	3	0	0	3

Course Type: Core

Total Lectures: 45

Learning outcomes:

The students will be able to

CLO1: Recall complex number systems and algebra of complex variables.

CLO2: Illustrate the concept of analytic function and discuss the necessary and sufficient conditions for a function to be analytic.

CLO3: Understand the notion of complex line integral and related results.

CLO4: Discuss Mobius transformations and their properties.

CLO5: Apply ideas of Complex analysis in allied areas.

Units/ Hours	Contents	Mapping with CLO
I 10 Hours	Functions of a complex variable, limit, continuity, uniform continuity, differentiability, analytic function, Cauchy- Riemann equations, harmonic functions and harmonic conjugate. **Activity:** Students will make use of Cauchy-Riemann equations to investigate the functions of	CLO1 CL02

	complex variables which are analytic or not.	
II 12 Hours	Complex line integral, Cauchy's theorem, Cauchy-Goursat theorem, Cauchy's integral formula and its generalized form, Cauchy's inequality. Poisson's integral formula (Statement only), Morera's theorem. Liouville's theorem. Contour integral, power series, Taylor's and Laurent's series.\n\n**Activity:** Students will find the applications of important theorems like Cauchy's theorem and Cauchy's integral formula. They will also work on various examples of contour integrals.	CLO3
III 12 Hours	Singularities of analytic functions, Fundamental theorem of algebra, zeros of analytic function, poles, residues, residue theorem and its applications to contour integrals. Maximum modulus principle, Schwarz lemma.\n\n**Activity:** Students will do the examples related to singularities and poles of analytic functions. They will explore the concept of residues and its applications to solve contour integrals.	CLO4

IV 11 Hours	Meromorphic functions, the argument principle, Rouche's theorem, Mobius transformations and their properties, definition and examples of conformal mappings. **Activity:** Students will explore the concept of Mobius transformations and its applications in different fields.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. H.S. Kasana, *Complex Variables:Theory and Applications,* 2nd Edition, PHI Learning Pvt. Ltd, 2005.
2. R. V. Churchill & J. W. Brown, *Complex Variables and Applications*, 8th Edition, Tata McGraw-Hill, 2014.
3. S. Ponnusamy, *Foundations of Complex Analysis*, 2nd Edition, Narosa Publishing House, 2007.
4. Theodore W. Gamelin, *Complex Analysis*. UTM, Springer-Verlag 2001.
5. W. Tutschke and H.L. Vasudeva, *An Introduction to Complex Analysis, Classical and Modern Approaches*, 1st Edition,CRC Publications, 2004.
6. Rajendra Kumar Sharma, Sudesh Kumari Shah and Asha Gauri Shankar, *Complex Numbers and Theory of Equations*, Anthem Press, 2011

Course Title: Abstract Algebra	L	T	P	Credits
Course Code: MAT.531				
Course Type: Core	3	0	0	3

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1: Explore the basic notions in group theory.

CLO2: Learn the applications of group theory in various fields of cryptography.

CLO3: Explain the basics of ring theory and ideals with examples and their applications.

CLO4: Illustrate various properties of finite fields and representation of elements of finite fields in different ways.

CLO5: Explore the properties of the splitting field and its various applications.

CLO6: Explore the concept of extension fields and their applications in cryptography and coding theory.

Units/ Hours	Contents	Mapping with CLO
I

12 Hours | **Group Theory:** Review of basic concepts of groups, Subgroups, Normal subgroups, Quotient groups, Homomorphism, Cyclic groups, Permutation groups, Alternating groups, Cayley's Theorem, Class equations. Fundamental theorem for finite Abelian groups, Sylow's theorems and their applications. | CLO1

CL02 |

	Activity: Students will work on different examples related to group theory and will explore the use of group theory in real life problems.	
II 11 Hours	**Ring Theory:** Review of basic concepts of rings, Units, Zero divisors, Nilpotent and idempotent elements, Characteristic of rings, Ideals, Ring homomorphism, Maximal and prime ideals, Polynomial rings, Unique factorization Domains, Euclidean and Principal ideal Domains. Gauss lemma, Eisenstein's irreducibility criterion. **Activity:** Students will explore the properties of ring and will solve some problems related to these concepts.	CLO3
III 12 Hours	**Field Extensions:** Field, Prime Field, Algebraic Extension, Simple Extension, Minimal Polynomial of an Algebraic Element, Finite Extension, Transitivity of Finite Extension, Simple Algebraic Extension, Splitting fields. Characterization of Finite Fields, Existence and Uniqueness of Finite Fields, Subfields of a Finite Field. **Activity:** The students will explore the concept of field extension and its applications. The students will solve problems related to these concepts.	CLO4 CLO5
IV 10 Hours	**Roots of an Irreducible Polynomial over Finite Fields**: Nature of roots, Trace function and its properties, Transitivity of trace, Norm function and its properties, Transitivity of norm, Bases, Dual bases, Normal basis, Artin lemma, Normal basis theorem, Representation of elements of finite fields **Activity:** The students will solve problems related to trace and norm functions. Also, they will explore the	CLO6

use of these concepts in advance algebra, coding theory and cryptography.			

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. M. Artin, *Algebra,* 2nd Edition, Prentice Hall of India, Delhi, 2011.
2. R. Lidl and H. Niederreiter, Introduction to finite fields and Applications, Revised edition, Cambridge University Press, 1992.
3. P. B. Bhattacharya, S. K. Jain and S.R Nagpal, *Basic Abstract Algebra*, Cambridge University Press, New Delhi, 2003.
4. J. A. Gallian,*Contemporary Abstract Algebra,* Narosa Publishing House, New Delhi, 2008.
5. N. S. Gopalakrishnan, *University Algebra*, John Wiley & Sons, 1986.
6. N. Herstein, *Topics in Algebra*,2nd Edition, Wiley Eastern Limited, New Delhi, 2006.
7. I. S. Luthar and I. B. S. Passi, *Algebra Vol. II: Rings*, Narosa Publishing House, 1999.
8. I. B. S. Passi and I. S. Luthar, *Algebra Vol. I: Groups*, Narosa Publishing House, 1996.
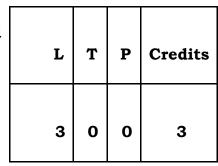
Course Title: Calculus of Variations and Integral Equations	L	T	P	Credits
Course Code: MAT.552				
Course Type: Core	3	0	0	3

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1: Explain the basic concept of Functional.
CLO2: Review the basic concepts of variational methods, for boundary value problems in ODE's & PDE's.

CLO3: Explain the basic concept of isoperimetric problems.
CLO4: Explain the basic concept of Volterra and Fredholm Integral Equations.

CLO5: Illustrate various properties of Volterra and Fredholm Integral Equations.

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	Functional, variation of functional and its properties, fundamental lemma of calculus of variation, Euler's-Lagrange equation of single independent and single dependent variable and application. Necessary and sufficient conditions for extrema. Brachistochrone problem, functional involving higher order derivatives. Activity: Exercises depending on unit-I	CLO1 CL02
II 11 Hours	Sturm-Liouville's theorem on extremals, one sided variations, Hamilton's principle, Hamilton's canonical equation of motion, The principle of least action, Langrange's equations from Hamilton's principle. variational methods, for boundary value problems in ODE's & PDE's, isoperimetric problems. Activity: Exercises depending on unit-II	CLO3

III 12 Hours	Volterra equations: Integral equations and algebraic system of linear equations. L_2 kernels and functions of Volterra equation. Volterra equations of first and second kind. Volterra integral equation and linear differential equation. Activity: Exercises depending on unit-III	CLO4
IV 10 Hours	Fredholm Equations: solution by the method of successive approximations. Solution of Fredholm integral equation for degenerate kernel, solution by the successive approximations, Neumann series and resolvent kernel. Activity: Exercises depending on unit-IV	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. H. Goldstein, *Classical Mechanics,* 2nd Edition, Narosa Publishing House, 1980.
2. J. L. Synge and B.A. Griffith, *Principle of Mechanics,* McGraw-Hill Book Company, 1970.
3. M.D. Raisinghania, *Integral equations and boundary value problems,* 9th Edition, S. Chand Publishing, New Delhi, 2016.
4. R. P. Kanwal, *Linear integral equations*, Birkhauser, Boston, 1996.
5. Rakesh Kumar and Nagendra Kumar, *Differential Equations and Calculus of Variations,* CBS Publishers and Distributors Pvt Ltd, 2013.

Course Title: Differentiable Manifolds

Course Code: MAT.555

Course Type: Core

Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1: Explain the basic concept of smooth manifolds and smooth functions.
CLO2: Review the basic concepts of Submersions, Immersions and embeddings, Smooth covering maps and Bump functions.
CLO3: Explain the concepts of Vector fields, Lie brackets and Lie groups.
CLO4: Define the differential forms, exterior derivative, exterior algebra and Lie derivative.

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	Topological manifolds, Charts, Atlases, Smooth manifolds, Examples of smooth manifolds, Manifolds with boundary, Smooth functions on a manifold, Smooth maps between manifolds, Examples of smooth maps, Diffeomorphism, Smoothness in terms of components, Bump functions and Partition of Unity. **Activity:** Exercises on charts, atlases and smooth maps.	CLO1
II 11 Hours	Tangent space and tangent bundle, The Differential of a smooth map, Chain rule, Bases for the tangent space at a point, Rank of a smooth map, Submersions, Immersions and embeddings, Critical and regular points, Submersion and immersion theorems, Smooth covering maps, Submanifolds: Embedded submanifolds, Immersed submanifolds,	CLO2

	Restricting maps to Submanifolds **Activity:** Exercises on Rank of smooth map, submersion, immersion and embedding.	
I 11 Hours	Topological groups, Lie groups, The product of two Lie groups, Lie subgroups, One parameter subgroups and exponential map, Homomorphism and isomorphism in Lie groups, Lie transformation groups, The tangent space and Left invariant vector fields of a Lie group. Vector fields on manifolds, Lie brackets and Lie Algebra of a Lie group. **Activity:** Exercises on vector fields, Lie Groups and Lie subgroups.	CLO3
I 11 Hours	Cotangent spaces and Cotangent bundles, Differential forms, pullback of differential forms, Exterior product, Exterior algebra, Exterior derivative and Lie derivative. **Activity:** Exercises on Exterior product, exterior derivative and Lie derivative.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. W. M. Boothby, *An Introduction to Differentiable Manifolds and Riemannian Geometry*, 2nd edition, Academic Press, New York, 2003.
2. S. S. Chern, W. H. Chen and K. S. Lam, *Lectures on Differential Geometry*, World Scientific Publishing Co. Pvt. Ltd., 2000.
3. L. Conlon, *Differentiable Manifolds*, 2nd edition, Birkhauser Boston, Cambridge, MA, 2001.

4. N. J. Hicks,*Notes of Differential Geometry*, D. Van Nostrand Reinhold Company, New York, 1965.
5. S. Kumaresan, *A Course in Differential Geometry and Lie Groups (Texts and Readings in Mathematics),* Hindustan Book Agency, 2002.
6. J. M. Lee, *Introduction to Smooth Manifolds*, GTM, Vol. 218, Springer, New York, 2003.
7. W. Tu, *An Introduction to Manifolds*, Second edition, Springer, 2011.

Course Title: Basics of Mathematics Software	**L**	**T**	**P**	**Credits**
Course Code: MAT.536	**0**	**0**	**2**	**1**

Course Type: Skill based

Total Hours: 30

To be performed using Computer with aid of MATLAB/MATHEMATICA/MAPLE or any other such software

1. Plotting the graphs of the functions,$\exp(ax+b)$, $\log(ax+b)$,$1/ax+b$,$\sin(ax+b)$, $\cos(ax+b)$ and $|ax+b|$to illustrate the effect of a and b on the graph.
2. Plotting the graphs of the polynomial of degree 4 and 5.
3. Sketching parametric curves (E.g. Trochoid, cycloid, hypocycloid).
4. Obtaining the surface of the revolution of curves.
5. Tracing of conics in Cartesian coordinates/polar coordinates.
6. Sketching ellipsoid, hyperboloid of one and two sheets (using Cartesian coordinates).
7. Construction of matrices and arithmetic operations among the matrices.

BOOKS RECOMMENDED:

1. Peter I. Kattan, MATLAB for Beginners: A Gentle Approach, Publisher: Petra Books, 2008.
2. H.Anton, I.Bivensand S.Davis, Calculus,10thEd., JohnWileyand Sons(Asia) P.Ltd., Singapore, 2002.
3. Shanti Narayan, P. K. Mittal, Differential Calculus, S. Chand, 2014.
4. Shanti Narayan, P. K. Mittal, Integral Calculus, S. Chand, 2014.
5. James Stewart, Single Variable Calculus, Early Transcendentals, Cengage Learning, 2016. 2. G.B. Thomas and R.L. Finney, Calculus, 9th Ed., Pearson Education, Delhi,2005.

Course Title: Partial Differential Equations

Course Code: MAT.561

Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1. Review the basic concepts of Cauchy Problems for First Order Hyperbolic Equations.
CLO2. Explain the methods for solving second order Partial Differential Equations with variable coefficients.
CLO3. understand how the the solutions of problems are dependent on Initial and Boundary values
CLO4. apply the method of separation of variables for solving Heat, Wave and Laplace equations.

Units/ Hours	Contents	Mapping with CLO
I 10 Hours	Cauchy Problems for First Order Hyperbolic Equations: method of characteristics, Integral surface passing through given curve. **Activity:** Students will explore the formation of partial differential equations representing some real phenomena.	CLO1
II 11 Hours	PDEs of second order with variable coefficients: Classification of second order PDEs, Canonical form, Parabolic, Elliptic and Hyperbolic PDEs, Well posed problems, Super imposition principle. **Activity:** Students will explore the formation of second order partial differential equations representing some real phenomena.	CLO2

III 12 Hours	Initial and Boundary Value Problems: Lagrange-Green's identity and uniqueness by energy methods. Stability theory, energy conservation and dispersion. **Activity:** Students will explore how the solutions of problems behave if we change the initial and boundary conditions.	CLO3
IV 12 Hours	Laplace equation: mean value property, weak and strong maximum principle, Green's function, Heat equation: initial value problem, fundamental solution, weak and strong maximum principle and uniqueness results. Wave equation: uniqueness, D'Alembert's method **Activity:** Students will derive the Laplace, heat and wave equations.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. L. C. Evans, *Partial Differential Equations. Graduate Studies in Mathematics*, 2nd Edition, American Mathematical Society, Indian Reprint, 2014.
2. S. J. Farlow, *Partial Differential Equations for Scientists and Engineers*, Birkhauser, New York, 1993.
3. F. John, *Partial Differential Equations,* Springer-Verlag, New York, 1982.
4. K, Sankara, Rao, *Introduction to Partial Differential Equations*, PHI Learning, 2010.
5. Ian N. Sneddon, *Elements of Partial Differential Equations,* Dover Publications, 2013
6. E. DiBenedetto, Partial Differential Equations, Birkhaüser, 1995.

Course Title: Measure Theory

Course Code: MAT.562

Course Type: Core

Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1. Explore the concept of algebras, σ –algebras and borel sets.
CLO2. Define Lebesgue outer measure and Lebesgue measure on R with their characterizations.
CLO3. Explain measurable functions and their properties.
CLO4. Discuss important theorems related to Lebesgue integral.
CLO5. Get in-depth understanding of L^p spaces.

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	Semi-algebras, Algebras, Monotone class, σ -algebras, Measure and outer measures, Outline of extension of measures from algebras to the generated sigma-algebras: Measurable sets; Lebesgue Measure and its properties. Borel sets, Lebesgue outer measure and Lebesgue measure on R, Translation invariance of Lebesgue measure **Activity:** Students will find the outer measure of some sets and will apply these concepts in integration.	CLO1 CLO2
II 11 Hours	Continuity of measure and Borel-Cantelli Lemma, Existence of a non-measurable set, Measurability of Cantor set.	CLO3

	Measurable functions on a measure space and their properties, Borel and Lebesgue measurable functions, Simple functions and their integrals, Littlewood's three principle and Egoroff's Theorem (statements only). **Activity:** Students will find some non-measurable sets and measurable functions. They will also try the proof of Littlewood's three principles and Egoroff's Theorem.	
III 11 Hours	Lebesgue integral on R and its properties. Bounded convergence theorem, Fatou's lemma, Lebesgue monotone convergence theorem, Lebesgue dominated convergence theorem, countable additivity and continuity of integration. **Activity:** Students will compare the Riemann integral and Lebesgue integral. They will also work on the counter examples where the above theorems fail to hold.	CLO3
IV 11 Hours	Functions of bounded variations: Jordan's theorem, L^p spaces, Young's inequality, Minkowski's and Hölder's inequalities, Riesz-Fischer theorem (statement only). **Activity:** Students will write some functions of bounded variations as the difference of two increasing functions.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. G.de Barra, *Measure Theory and Integration,* Ellis Horwood Limited, England, 2003.
2. G.B. Folland, *Real Analysis,* 2nd Edition, John Wiley, New York, 1999.
3. P. R. Halmos, *Measure Theory,* 14th Edition, Springer, New York, 1994.
4. B. Krishna and A. Lahiri, *Measure Theory,* Hindustan Book Agency, 2006.
5. I. K. Rana, *An Introduction to Measure and Integration,* 2nd Edition, Narosa Publishing House, New Delhi, 2005.
6. H. L. Royden, *Real Analysis,* Macmillan, New York, 1988.

Course Title: Partial Differential Equations (Practical)	L	T	P	Credits
Course Code: MAT.563	0	0	2	1

Course Type: Skill based

Total Hours: 30

List of Practicals (using any software)

1. Overview of software like MATLAB, MATEMATICA etc,.
2. Solution of Cauchy problem for first order PDE.
3. Finding the characteristics for the first order PDE.
4. Plot the integral surfaces of a given first order PDE with initial data.
5. Solution of the wave equation for the associated conditions.
6. Solution of heat equation for the associated conditions.

Books Recommended

1. Tyn Myint-U and Lokenath Debnath, *Linear Partial Differential Equations for Scientists and Engineers,* 4th Ed., Springer, Indian reprint, 2006.

2. S.L. Ross, *Differential Equations,* 3rd Ed., John Wiley and Sons, India, 2004.

3. Martha L Abell, James P Braselton, *Differential Equations with MATHEMATICA,* 3rd Ed., Elsevier Academic Press, 2004.

Course Title: Mathematical Statistics

L	T	P	Credits
3	0	0	3

Course Code: MAT.512

Course type: Discipline Elective Course

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1: Define the sample space and concept of random variables (discrete and continuous).
CLO2: explore the concept of Expectations, Moment generating function and characteristic functions with examples.
CLO3: Illustrate various properties of Discrete and continuous Distributions.
CLO4: Explain concepts of sampling distribution and its standard error, Chi-square, t and F distribution.

Units/ Hours	Contents	Mapping with CLO
I 11 Hours	Concept of random variables (discrete and continuous). Distribution Function and its properties, mean and variance. Bivariate random variables and their joint, marginal and conditional p.m.fs. and p.d.fs. Independence of random variables. **Activity:** Students will try to work on various examples related to the concepts of p.m.fs. and p.d.fs of random variables.	CLO1
II 12 Hours	Expectation, Conditional expectation, Moments, Moment generating function and its properties,,	CLO2

	Tchebyshey's inequalities, Markov's inequality, Jensen's inequality, Characteristic function and its elementary properties, weak and strong laws of large numbers, Central Limit theorems (i.i.d. case). **Activity:** Students will explore the use of expectations and its properties in various concepts of statistics. They will also solve problems based on moment generating functions, characteristic functions and weak & strong law of large numbers.	
III 11 Hours	Discrete Distributions: Bernoulli, Binomial, Poisson, hyper-geometric, geometric, negative binomial. Continuous Distributions: Uniform, normal, exponential, gamma, Beta. **Activity:** Students will explore the use of these discrete and continuous distributions in real life problems.	CLO3
IV 11 Hours	Chi-square, t and F distributions and their applications. Elementary concepts in testing of statistical hypotheses, Tests of significance: tests based on normal distribution, Chi-square, t and F statistic. **Activity:** Students will do the examples applying the tests based on normal distribution, Chi-square, t and F statistic	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. E. J. Dudewicz and S. N. Mishra, *Modern Mathematical Statistics*, Wiley International Student Edition, 1988.

2. I. Miller and M. Miller, *Mathematical Statistics,* 6th Edition, Oxford & IBH Pub., 1999.

3. P. Billingsley,*Probability and Measure*,4th Edition, John Wiley & Sons, 2012.

4. P.L. Meyer, Introductory probability and statistical applications, Addison-Wesley Publishing Company, Inc., 1972.

5. S. M. Ross, *Introduction to Probability Models*, 11th Edition, 2014.

6. V. K. Rohtagi and A. K. M. E. Saleh, *An Introduction to Probability Theory and Mathematical Statistics*, Wiley Eastern, 2010.

Course Title: Mathematical Modeling

Course Code: MAT.532

L	T	P	Credits
3	0	0	3

Course type: Discipline Elective Course

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1. Understand the mechanics, uses, and limitations of the modeling process
CLO2. learn the role of eigenvalues in stability analysis
CLO3. Apply population models in various situations.

CLO4. Learn the basic concepts of Hopf bifurcation.

Units/ Hours	Contents	Mapping with CLO
I 11 Hours	Overview of mathematical modeling and types of mathematical models, Introduction to population dynamics, solution methods of linear difference equations and discrete time model. **Activity:** Students will study some epidemic models.	CLO1
II 11 Hours	Linear system theory, stability analysis, role of eigenvalues & vectors and phase diagrams. **Activity:** Students will study some autonomous systems and will check their stability.	CLO2
III 11 Hours	Single-species population model, Allee effect, Predator-Prey model, Lotka-Volterra model and SIR model. **Activity:** Students will study some population models with available data.	CLO3
IV 12 Hours	**I**ntroduction to models in chemical-kinetics, Hopf bifurcation, Poincare-Bendixson theory and index theory. **Activity:** Students will study the bifurcation of some first order differential equation systems.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. Brauer, F., Driessche, P. V. D. and Wu, J., Mathematical Epidemiology, Springer, 2008.
2. Keshet, L. E., Mathematical Models in Biology, SIAM, 1988.
3. Giordano, Fox, Horton, A First Course in Mathematical Modeling, 5th edition, Cengage, 2013.
4. Clive L. Dym, Principles of Mathematical Modelling, Elsevier Press, Second Edition, 2004.
5. Edward A. Bender, An Introduction to Mathematical Modeling, Dover, 2000.

Course Title: Operations Research

Course Code: STA.511

L	T	P	Credits
3	0	0	3

Course type: Discipline Elective Course

Course Type: DE

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1: Discuss the concept of convex sets and linear programming problems with formulation.
CLO2: Apply different methods to solve linear programming problems.
CLO3: explore the concept of Duality theory and Sensitivity analysis.

CLO4: Explain transportation problems and assignment problems with their mathematical formulation.
CLO5: Apply methods to test the optimality of transportation problems.
CLO6: Develop understanding of Queuing and inventory models.

Units/ Hours	Contents	Mapping with CLO
I 11 Hours	Mathematical formulation of linear programming problem, Linear Programming and examples, Convex Sets, Hyper plane, Open and Closed half-spaces, Feasible, Basic Feasible and Optimal Solutions, Extreme Point & graphical methods. **Activity:** Students will formulate linear programming problems and find solutions with graphical methods.	CLO1 CLO2
I 11 Hours	Simplex method, Big-M method, Two phase method, Determination of Optimal solutions, Unrestricted variables. Duality theory, Dual linear Programming Problems, Fundamental properties of dual problems, Complementary slackness, Unbounded solution in Primal. Dual Simplex Algorithm. **Activity:** Students will do problems to find solutions through Simplex method, Big-M method and two phase method. They will exercise dual linear programming problems.	CLO3
I 11 Hours	Sensitivity analysis: Discrete changes in the cost vector, requirement vector and coefficient matrix. The General transportation problem, Duality in transportation problem, Loops in transportation tables, Solution of transportation problem, Test for optimality, Degeneracy, Transportation algorithm (MODI method), Minimization transportation problem. **Activity:** Students will do exercises on Sensitivity analysis and transportation problems.	CLO4

I 11 Hours	Assignment Problems: Mathematical formulation of assignment problem, Hungarian method for solving assignment problems, Traveling salesman problem. Sequencing Problem: General assumptions and basic terms used in sequencing. Processing n jobs through 2 machines, Processing n jobs through 3 machines. **Activity:** Students will do exercises on Assignment problem and sequencing problem	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. G. Hadley, *Linear Programming*, Narosa Publishing House, New Delhi, 1987.
2. H. A. Taha, *Operations Research - An Introduction*, Macmillan Publishing Company Inc., New York, 2006.
3. K. Swarup, P. K. Gupta, and M. Mohan, *Operations Research*, Sultan Chand & Sons, New Delhi, 2001.
4. N. S. Kambo, *Mathematical Programming Techniques*, Affiliated East-West Press Pvt. Ltd., 1984, Revised Edition, New Delhi, 2005.
5. S. M. Sinha, *Mathematical Programming, Theory and Methods,* Delhi: Elsevier, 2006.

		L	T	P	Credits
Course Title: Vector and Tensor Analysis					
Course Code: MAT.515		2	0	0	2

Course Type: VAC

Total Lectures: 30

Learning outcomes:

The students will be able to

CLO1: Explain and use vector dot product and cross product.
CLO2: Understand the Gradient, Divergence and Curl.
CLO3: Understand and use Green's Theorem, Stokes Theorem and Divergence Theorem.
CLO4: Understand Tensors and their applications in Mathematics and allied areas.

Units/ Hours	Content	Mapping with CLO
I 8 Hours	Vectors and Scalars, Vector algebra, Unit vectors, Linear Independence and Linear dependence, Vector fields and scalar fields. Dot and cross product of vectors, Reciprocal set of vectors. Vector differentiation: Ordinary derivative, continuity and differentiability, partial derivatives, Serret-Frenet formulas. **Activity:** To check Linearly independent and Linearly dependent set of vectors, exercises on dot and cross product and vector differentiation.	CLO1
II 7 Hours	Gradient, Directional derivative, Divergence, Curl. Vector Integration: Ordinary integral, line integrals, surface integrals and volume integrals. Divergence Theorem of Gauss, Stokes Theorem, Green's theorem	CLO2

	in plane. **Activity:** Exercises on Gradient, Divergence, Curl and Vector integration.	
III 7 Hours	Transformation of coordinates, orthogonal curvilinear coordinates, arc length and volume elements, Gradient, Divergence and curl in curvilinear coordinates, special orthogonal coordinate systems. **Activity:** Exercises on arc-length, volume, Div. and Curl in Curvilinear coordinates.	CLO3
IV 8 Hours	Contravariant and covariant vectors. Contravariant, Covariant and Mixed Tensors. Tensors of rank greater than two, Tensor fields, Fundamental operations with Tensors, Line element and metric Tensor, Associated Tensors, Christoffel Symbols, Length of a vector, Angle between vectors, Geodesics, Covariant derivative. **Activity**: Exercise on Tensors and their applications.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching / Experimentation /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. Narayan Shanti, Mittal P.K., A Text Book of Vector Analysis, S Chand & Company, Paperback edition, 2010.
2. Murray Spiegel, Seymour Lipschutz, Dennis Spellman, VECTOR ANALYSIS: Schaum's Outlines Series, McGraw Hill Education, 2nd Edition Paperback ,2017.
3. Louis Brand, Vector and Tensor Analysis, Dover Publications, Paperback edition, 2020.
4. A. I. Borisenko, Vector and Tensor Analysis with Applications, Dover Publications, Paperback edition, 2003.
5. Robert C. Wrede, Introduction to Vector and Tensor Analysis, Dover Publications, Paperback edition, 1972.

Course Title: Linear Programming

Course Code: MAT.528

Course Type: VAC

Total Hours: 30

L	T	P	Credits
2	0	0	2

Learning outcomes:

The students will be able to

CLO1: Discuss the linear programming problem with formulation.
CLO2: Apply different methods to solve linear programming problems.
CLO3: explore the concept of Duality theory and Sensitivity analysis.
CLO4: Explain transportation problems and assignment problems with their mathematical formulation.

Units/ Hours	Content	Mapping with CLO
I 8 Hours	Formulation of linear programming problems (LPP).Graphical solution to LPPs. Cases of unique and multiple optimal solutions. **Activity:** Students will do formulation of Linear programming problems and find the solutions using graphical methods.	CLO1
II 8 Hours	Feasible solution, basic feasible solutions, Optimal solution, Convex sets, Solution of LPP with Simplex methods. **Activity:** Students will solve linear programming problems with the simplex method.	CLO2
III 6 Hours	The dual problem.Formulation of the dual.Dual Simplex method **Activity:** Students will do exercises related to dual linear programming problems.	CLO3

	Transportation and Assignment Problem:	CLO4
IV 8 Hours	Transportation problems, Formulation of transportation problems, Feasible and optimal solution of transportation problems. Assignment problems. **Activity:** Students will do exercises on transportation problems and assignment problems.	

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. H. A. Taha, *Operations Research - An Introduction,* Macmillan Publishing Company Inc., New York, 2006.
2. K .Swarup, P. K. Gupta and Man Mohan, *Operations Research*, Sultan Chand & Sons, New Delhi, 2001.
3. F. S. Hillier and G. J. Lieberman, *Introduction to Operations Research*, McGraw-Hill, New York, 2001.

Course Title: Mathematical Methods

Course Code: MAT.534

Course type: VAC

Total Hours: 30

L	T	P	Credits
2	0	0	2

Learning outcomes:

CLO1. Students will be able to Integral Transforms.
CLO2. Understand the basic concepts of wavelet transforms.
CLO3. Understand the method of reduction of IVPs BVPs and eigenvalue problems.

CLO4. apply regular and singular perturbation methods.

Units/ Hours	Contents	Mapping with CLO
I 8 Hours	Integral Transforms**:** General definition of Integral transforms, Kernels, etc. Development of Fourier integral, Fourier transforms – inversion, Illustration on the use of integral transforms, Laplace, Fourier, Hankel and Mellin transforms to solve ODEs and PDEs - typical examples.	CLO1
II 7 Hours	Discrete orthogonality and Discrete Fourier transform. Wavelets with examples, wavelet transforms. Integral Equations: Definition, Volterra and Fredholm integral equations. Solution by separable kernel, Neumann's series resolvent kernel and transform methods, Convergence for Fredholm and Volterra types. **Activity:** Students will write some differential equations in the form of integral equations and then will solve them.	CLO2
III 7 Hours	Reduction of IVPs BVPs and eigenvalue problems to integral equations. Hilbert Schmidt theorem, Raleigh Ritz and Galerkin methods. **Activity:** Students will use Raleigh Ritz and Galerkin methods to solve some scientific problems.	CLO3
IV 8 Hours	Regular and singular perturbation methods:	CLO4

| | Parameter and co-ordinate perturbations. Regular perturbation solution of first and second order differential equations involving constant and variable coefficients.

Activity: Students will obtain the regular perturbation solutions of some first and second order differential equations. | |

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. I.N. Sneddon – The use of Integral Transforms, Tata Mc Graw Hill, Publishing Company Ltd, New Delhi, 1974.
2. R.P. Kanwal: Linear integral equations theory and techniques, Academic Press, New York, 1971.
3. C.M. Bender and S.A. Orszag – Advanced mathematical methods for scientists and engineers, McGraw Hill, New York, 1978.

M. S. Mathematics (Semester-III)

Course Title: Research Methodology

Course Code: MAT.502

Course type: Compulsory Foundation

L	T	P	Credits
4	0	0	4

Total Hours: 60

Learning outcomes:

The students will be able to

CLO1 Explain the various terms like objective, meaning of research, significance research etc. which is used in research.

CLO2 Review the basic concepts of literature survey and formulation research problems.
CLO3 Basic concepts of the research design.
CLO4 Review the basic concepts of the research writing problems.

Unit I 14 Hours	**Introduction:** Meaning, Objectives, Characteristics, Significance, and Types of Research; Research Approaches, Research Methods vs. Research Methodology, Research Process, and Criteria of Good Research. **Activity:** Students will gain theoretical and practical knowledge of a specific area of research.	CLO1
Unit II 16 Hours	**Literature Survey and Review:** Meaning of Literature Survey and Review, Sources of Literature, Methods of Literature Review, and Techniques of Writing the Reviewed Literature. **Formulating Research Problem:** Understanding a Research Problem, Selecting the Research Problem, Steps in Formulation of a Research Problem, Formulation of Research Objectives, and Construction of Hypothesis. **Activity:** Students will gain a literature survey and formulate research problems of a specific area of research.	CLO2
Unit III 14 Hours	**Research Design**: Meaning of and Need for Research Design, Characteristics of a Good Research Design, Different Research Designs, Basic Principles of Experimental Designs, Data Collection, Processing, and Interpretation. **Activity:** Students will explore the concept of research design and data collection of a research problem of a specific area of research.	CLO3
Unit IV 16	**Report Writing:** Types of Reports – Technical and Popular Reports, Significance of Report Writing, Different Steps in	CLO4

Hours	Writing Report, Art of Writing Research Proposals, Research Papers, Project Reports, and Dissertations/Thesis; Basics of Citation and Bibliography/Reference Preparation Styles; Report Presentation: Oral and Poster Presentations of Research Reports.				
	Activity: Students will explore the concept of the report writing and report presentation of a research problem.				

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. Anderson, J. (2001): *Thesis and Assignment Writing*, 4th ed., Wiley, USA

2. Dawson, Catherine, (2014): *Practical Research Methods,* New Delhi, UBS Publishers' Distributors.

3. Gray, David E. (2004): *Doing Research in the Real World.* London, UK: Sage Publications.

4. Kothari, C.R. and G. Garg (2014): *Research Methodology*: Methods and Techniques, 3rd ed., New Age International Pvt. Ltd. Publisher

5. Kumar, R. (2014): *Research Methodology – A Step-By-Step Guide for Beginners*, 4th ed., Sage Publications

Course Title: Functional Analysis	**L**	**T**	**P**	**Credits**
Course Code: MAT.571	3	0	0	3

Course Type: Core

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1. Describe the basic notion of normed linear spaces and Banach spaces with examples.
CLO2. Explain Bounded linear transformations and Dual spaces with related examples.
CLO3. Understand the concept of Reflexive spaces
CLO4. Discuss three main theorems on Banach spaces

Units/ Hours	Contents	Mapping with CLO
I 10 Hours	**Fundamentals of Normed Linear Spaces:** Normed Spaces, with examples of Function spaces $L^p($ [a,b] $)$,C([a,b]) and C^1([a,b]), Sequence Spaces l^p, c , c_0, c_{00} Banach spaces and examples, finite dimensional normed spaces and subspaces. **Activity:** Students will find examples of Banach spaces and normed linear spaces which are not Banach spaces.	CLO1
II 11 Hours	Linear operators definition and examples, Bounded linear transformations, Normed linear spaces of bounded linear transformations, Concept of algebraic Dual and algebraic reflexive spaces, Dual spaces with examples **Activity:** Students will do results related to bounded linear transformations and Dual spaces.	CLO2
III 12 Hours	**Geometry of Hilbert spaces:** Inner product spaces and Hilber spaces, Further properties of inner product spaces, orthonormal sets, Approximation and optimization, Projections and Riesz Representation theorem for Hilbert spaces. Bounded Operators on Hilbert spaces: Bounded operators and adjoints;	CLO3

	normal, unitary and self adjoint operators.	
	Activity: Students will do exercises on Hilbert spaces and examples of inner product spaces which are not Hilbert spaces.	
IV 12 Hours	Hahn-Banach theorem for real linear spaces and its consequences, Reflexive spaces, Solvability of linear equations in Banach spaces. **Three Main Theorems on Banach Space**: Banach Steinhauns theorem (Uniform boundedness theorem) and some of its consequences, Open mapping and closed graph theorems. **Activity:** Students will work on the consequences of Hahn-Banach theorem and Uniform boundedness theorem.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:
1. S. K. Berberian, *Introduction to Hilbert Spaces,* AMS Chelsea Publishing, Rhode Island, 1996.
2. C. Goffman, and G. Pedrick, *First Course in Functional Analysis,* Prentice Hall of India, New Delhi, 1983.
3. E. Kreyszig, *Introductory Functional Analysis with Application,* Willey, 2007.
4. B. V. Limaye, *Functional Analysis,* New Age International (P) Ltd, New Delhi, 1996.
5. F. K. Riesz, and B. S. Nagy, *Functional Analysis,* Dover Publications, 1990.
6. A. H. Siddiqui, *Functional Analysis,* Tata-McGraw Hill, New Delhi, 1987.
7. W. Rudin, *Functional Analysis,* McGraw Hill Education; 2 edition, 2017.

Course Title: Advanced Complex Analysis

Course Code: MAT.556

	L	T	P	Credits
	3	0	0	3

Course Code: Discipline Elective

Total Hours: 45

Learning outcomes:

The students will be able to:

CLO1: understand further deeper topics of Complex Analysis
CLO2: learn basic topics needed for students to pursue research in pure Mathematics.

CLO3: applications of the analytic functions

CLO4: explanation of Weierstrass Elliptic functions

CLO5: Apply the Weierstrass Zeta function in solving some problems

Units/ Hours	Contents	Mapping with CLO
I 11 Hours	**Harmonic function:** definition, relation between a harmonic function and an analytic function, examples, harmonic conjugate of a harmonic function, poisson's integral formula, mean value property, the maximum & minimum principles for harmonic functions, Dirichlet problem for a disc and uniqueness of its solution, characterization of harmonic functions by mean value property. **Activity:** Students will do some exercise on Dirichlet problems.	CLO1 CL02
II 11 Hours	**Analytic continuation:** direct analytic continuation, analytic continuations along arcs, homotopic curves, the monodromy theorem, analytic continuation via reflection. Harneck's principle. Open mapping theorem, normal families, the riemann mapping theorem, Picard's theorem. **Activity:** Students will explore the applications of Open mapping theorem, Riemann mapping theorem, Picard's theorem.	CLO3

III 12 Hours	**Weierstrass Elliptic functions:** periodic functions, simply periodic functions, fundamental period, Jacobi's first and second question, doubly periodic functions, elliptic functions, pair of primitive periods, congruent points, first and second Liouville's theorem, relation between zeros and poles of an elliptic function, definition of Weierstrass elliptic function (z) and their properties, the differential equation satisfied by (z) [i.e., the relation between (z) and ( )], Integral formula for (z), addition theorem and duplication formula for (z). **Acitivity:** students will apply the Weierstrass Zeta function in solving some problems	CLO4
IV 11 Hours	**Weierstrass Zeta function:** Weierstrass zeta function and their properties, quasi periodicity of (z), Weierstrass sigma function (z) and their properties, associated sigma functions. **Acitivity:** Students will practice the properties of Weierstrass zeta function and Weierstrass sigma function.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. J. B. Conway, *Functions of One Complex Variable*, 2nd Edition, Springer-Verlag International, USA, 1978.

2. L.V. Ahlfors, *Complex Analysis: An Introduction to the Theory of Analytic Functions of One Complex Variable*, 3rd Edition, McGraw-Hill, Higher Education, New Delhi, 1979.

3. R. Walter, *Real and Complex Analysis*, 3rd Edition, McGraw-Hill Book Co., New Delhi, 1986.

4. S. Lang**,** *Complex Analysis*, 4th Edition, Springer, New York, 2003.

5. S. Ponnusamy, *Foundations of Complex Analysis*, 2nd Edition, Narosa Publication House, New Delhi, 1995.

Course Title: Advanced Partial Differential Equations	L	T	P	Credits
Course Code: MAT.557	3	0	0	3

Course Code: Discipline Elective

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1. use smooth functions for approximations.

CLO2. understand the basic concepts of Weak solutions of elliptic boundary value problems

CLO3. study scientific evolution equations.

CLO4. learn the conditions for existence of minimizers

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	**Distribution**: Test functions and distributions, examples, operations on distributions, supports and singular supports, convolution, fundamental solutions, fourier transform, Schwartz space, tempered distributions.	CLO1

	Sobolev Spaces: Basic properties, approximation by smooth functions, extension theorems, compactness theorems, dual spaces, functional order spaces, trace spaces, trace theory, inclusion theorem. **Activity:** Students will use smooth functions for approximations.	
II 11 Hours	**Weak solutions of elliptic boundary value problems**: variational problems, weak formulation of elliptic PDE, regularity, Galerkin method, Maximum principles, eigenvalue problems, Introduction to finite element methods. **Activity:** Students will obtain weak solutions of some elliptic boundary value problems.	CLO2
III 11 Hours	**Evolution Equations**: unbounded linear operators, C_0 – semigroups, Hille-Yosida theorem, contraction semigroup on Hilbert spaces, heat equation, wave equation, Schrödinger equation, inhomogeneous equations. **Activity:** Students will study scientific evolution equations.	CLO3
IV 11 Hours	**Calculus of Variations**: Euler-Lagrange equation, second variation, existence of minimizers (coactivity, lower semi-continuity, convexity), regularity, constraints (nonlinear eigenvalue problems, variational inequalities, harmonic maps, incompressibility), critical points (mountain pass theorem and applications to elliptic PDE). **Activity:** Students will check the conditions for existence of minimizers.	CLO4

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TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. S. Kesavan, *Topics in Functional Analysis and Application,* Wiley-Eastern, New International, New Delhi, 1999.
2. L. C. Evans, *Partial Differential Equations. Graduate Studies in Mathematics,* 2nd Edition, American Mathematical Society, Indian Reprint, 2014.
3. K. S. Rao, *Introduction to Partial Differential Equation,* 2nd Edition, PHI Learning Pvt. Ltd. 2010.
4. T. Amarnath, *An Elementary Course in Partial Differential Equations,* 2nd Edition, Narosa Publishing House 2012.
5. I. N. Sneddon, *Elements of Partial Differential Equations,* McGraw-Hill Book Company, New York 1988.

Course Title: Algebraic Topology	**L**	**T**	**P**	**Credits**
Course Code: MAT.558	**3**	**0**	**0**	**3**

Course Code: Discipline Elective

Total Hours: 45

Learning outcomes:
The students will be able to
CLO 1: Understand the fundamental concept of Homotopy theory to pursue research.
CLO 2: Develop the knowledge of fundamental groups and covering spaces with related properties.
CLO 3: Construct homotopies and prove homotopy equivalence.
CLO 4: Understand free products and free groups and their applications.
CLO 5: Understand the classification of covering spaces.

CLO 6: apply his or her knowledge of algebraic topology to formulate and solve problems of a geometrical and topological nature in mathematics.

Unit/Hours	Contents	Mapping with CLO
I 11 Hours	The Fundamental group: Homotopy of paths, Homotopy classes, The Fundamental group, Change of base point, Topological invariance, Covering spaces, The Fundamental group of the circle. **Activity:** To find fundamental groups of some important topological structures.	CLO 1 CLO 2 CLO 3 CLO 6
II 12 Hours	Retractions and fixed points, No Retraction Theorem, The Fundamental theorem of Algebra, The Borsuk-Ulam theorem, The Bisection theorem, Deformation Retracts and Homotopy type, Homotopy invariance. **Activity:** To find applications of above important theorems in terms of examples.	CLO 1 CLO 2 CLO 3 CLO 6
III 11 Hours	Direct sums of Abelian Groups, Free products of groups, Uniqueness of free products, Least normal subgroups, Free groups, Generators and relations, The Seifert-Van Kampen theorem, The Fundamental group of a wedge of circles. **Activity:** Exercises on Abelian groups, free groups and free products.	CLO 4 CLO 6
IV 11 Hours	Classification of covering spaces: Equivalence of covering spaces, The general lifting lemma, The universal covering space, Covering transformation, Existence of covering spaces. **Activity:** Exercises on covering spaces.	CLO 5 CLO 6

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:
1. M. A. Armstrong, *Basic Topology,* UTM Springer, 2000.
2. S. Deo, *Algebraic Topology: A Primer (Texts and Readings in Mathematics),* Hindustan Book Agency, 2003.

3. M. J. Greenberg and J. R. Harper, *Algebraic Topology:* A First Course, 2nd Edition, Addison-Wesley Publishing Co, 1997.
4. A. Hatcher, *Algebraic Topology*, Cambridge University Press, 2002.
5. W. S. Massey, *A Basic Course in Algebraic Topology,* SPRINGER (SIE), 2007.
6. J. R. Munkres, *Elements of Algebraic Topology*, Perseus Books, 1995.
7. J. J. Rotman, *An Introduction to Algebraic Topology, Text in Mathematics, No. 119*, Springer, New York, 2004.
8. E. H. Spanier, *Algebraic Topology (2nd edition)*, Springer-Verlag, New York, 2000.

Course Title: Riemannian Geometry

L	T	P	Credits
3	0	0	3

Course Code: MAT.572

Course Code: Discipline Elective

Total Hours: 45

Learning outcomes:
The students will be able to
CLO 1: Understand the concepts of differentiable manifolds and covariant differentiation of vector fields
CLO 2: Explain the theory of Tensors and curvature.
CLO3: Discuss the Jacobi fields and Gauss lemma.
CLO4: Understand the concept of Global differential geometry and related properties.
CLO5: appreciate the topics covered in allied courses like, Riemann-Finsler geometry, Mathematical Physics and their applications in allied areas.
CLO6: adequately prepared for pursuing research in Riemannian geometry and its allied areas
CLO7: understand the fundamentals of Theory of General Relativity.

Units/	Content	Mapping

Hours		with CLO
I 11 Hours	Review of differentiable manifolds and vector fields, Covariant differentiation of vector fields and affine connection, Riemannian metric, Riemannian manifolds, Riemannian connection, Fundamental theorem of Riemannian geometry via Koszul's formula. **Activity:** Exercises on covariant differentiation, Reiemannian metric and Riemannian connection.	CLO1 CLO5 CLO6 CLO7
II 11 Hours	Tensors and tensor fields (Riemannian metric as the most significant example), Tensorial property, Covariant differentiation of tensor fields, Riemann curvature tensor, Ricci tensor, Sectional, Ricci and scalar curvatures, Isometries, Notion of covering spaces, Pull-back metrics via diffeomorphisms. **Activity:** Exercises on different curvature tensors and isometries.	CLO2 CLO5 CLO6 CLO7
III 12 Hours	Covariant differentiation of a vector field along a curve with specific examples, Arc length and energy of a piecewise smooth curve, Geodesics as length minimizing curves, First variation of arc length, To show that geodesics are critical points of the fixed end point first variation formula, Exponential map, Geodesic completeness, Geodesic normal coordinates, Hopf-Rinow theorem (statement only), Geodesic variations, Jacobi fields and Gauss lemma. **Activity:** Exercises on arc-length, energy, geodesics and exponential map.	CLO3 CLO5 CLO6 CLO7
IV 11 Hours	Second variation formula, The index form (Jacobi fields as minimizers of the index form), Global differential geometry, Spaces of constant sectional curvature, Bonnet-Myers theorem, Cartan-Hadamard theorem, Cartan's theorems (on determination of metric by curvature). **Activity:** Exercises on the application of the above mentioned theorems.	CLO4 CLO5 CLO6 CLO7

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. M. Berger, *A Panoramic View of Riemannian Geometry*, Springer; 1st Edition, 2003. Corr. 2nd printing, 2007.
2. W. M. Boothby, *An Introduction to Differentiable Manifolds and Riemannian Geometry*, 2nd Edition, Academic Press, New York, 2003.
3. S. S. Chern, W. H. Chen and K. S. Lam*, Lectures on Differential Geometry*, World Scientific Publishing , 2000.
4. M. P. Docarmo, *Riemannian Geometry*, Birkhausker Boston, 1992.
5. S. Kumaresan, *A Course in Differential Geometry and Lie Groups (Texts and Readings in Mathematics),* Hindustan Book Agency, 2002.
6. J. M. Lee, *Riemannian Manifolds: An Introduction to Curvature*, GTM, Springer, 1st Edition, 1997.
7. B. O' Neill, *Semi-Riemannian Geometry with Applications to Relativity*, Academic Press, New York, 1983.

Course Title: Discrete Differential Geometry

Course Code: MAT.560

L	T	P	Credits
3	0	0	3

Course Code: Discipline Elective

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1: understand combinatorial surfaces and their curvatures.
CLO2: understand the exterior product and Differential forms.
CLO3: know about the curvature of Discrete surfaces and curvature flow.
CLO4: explain different designs and decompositions of surfaces.

Units/ Hours	Contents	Mapping with CLO

I 12 Hours	Combinatorial Surfaces: Abstract Simplicial Complex, Anatomy of a Simplicial Complex, Star, Closure, and Link, Simplicial Surfaces, Adjacency Matrices, Halfedge Mesh. The Geometry of Surfaces, Derivatives and Tangent Vectors, The Geometry of Curves, Curvature of Surfaces, Geometry in Coordinates. **Activity:** Exercises on Simplicial complex, simplicial surfaces and curvature of surfaces.	CLO1
II 11 Hours	Exterior Algebra, Examples of Wedge and Star in $\mathbf{R}_n$, Vectors and 1-Forms, Differential Forms and the Wedge Product, Hodge Duality, Differential Operators, Integration and Stokes' Theorem, Discrete Exterior Calculus. **Activity:** Exercises on Wedge product, differential forms and Stoke's theorem.	CLO2
III 11 Hours	Curvature of Discrete Surfaces: Vector Area, Area Gradient, Volume Gradient, Other Definitions, Gauss-Bonnet, Numerical Tests and Convergence. The Laplacian: Basic Properties, Discretization in FEM, Discretization via DEC, Meshes and Matrices, The Poisson Equation, Implicit Mean Curvature Flow. **Activity:** Exercises on Gradient, Divergence, Poisson equation and curvature flow.	CLO3
IV 11 Hours	Surface Parameterization: Conformal Structure, The Cauchy-Riemann Equation, Differential Forms on a Riemann Surface, Conformal Parameterization, Eigenvectors, Eigenvalues, and Optimization. **Activity:** Exercises on CR-equations, Riemann surfaces and conformal parameterization.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. Alexander I. Boenko and Yuri B. Suris, Discrete Differential Geometry: Integrable Structure: 98 (Graduate Studies in Mathematics), American Mathematical Society; New ed. edition, 2009.
2. Alexander I. Bobenko, Advances in Discrete Differential Geometry Springer; Paperback, 2018.
3. Jiri Matousek, Lectures on Discrete Geometry: Springer- 212, GTM, 2nd edition, 2002.
4. Chuanming Zong, Strange Phenomena in Convex and Discrete Geometry, Springer (Universitext) Paperback 1st edition, 1996.

Course Title: Category Theory

L	T	P	Credits
3	0	0	3

Course Code: MAT.564

Course type: Discipline Elective Course

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1: discuss the definition of Categories and Functors with examples.
CLO2: learn about Universal Mapping Properties and Free Objects
CLO3: learn about dual category, Epis, Monos, Equalizers, Co-Equalizers

CLO4: Understand the concept of Coproducts, Pullbacks and Categorical Limits

CLO5: learn about Natural Transformations and Adjunctions.

Units/ Hours	Contents	Mapping with CLO
I 10 Hours	Definition and examples of Categories: Sets, Pos, Rel, Mon, Groups, Top, Dis(X) Finite Categories. Isomorphic Objects. Constructions: Product of two categories, The Dual Category, The Arrow Category, The Slice and Co- Slice Category. The concept of functor and the category Cat. Free Monoids and their UMP. The UMP of Products. The Product Functor. The Free Monoid Functor. **Activity:** Students will do examples/exercises of categories and Functors and explore the presence of other categories and UMPs.	CLO1 CLO2
II 11 Hours	Contravariance and Duality, Functor of Several Variables, Covariant Representable Functor, Contravariant Representable Functor, Functors preserving Binary Products: The Canonical Comparison Arrow and the Necessary and Sufficient Condition for a Functor to preserve products. H^A preserve products. Epis and mono, Initial and Terminal objects, Generalized elements. **Activity:** Students will work on the exercises and examples on these topics.	CLO3
III 12 Hours	Coproducts. Coproduct of monoids. Equalizers, Equalizers as a monic, Generalized elements and equalizers, Coequalizers, Coequalizers as an epic. Coequalizer diagram for a monoid. Pullbacks, Properties of Pullbacks, Pullback as a functor. Limits, Cone to a diagram, limit for a diagram, Limits in	CLO4

	terms of equalizers and pullbacks. **Activity:** Students will do exercises/examples on these topics.	
IV 12 Hours	Naturality, Examples of natural transformations. The Yoneda Lemma and its applications. Adjunction between categories, Hom-Set definition of adjoints. Unit and Co-Unit of Adjunction. Examples of Adjoints, Uniqueness up to isomorphism. Order Adjoints and interior operation in Topology as an order adjoint. Preservation of Limits (Co limits) by Right (Left) Adjoints. **Activity:** Students will do examples of Natural Transformations and Explore the occurrence of Adjunctions in Mathematics.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Recommended Books:

1. S. Awodey, Category Theory, (Oxford Logic Guides, 49, Oxford University Press.)

2. F. Borceux, Handbook of Categorical Algebra-1: Basic Category Theory, Cambridge University press, 1994.

3. S. Mac Lane, Categories for the working mathematicians, 2nd Edition, Springer 1971.

4. E. Riehl, Category theory in context, Aurora: Dover Modern math originals, 2017.

Course Title: Dynamical

Systems

Course Code: MAT.565

L	T	P	Credits
3	0	0	3

Course Code: Discipline Elective

Total Hours: 45

Learning outcomes:

The students will be able to

> **CLO1**. know about dynamical Systems from an applied and practical point of view.
> **CLO2.** how to compute the behavior of differential equations as parameters vary?
> **CLO3.** know about the techniques that include bifurcation analysis and computation of normal forms, geometric methods, and the method of averaging.
> **CLO4.** To understand the concept of Local and Global bifurcations.

Units/ Hours	Contents	Mapping with CLO
I 11 Hours	**Basic Concepts**: Discrete and continuous dynamical systems. Linear and nonlinear systems and principle of superposition. Linear and nonlinear forces. Concepts of evolution, iterations, orbits, fixed points, periodic and aperiodic (chaotic) orbits. Basics of Linear Algebra: Symmetric & Skew-symmetric matrices, matrix norm and singular value decomposition. Eigenvalues, eigenvectors, and dynamical interpretation. **Activity:** Students will apply some basics of linear	CLO1

	algebra in study of dynamical systems.	
II 12 Hours	Canonical forms; simple and non-simple canonical systems. System of Equations. **Stability Analysis**: Stability of a fixed point and classification equilibrium states (for both discrete and continuous systems). Concept of bifurcation and classification of bifurcations. Concepts of Lyapunov stability & Asymptotic stability of orbits. **Activity:** Students will check the stability of some dynamical systems by using the concept of bifurcation.	CLO2
III 11 Hours	Phase Portraits of various Linear and Nonlinear systems. Hopf bifurcation. Concept of attractors and repellers, limit cycles and torus. **Phenomena of Bifurcation**: Definition of bifurcation. Bifurcations in one, two and higher dimensional systems. **Activity:** Students will draw the phase portraits of some dynamical systems using some software.	CLO3
IV 11 Hours	Hopf, Period doubling, Saddle node, Transcritical bifurcations. Feigenbaum's number. Local and Global bifurcations. Homoclinic & Hetero-clinic points and orbits. Poincaré-Bendixson Theorem. Conservative and Dissipative Systems. **Activity:** Students will draw the phase portraits of some dynamical systems using some software and will study the orbits.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1.   P. G. Drazin, *Nonlinear Systems*, Cambridge University Press India.
2.   R. L. Devaney, *An Introduction to Chaotic Dynamical Systems*, Addison Wesley, 1989.
3.   Edward Ott, *Chaos in Dynamical Systems*, Cambridge University Press, 2002
4.   G. L. Baker and J. P. Gollub, *Chaotic Dynamics – An Introduction*, Cambridge University Press, 1996.
5.   J. Guckenheimer and P. Holmes, *Nonlinear Oscillations, Dynamical Systems and Bifurcations of Vector Fields*, Springer, 1983.
6.   L. Perko, Differential Equations and Dynamical Systems, Springer Verlag, 1991.
7.   M. W. Hirsch and S. Smale, Differential Equations, Dynamical Systems and Linear Algebra, Academic Press, 174.
8.   P. Hartman, Ordinary Differential Equations, 2nd edition, SIAM 2002.
9.   C. Chicone, Ordinary Differential Equations with Applications, 2nd Edition, Springer, 2006.

Course Title: Advanced Numerical Analysis

L	T	P	Credits
3	0	0	3

Course Code: MAT. 566

Course Code: Discipline Elective

Total Hours: 45

Learning outcomes:

The students will be able to

CLO1. Review the basic concepts of various advanced numerical techniques for a variety of nonlinear mathematical problems occurring in science and engineering.
CLO2. Explain the concept of solving the Polynomial equations.
CLO3. Learn the polynomial interpolation and approximations
CLO4. Explain the concept of Differentiation and integration using cubic splines, Romberg integration and multiple integrals.
CLO5. Apply the Shooting and finite difference methods for second order boundary value problems.

Units/ Hours	Contents	Mapping with CLO
I 11 Hours	**Non-Linear Equations**: Methods for multiple roots, Muller's, Iteration and Newton-Raphson method for non-linear system of equations, and Newton-Raphson method for complex roots.	CLO1
II 12 Hours	**Polynomial Equations**: Descartes' rule of signs, Birge-Vieta, Bairstow and Giraffe's methods. **System of Linear Equations:** LU Decomposition methods, SOR method with optimal relaxation parameters.	CLO2
III 11 Hours	**Interpolation and Approximation:** B - Spline and bivariate interpolation, Gram-Schmidt orthogonalisation process and approximation by orthogonal polynomial, Legendre and Chebyshev polynomials and approximation. **Differentiation and Integration:** Differentiation and integration using cubic splines, Romberg integration and multiple integrals.	CLO3 CLO4
IV 11 Hours	**Ordinary Differential Equations:** Shooting and finite difference methods for second order boundary value problems.	CLO5

Suggested Readings:

1. C. F. Gerald and P. O. Wheatly, *Applied Numerical Analysis*, 7th Edition, Pearson LPE, 2009.

2. K. Atkinson, *An Introduction to Numerical Analysis*, John Wiley & Sons, 2nd Edition, 1989.
3. M. K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation*, 6th Edition, New Age International, New Delhi, 2015.
4. R. S. Gupta, *Elements of Numerical Analysis*, 2nd Edition, Cambridge University Press, 2015.

5. R.L. Burden and J. D. Faires, *Numerical Analysis*, 9th Edition, Cengage Learning, 2011.
6. S.D. Conte and Carl D. Boor, *Elementary Numerical Analysis: An Algorithmic Approach*, Tata McGraw Hill, 2005.

Course Title: Introduction to Cryptography	L	T	P	Credits
Course Code: MAT.569				
Course Type: Discipline Elective	3	0	0	3

Total Hours: 45
Learning outcomes:

The students will be able to

CLO1: Understand the basic notion of cryptography and existence of cryptography before the computer age.

CLO2: Explore the concept of cryptanalysis of simple substitution cipher and properties of public key cryptography.

CLO3: Understand the algorithms of various public key cryptosystems (PKCs) and their properties.

CLO4: Learn the techniques of encryption and decryption process for cryptosystems.

CLO5: Understand the concept of perfect secrecy of cryptosystems.

CLO6: Understand the concept of digital signatures and their applications in cryptography.

Units/	Contents	Mapping with CLO

Hours		
I **12 Hours**	**Introduction to Cryptography:** Private and Public key Cryptosystems, Classical Cryptography, Simple Substitution Ciphers, Cryptanalysis of Simple Substitution Ciphers, Cryptography before the Computer Age, Symmetric and Asymmetric Ciphers, An Encoding Scheme and an Encryption Scheme, Symmetric Encryption of Encoded blocks, Examples of Symmetric Ciphers **Activity:** Students will work on different examples related to substitution cipher and will explore cryptography before the computer age.	**CLO1** **CL02**
II **11 Hours**	**Public key Cryptography:** Introduction to asymmetric ciphers, Origin of Public Key Cryptography, The Discrete Logarithm Problem, Diffie-Hellman Key Exchange Algorithm, The ElGamal Public Key Cryptosystem, Hardness of the Discrete Logarithm Problem, Order Notation, A Collision Algorithm for Discrete Logarithm Problem, Integer factorization and the RSA cryptosystem: Euler's formula, Roots modulo pq with p & q as distinct primes **Activity:** Students will explore the properties of various public key cryptosystems and will solve some problems based on Euler's formula.	**CLO3**
III **12 Hours**	**Primality Testing:** The RSA public key cryptosystem, It's implementation and security issues, Primality testing, Miller-Rabin test for composite numbers, The prime number theorem (statement only), AKS primality test (statement only), Riemann zeta function, Riemann hypothesis, Pollard's $p-1$ factorization algorithm, Probabilistic encryption and the Goldwasser-Micali cryptosystem. **Activity:** The students will explore the concept of primality testing and applications of prime numbers in different areas of mathematics and computer science.	**CLO4**

	The students will solve problems related to these concepts.	
IV **10 Hours**	**Information theory:** Perfect secrecy, Conditions for perfect secrecy, Entropy, Redundancy and the entropy of natural language, The algebra of secrecy systems, Complexity theory and *P* versus *NP*, Digital signatures: Definition, Components of a digital signature scheme, RSA digital signatures, ElGamal digital signatures digital signature algorithm (DSA). **Activity:** The students will explore the concept of perfect secrecy of cryptosystems. The students will learn the concept of digital signatures and their applications in cryptography.	**CLO5** **CLO6**

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. J Hoffstein, J Pipher & J H Silverman, An introduction to mathematical cryptography, Springer (India) Pvt. Ltd., 2011
2. V V Yaschenko, Cryptography: An introduction, American Mathematical Society, 2009
3. G. H. Hardy and E. M. Wright – An Introduction to Theory of Numbers, Oxford University Press, 2008, 6th Ed.,
4. J Talbot and D Welsh, Complexity and Cryptography: An Introduction, Cambridge University Press, 2006

Course Title: Review of Mathematical Concepts	**L**	**T**	**P**	**Credits**
Course Code: MAT.567	**2**	**0**	**0**	**2**

Course Type: DEC

Total Hours: 30

Learning outcomes:

Students will be able to

CLO1: Review the basic concepts of Analysis.
CLO2: Understand the basic concepts of Advanced Analysis and Topology.
CLO3: Apply the techniques of Linear Algebra for solving problems.
CLO4: Review the concepts in Complex Analysis.

CLO5: understand the basic concepts of Algebra

CLO6: understand and use the concepts of differential equations.

CLO7: understand and use the concepts of Numerical Analysis, Calculus of variations and Linear Integral equations.

Units/ Hours	Contents	Mapping with CLO
I 12 Hours	**Analysis:** Elementary set theory, finite, countable and uncountable sets, Real number system as a complete ordered field, Archimedean property, supremum, infimum. Sequences and series, convergence, limsup, liminf. Bolzano Weierstrass theorem, Heine Borel theorem. Continuity, uniform continuity, differentiability, mean value theorem. Sequences and series of functions, uniform convergence. Riemann sums and Riemann integral, Improper Integrals. Monotonic functions, types of discontinuity, functions of bounded variation, Lebesgue measure, Lebesgue integral. Functions of several variables, directional derivative, partial derivative, derivative as a linear transformation, inverse and implicit function theorems. Metric spaces, compactness, connectedness. Normed linear Spaces. Spaces of continuous functions as examples. **Linear Algebra:** Vector spaces, subspaces, linear dependence, basis, dimension, algebra of linear transformations. Algebra of matrices, rank and determinant of matrices, linear equations. Eigenvalues and eigenvectors, Cayley-Hamilton theorem. Matrix representation of linear	CLO1 CLO2 CLO3

	transformations. Change of basis, canonical forms, diagonal forms, triangular forms, Jordan forms. Inner product spaces, orthonormal basis. Quadratic forms, reduction and classification of quadratic forms

Topology: basis, dense sets, subspace and product topology, separation axioms, connectedness and compactness.

Activity: Problem solving based on NET/GATE questions. | |
| II
11 Hours | **Complex Analysis:** Algebra of complex numbers, the complex plane, polynomials, power series, transcendental functions such as exponential, trigonometric and hyperbolic functions. Analytic functions, Cauchy-Riemann equations. Contour integral, Cauchy's theorem, Cauchy's integral formula, Liouville's theorem, Maximum modulus principle, Schwarz lemma, Open mapping theorem. Taylor series, Laurent series, calculus of residues. Conformal mappings, Mobius transformations.

Algebra: Permutations, combinations, pigeon-hole principle, inclusion-exclusion principle, derangements. Fundamental theorem of arithmetic, divisibility in Z, congruences, Chinese Remainder Theorem, Euler's Ø- function, primitive roots. Groups, subgroups, normal subgroups, quotient groups, homomorphisms, cyclic groups, permutation groups, Cayley's theorem, class equations, Sylow theorems. Rings, ideals, prime and maximal ideals, quotient rings, unique factorization domain, principal ideal domain, Euclidean domain. Polynomial rings and irreducibility criteria. Fields, finite fields, field extensions, Galois Theory.
Activity: Problem solving based on NET/GATE questions. | CLO4
CLO5 |
| III
11 Hours | **Ordinary Differential Equations (ODEs):** Existence and uniqueness of solutions of initial value problems for first order ordinary differential equations, singular solutions of first order ODEs, system of first order ODEs. General theory of | CLO6 |

	homogeneous and non-homogeneous linear ODEs, variation of parameters, Sturm-Liouville boundary value problem, Green's function.	
	Partial Differential Equations (PDEs): Lagrange and Charpit methods for solving first order PDEs, Cauchy problem for first order PDEs. Classification of second order PDEs, General solution of higher order PDEs with constant coefficients, Method of separation of variables for Laplace, Heat and Wave equations.	
	Activity: Problem solving based on NET/GATE questions.	
IV 11 Hours	**Numerical Analysis:** Numerical solutions of algebraic equations, Method of iteration and Newton-Raphson method, Rate of convergence, Solution of systems of linear algebraic equations using Gauss elimination and Gauss-Seidel methods, Finite differences, Lagrange, Hermite and spline interpolation, Numerical differentiation and integration, Numerical solutions of ODEs using Picard, Euler, modified Euler and Runge-Kutta methods**.** **Calculus of Variations:** Variation of a functional, Euler-Lagrange equation, Necessary and sufficient conditions for extrema. Variational methods for boundary value problems in ordinary and partial differential equations. **Linear Integral Equations:** Linear integral equation of the first and second kind of Fredholm and Volterra type, Solutions with separable kernels. Characteristic numbers and eigenfunctions, resolvent kernel. **Activity:** Problem solving based on NET/GATE questions.	CLO7

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. A. Kumar and S. Kumaresan, *A Basic Course in Real Analysis*, Narosa, Publishing House, 2014.
2. G. De Barra, *Measure Theory and Integration*, Ellis Horwood Limited, England, 2003.
3. H. L. Royden, *Real Analysis*, Macmillan, New York, 1988.
4. J. Gilbert and L. Gilbert, *Linear Algebra and Matrix Theory,* Cengage Learning, 2004.
5. J. R. Munkres, *Topology- A First Course,* Prentice Hall of India, New Delhi, 1975.
6. K. Hoffman and R. Kunze: *Linear Algebra* 2nd Edition, Pearson Education (Asia) Pvt. Ltd/ Prentice Hall of India, 2004.
7. L. V. Ahlfors, *Complex Analysis*, Tata McGraw Hill, 1979.
8. M. A. Armstrong, *Basic Topology,* Springer, Paperback Edition, 2004.
9. P. B. Bhattacharya, S.K. Jain and S.R. Nagpaul, *Basic Abstract Algebra,* Wiley Eastern, Delhi, 2003.
10. S. Kumaresan, *Topology of Metric Spaces,* second edition, Narosa Publishing House New Delhi, 2015.
11. S. Ponnusamy, *Foundations of Complex Analysis*, Narosa Publishing House, 2007.
12. W. Rudin, *Principles of Mathematical Analysis,* 3rd Edition, McGraw Hill, Kogakusha, International student Edition, 1976.
13. A. Pinckus, and S. Zafrany, *Fourier series and Integral Transform*, Cambridge University Press, New York, 1997.
14. G. D. Smith, *Numerical Solution of Partial Differential Equations*, Oxford: Clarendon Press, 1986.
15. I. N. Sneddon, *Elements of Partial Differential Equations*, McGraw-Hill, 2006.

16. J. A. Gallian,*Contemporary Abstract Algebra,* Narosa Publishing House, New Delhi, 2008.

17. L. C. Evans, *Partial Differential Equations. Graduate Studies in Mathematics*, American Mathematical Society, 2nd Edition, Indian Reprint, 2014.
18. M. D. Raisinghania,*Advanced Differential Equations*, S. Chand & Company Ltd., New Delhi, 2001.

19. *M. K. Jain, S.R.K. Iyengar and R.K. Jain, Numerical Methods for Scientific and Engineering Computation, 6th Edition, New Age International, New Delhi, 2015.*
20. P. B. Bhattacharya, S.K. Jain and S.R Nagpal, *Basic Abstract Algebra*, Cambridge University Press, New Delhi, 2003.
21. R. L. Burden and J. D. Faires, *Numerical Analysis*, 9th Edition, Cengage Learning, 2011.
22. R. P. Kanwal, *Linear Integral Equations*, Birkhauser, Boston, 1996.
23. R. S. Gupta, *Elements of Numerical Analysis*, Cambridge University Press, 2nd Edition, 2015.
24. S. L. Ross, *Differential Equations*, Wiley, 1984.I. Miller and M. Miller, *Mathematical Statistics,* 6th Edition, Oxford & IBH Pub., 1999.

Course Title: Entrepreneurship

Course Code: MAT.563

L	T	P	Credits
1	0	0	1

Course Type: Compulsory foundation

Total Hours: 15
Learning Outcomes:

The students will be able to

CLO1 Understand the basic concepts of entrepreneur, entrepreneurship and its importance.
CLO2 Aware of the issues, challenges and opportunities in entrepreneurship.
CLO3 Develop capabilities of preparing proposals for starting small businesses.

CLO4 Know the availability of various institutional supports for making a new start-up.

Unit I 3 Hours	Introduction to entrepreneur and entrepreneurship; Characteristics of an entrepreneur; Characteristics of entrepreneurship; entrepreneurial traits and skills; innovation and entrepreneurship; Types of entrepreneurial	CLO1

	ventures; enterprise and society in Indian context; Importance of women entrepreneurship	
Unit II 5 Hours	Promotion of a venture – Why to start a small business; How to start a small business; opportunity analysis, external environmental analysis, legal requirements for establishing a new unit, raising of funds, and establishing the venture - Project report preparation – format for a preliminary project report, format for a detailed/final project report.	CLO2
Unit III 4 Hours	Mathematics and Statistics as a tool for innovation, current challenges to be tackled in marketing, health and environmental sectors, figuring out scientific needs of the society, mathematics and statistics in cross-disciplinary industries, examples of successful mathematics and statistics spin-offs, funding from scientific and governmental bodies.	CLO3
Unit IV 3 Hours	Communicating with data and statistics, hypothesis testing and modeling, importance of units and measurement, from idea to research to product design and development, scope of innovation in: theoretical physics, String theory, mathematical modeling, optimization problems, Image Processing, Architecture, Machine Learning, Econometrics and many more.	CLO4

Suggested Readings:

1.   Renu Arora, Entrepreneurship and Small Business, Dhanpat Rai & Sons Publications, 2008.

2.   Prasaaan Chandra, Project Preparation, Appraisal, Implementation, Tata Mc-Graw Hills, 2018.

3.   Vasant Desai, Management of a Small Scale Industry, Himalaya Publishing House, 2019.

4.   P. C. Jain, Handbook of New Entrepreneurs, Oxford University Press, 2015.

5.   S. B. Srivastava, A Practical Guide to Industrial Entrepreneurs, Sultan Chand & Sons, 2009.

	L	T	P	Credits
Course Title: Dissertation Part-I				
Course Code: MAT.600	**0**	**0**	**8**	**4**

Course Type: Skill Based

Total Hours: 120

Learning outcome:

The students will be able to

CLO1: develop interest in theoretical and practical research.
CLO2: decide their area of research as per their competency.
CLO3: get theoretical and practical knowledge of a specific area of research.
CLO4: prepare themselves for quality research in any mathematical discipline and allied areas.

Students will prepare a research proposal based on literature review and extensive student-mentor interactions involving discussions, meetings and presentations. Each student will submit a research/dissertation proposal of the research work planned for the M.Sc. dissertation with origin of the research problem, literature review, hypothesis, objectives and methodology to carry out the planned research work, expected outcomes and bibliography.

Students will have an option to carry out dissertation work in industry, national institutes or Universities in the top 100 NIRF ranking. Group dissertation may be opted, with a group consisting of a maximum of four students. These students may work using a single approach or multidisciplinary approach. Research projects can be taken up in collaboration with industry or in a group from within the discipline or across the discipline.

Evaluation Criteria:

Dissertation Proposal				
	Proposal (30)	**Presentation (10)**	**Viva-Voce (10)**	**Marks Obtained (50)**
Supervisor				

HoD and Senior faculty member				

Transaction mode: Lecture/Demonstration/ Co Operative learning/ programming / Practical/ Group discussion/Team teaching/Experimentation/Tutorial/Problem solving/Self-learning.

M. Sc. Mathematics (Semester-IV)

Course Title: Dissertation Part-II

Course Code: MAT.601

L	T	P	Credits
0	0	40	20

Total Hours: 600

Course Type: Skill Based

Learning outcome:

The students will be able to

CLO1: gain Theoretical and Practical knowledge of a specific area of research.
CLO2: have a good understanding of the subject to pursue research in reputed Institutions of higher learning.
CLO3: apply theoretical and practical knowledge to real life situations.
CLO4: prepare themselves for collaborative research in India and abroad.

CLO5: get Phd positions in reputed universities/institutes at regional/national/international level.

Students will carry out their research work under the supervision of a faculty member. Students will interact with the supervisors through meetings and presentations on a regular basis. After completion of the research work, students will complete the dissertation under the guidance of the supervisor. The dissertation will include literature review, hypothesis, objectives, methodology, results, discussion, and bibliography.

Evaluation Criteria:

Dissertation						
	Continuous Assessment		**Report**	**Presentation**	**Viva-Voce**	**Total Marks**
	Regularity in work	**Mid-term evaluation**				
Supervisor	10	10	20	05	05	50
HoD, Senior faculty member and external expert	-	-	30	10	10	50

Evaluation patterns similar to fourth semester dissertation will apply for an internship where supervisor will award 50% marks and external co-supervisor, HoD and senior-most faculty will award 50% marks.

Transaction mode: Lecture/Demonstration/ Co Operative learning/ programming / Practical/ Group discussion/Team teaching/Experimentation/Tutorial/Problem solving/Self-learning.