**Central University of Punjab**


# M.Sc. MATHEMATICS

**Batch: 2024-2026**

**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.562 | Basics of Latex (Practical) | Skill based | 0 | 0 | 2 | 1 |
| | Remedial Classes | - | - | 2* | - | - |
| **Total** | | | **18** | **0** | **4** | **20** |

***Non-Credit Course**

## 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.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.513 | Numerical Analysis | Discipline Elective | | | | |
| MAT.512 | Mathematical Statistics | | | | | |
| MAT.565 | Dynamical Systems | | 3 | 0 | 0 | 3 |
| Interdisciplinary Elective (Choose any course offered by other Departments) | | | | | | |
| ABC | Interdisciplinary Elective | IDC | 2 | 0 | 0 | 2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Remedial Classes | - | - | 2* | - | - |
| **Total** | | | **23** | **0** | **2** | **24** |

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

| | | | | | | |
|---|---|---|---|---|---|---|
| MAT.510 | Basic Mathematics (IDC) | IDC | 2 | 0 | 0 | 2 |
| MAT.515 | Vector Analysis (IDC) | | | | | |
| MAT.529 | Numerical Methods (IDC) | | | | | |

## M.Sc. Mathematics (Semester-III)

| Course Code | Course Title | Course Type | Credit Hours | | | Course Credits |
|---|---|---|---|---|---|---|
| | | | L | T | P | |
| STA.511 | Operations Research | 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 | Discipline Elective | | | | |
| MAT.564 | Category Theory | | | | | |
| MAT.558 | Algebraic Topology | | | | | |
| MAT.572 | Riemannian Geometry | | 3 | 0 | 0 | 3 |
| Discipline Elective Course (opt any one of the following) | | | | | | |
| MAT.557 | Advanced Partial Differential Equations | Discipline Elective | | | | |
| MAT.560 | Discrete Differential Geometry | | | | | |
| MAT.532 | Mathematical Modeling | | 3 | 0 | 0 | 3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| MAT.567 | General Relativity | | | | | |
| MAT.569 | Introduction to Cryptography | | | | | |
| STA.559 | Entrepreneurship | Compulsory Foundation | 2 | 0 | 0 | 2 |
| MAT.601 | Dissertation Part-I | Skill based | 0 | 0 | 8 | 4 |
| Value Added Course (opt any one course offered by any Department) | | | | | | |
| ABC | Value Added Course (From Other Departments) | VAC (Value Based) | 2 | 0 | 0 | 2 |
| | Remedial Classes | - | - | 2* | - | - |
| **Total** | | | **17** | **0** | **8** | **21** |

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

| | | | | | | |
|---|---|---|---|---|---|---|
| MAT.528 | Tensor Algebra | VAC (Value Based) | 2 | 0 | 0 | 2 |
| MAT.534 | Mathematical Methods | | | | | |
| MAT.535 | Vedic Mathematics and Data Science | | | | | |

## M.Sc. Mathematics (Semester IV)

| Course Code | Course Title | Course Type | Credit Hours | | | Course Credits |
|---|---|---|---|---|---|---|
| | | | L | T | P | |
| MAT.602 | Dissertation-Part II | Skill Based | 0 | 0 | 40 | 20 |

**Total Credits for the course: 85**

**Examination pattern and evaluation for Masters' students from 2023-24 session onwards**

**Formative Evaluation: I**nternal assessment shall be 25 marks using any two or more of the given methods: tests, open book examination, assignments, term paper, etc. The Mid-semester test shall be descriptive type of 25 marks including short answer and essay type. The number of questions and distribution of marks shall be decided by the teachers.

**Summative Evaluation:** The End semester examination (50 marks) with 70% descriptive type and 30% objective type shall be conducted at the end of the semester. The objective type shall include one-word/sentence answers, fill-in the blanks, MCQs', and matching. The descriptive type shall include short answer and essay type questions. The number of questions and distribution of marks shall be decided by the teachers. **Questions for exams and tests shall be designed to assess course learning outcomes along with focus on knowledge, understanding, application, analysis, synthesis, and evaluation.**

The evaluation for IDC, VAC and entrepreneurship, innovation and skill development courses shall include MST (50 marks) and ESE (50 marks). The pattern of examination for both MST and ESE shall be same as ESE described above for other courses.

Evaluation of dissertation proposal in the third semester shall include 50% weightage by supervisor and 50% by HoD and senior-most faculty of the department. The evaluation of dissertation in the fourth semester shall include 50% weightage for continuous evaluation by the supervisor for regularity in work, mid-term evaluation, report of dissertation, presentation, and final viva-voce; 50% weightage based on average assessment scores by an external expert, HoD and senior-most faculty of the department. Distribution of marks

is based on report of dissertation (30%), presentation (10%), and final viva-voce (10%). The external expert may attend final viva-voce through offline or online mode.

**Examination pattern from 2022-23 session onwards**

| **Core, Discipline Elective, and Compulsory Foundation Courses** | | | **IDC, VAC, and Entrepreneurship, Innovation and Skill Development Courses** | |
|---|---|---|---|---|
| | **Marks** | **Evaluation** | **Marks** | **Evaluation** |
| Internal Assessment | 25 | Various methods | - | - |
| Mid-semester test (MST) | 25 | Descriptive | 50 | Descriptive (70%)<br>Objective (30%) |
| End-semester exam (ESE) | 50 | Descriptive (70%)<br>Objective (30%) | 50 | Descriptive (70%)<br>Objective (30%) |

| **Dissertation Proposal (Third Semester)** | | | **Dissertation (Fourth Semester)** | | |
|---|---|---|---|---|---|
| | **Marks** | **Evaluation** | | **Marks** | **Evaluation** |

| | | | | | |
|---|---|---|---|---|---|
| Supervisor | 50 | Dissertation proposal and presentation | Supervisor | 50 | Continuous assessment (regularity in work, mid-term evaluation) dissertation report, presentation, final viva-voce |
| HoD and senior-most faculty of the department | 50 | Dissertation proposal and presentation | External expert, HoD and senior-most faculty of the department | 50 | Dissertation report (30), presentation (10), final viva-voce (10) |

Marks for internship shall be given by the supervisor, HoD and senior-most faculty of the department.

**Some Guidelines for Internal Assessment**

1. The components/pattern of internal assessment/evaluation should be made clear to students during the semester.

2. The results of the internal assessment must be shown to the students.

3. The question papers and answers of internal assessment should be discussed in the class.

4. The internal assessment shall be transparent and student-friendly and free from personal bias or influence.

**Evaluation Criteria for Practical Courses**

A.Practical file: [15 Marks]

B.Practical Exam: [75 Marks]

C. Viva-Voce Examination: [10 Marks]

**Multiple Entry and Exit in the courses in M.Sc. Mathematics**

Students who exit after the first year shall be awarded the following Post-Graduate Diploma:

**Post-Graduate Diploma in Mathematics and Computing:** For the candidates who join the two-year Master's programme in Mathematics and leaving after completion of one year. For the exit scheme, the candidate has to complete any one course/task mentioned below along with his/her courses read in first year of his/her M.Sc. programme.

1. Propose skills based and vocational courses (4 credits) relevant to your program, a basket of all such courses will be available to the students who opt to exit the program.

2. The skill based courses can also be enlisted from MOOCs (to be approved in CDDC).

3. A mini project, industrial training can also be proposed (with proper evaluation).

**M. Sc. Mathematics**
**Semester-I**

**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<br>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.<br>**Activity:** Students will solve some problems which will be based on concepts of compact sets and connected sets | CLO1<br>CL02 |
| II<br>11 Hours | **Sequences in Metric spaces:** Convergent sequences, 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.<br>**Activity:** Students will solve some problems which will be based on application of sequences, category theorem and Banach contraction theorem. | CLO3 |
| III<br>12 Hours | **Continuity:** Limits of functions (in Metric spaces), Continuous functions, Continuity and compactness, Continuity and connectedness, Discontinuities, Uniform continuity.<br>**Riemann Stieltje's Integral:** Definition and existence of | CLO4 |

| | | |
|---|---|---|
| | 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.<br>**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. | |
| IV<br>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.<br>**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*, 2nd Edition, Addition –Wesley, USA, 2002.
2. A. Kumar and S. Kumaresan, *A Basic Course in Real Analysis*, Narosa, Publishing House, New Delhi, 2014.
3. W. Rudin, *Principles of Mathematical Analysis,* 3rd Edition, McGraw Hill, Kogakusha, International student Edition, 1976.
4. E. C. Titchmarsh, *The Theory of functions,* Oxford University Press, Oxford, 2002.
5. S. P. S. Kainth, A Comprehensive Textbook on Metric Spaces, Springer Verlag, Singapore, 2023.


**Course Title: Linear Algebra**
**Course Code: MAT.508**
**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 and its application in construction of orthonormal basis.

| **Unit/ Hours** | **Content** | **Mapping with CLO** |
|---|---|---|
| **I**<br>**11 Hours** | **Linear Transformations:** Linear transformations, Algebra of linear transformations, Isomorphism,<br>**Matrix representation:** Matrix representation of a linear transformation. Change of basis, Rank and nullity of a linear transformation.<br><br>**Activity:** Students will try to find the applications of linear transformations and matrices | CLO1<br>CLO2 |
| **II**<br>**11 Hours** | Inner product spaces. Norms and distances, Orthonormal basis, Orthogonality, Schwarz inequality, The Gram-Schmidt orthogonalization process. Orthogonal and positive definite matrices.<br><br>**Activity:** Students will try to find the applications of Gram-Schmidt orthogonalization process | CLO5<br>CLO6 |
| **III**<br>**12 Hours** | Annihilating Polynomials: Characteristic polynomial and minimal polynomial of a linear transformation, Characteristic values and Characteristic vectors of a linear transformation, Cayley Hamilton theorem.<br><br>**Activity:** Students will try to find the applications of Cayley Hamilton theorem. | CLO3 |
| **IV**<br>**11 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.<br><br>**Activity:** Students will try to find the applications of Characteristic polynomials and minimal polynomials of block matrices. | 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. J. Gilbert and L. Gilbert, *Linear Algebra and Matrix Theory,* Cengage Learning, 2004.
2. K. Hoffman and R. Kunze: *Linear Algebra*, Pearson Education (Asia) Pvt. Ltd/ Prentice Hall of India, 2018.
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**

**Course Code: MAT.509**

**Total Hours: 45**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**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<br>12 Hours | **Existence and Uniqueness of Initial Value Problems:** Picard's and Peano's Theorems, Gronwall's inequality, continuation of solutions and maximal interval of existence, continuous dependence.<br>**Activity:** Students will try to find the applications of existence and uniqueness theorem of initial value problems | CLO1 |

| | | |
|---|---|---|
| II<br>11 Hours | **Higher Order Linear Equations and linear Systems:** fundamental solutions, Wronskian, variation of constants, matrix exponential solution, behaviour of solutions.<br><br>**Activity:** Students will explore the use of Wronskian for checking the behaviour of solutions higher order linear equations and linear Systems | CLO2 |
| III<br>12 Hours | Boundary Value Problems: Green's function and its applications to boundary value problems, Sturm-Liouville boundary value problem, Eigenvalues and Eigenfunctions.<br>**Activity:** Students will solve some boundary value problems using the Green's function. | CLO3 |
| IV<br>10 Hours | Two Dimensional Autonomous Systems and Phase Space Analysis: critical points, proper and improper nodes, spiral points and saddle points.<br><br>**Activity:** Students will check the behaviour 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, 2007.

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

8. A.K. Nandakumaran, P.S. Datti and Raju K. George, *Ordinary Differential Equations, Principles and Applications*, Cambridge University Press; 1st edition, 2017.

**Course Title: Number Theory**

**Course Code: MAT.511**
**Course Type: Core**

| L | T | P | Credits |
|---|---|---|---|
| 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<br>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.<br><br>**Activity:** Students will work on different examples related to divisibility of integers, residue and reduced residue classes with applications. | CLO1<br><br>CL02 |
| II<br>11 Hours | Chinese remainder theorem, Fermat's little theorem, Wilson's theorem, Euler's theorem. Arithmetic functions $\sigma(n)$, $d(n)$, $\tau(n)$, $\mu(n)$, Order of an integer modulo n, primitive roots for primes.<br><br>**Activity:** Students will explore the use of number theoretic functions based on Chinese remainder theorem, Fermat's little theorem etc. | CLO3 |

| | | |
|---|---|---|
| III<br><br>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.<br><br>**Activity:** Students will explore the concept of Legendre symbol and its applications to find the solution of quadratic congruences. | CLO4 |
| IV<br><br>10 Hours | **Diophantine equations:** Representation of an integer as a sum of two and four squares, Diophantine equations ax + by = c, x2+y2=z2 and its application to x4+y4=z2.<br><br>**Activity:** Students learn the basics 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, 2017.
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, 6th Edition, 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 $R^3$.

**CLO3:** Use 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<br>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.<br>**Activity:** To find curvature and torsion of some important plane and space curves and study global properties of curves. | CLO1 |
| II<br>11 Hours | Surfaces in space**:** Definition and examples, Smooth surfaces, Smooth maps, Tangents and derivatives, Normal and orientability. Examples of surfaces: Level surfaces, Generalised cylinder and generalised cone, Ruled surfaces, Surface of revolution, Compact surfaces. First fundamental form, Isometries of surfaces, Conformal mapping of surfaces, Equiareal maps and theorem of Archimedes.<br>**Activity:** To find the first fundamental form and surface area of some important surfaces. | CLO2 |
| III<br>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, | CLO3 |

| | | |
|---|---|---|
| | Surfaces of constant Gaussian curvature, Flat surfaces, Surfaces of constant mean curvature, Gaussian curvature of compact surfaces.<br>**Activity:** To find a second fundamental form, principal curvatures and Gaussian curvature of some important surfaces. | |
| IV<br>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.<br>**Activity:** To find geodesics, geodesic equations and compact surfaces of constant Gaussian curvature. | CLO4<br>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, 2011.
2. M. P. Do Carmo, *Differential Geometry of Curves and Surfaces*, 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, 2017.
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, 2010.
7. J. A. Torpe, Elementary Topics in Differential Geometry, UTM, Springer, 2011.
8. T. J. Willmore, *An Introduction to Differential Geometry*, First Edition, Dover Publications, Inc., Mineola, New York, 2012.


**Course Title: Differential Geometry (Practical)**

**Course Code: MAT.527**

**Total Hours: 3**

| L | T | P | Credits |
|---|---|---|---|
| 0 | 0 | 2 | 1 |

## 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 curves with assigned curvature function.

6.Translating, rotating and reflection of curves.

7.Constructing tangent, normal and binormal vectors and visualising 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.Visualisation 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, 2011.

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, 2017.
4. R. S. Millman & G. D. Parkar, *Elements of Differential Geometry*, Englewood Cliffs, N.J. : Prentice Hall, 1977.

**Course Title: Topology**
**Course Code: MAT.530**
**Course type: Core**
**Total Hours: 45**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**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<br>12 Hours | Topological spaces: Definitions and Examples, Basis and Subbasis for a Topology, limit points, closure, interior; Continuous functions, Homeomorphisms; Subspace Topology, Metric Topology, Product & Box Topology, Order Topology; Quotient spaces.<br>**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<br>CL02 |
| II<br>12 Hours | Connectedness: Connected spaces, Connected subspaces of the real line, Components and path components, Local connectedness.<br>**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 | CLO3 |

| | | |
|---|---|---|
| | applications to detect when two topological spaces are not homeomorphic. | |
| III<br>11 Hours | Compactness: Compact spaces, Sequentially compact spaces, Heine-Borel theorem, Compact subspaces of the real line, Limit point compactness, Local–compactness and one point compactification.<br><br>**Activity:** Students will explore other important topological properties with examples and applications which will again help to determine non-homeomorphic topological spaces. | CLO4 |
| IV<br>10 Hours | **Countability Axioms:** First countable spaces, Second countable spaces, Separable spaces, Lindeloff spaces. Separation Axioms: Hausdorff, Regular and Normal spaces; Urysohn's lemma; Uryohn'sMetrization theorem; Tietze extension theorem. (Statements only).<br><br>**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)**

| L | T | P | Credits |
|---|---|---|---|
| 0 | 0 | 2 | 1 |

**Code: MAT.568**

**Total Hours: 30**

## 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,* Philadelphia, Pennsylvania, SIAM, 2016.
2. L. Lamport. LATEX: A Document Preparation System, User's Guide and Reference Manual. 2nd Edition, Addison Wesley, New York, 1994.
3. M. Goossens, F. M. Michel, and S. Alexander, The LaTeX companion, 2nd Edition, Addison-Wesley, 1994.

**M. Sc. Mathematics**
**Semester-II**

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

**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<br><br>10 Hours | Functions of a complex variable, limit, continuity, uniform continuity, differentiability, analytic function, Cauchy- Riemann equations, harmonic functions and harmonic conjugate.<br><br>**Activity:** Students will make use of Cauchy- Riemann equations to investigate the functions of complex variables which are analytic or not. | CLO1<br><br>CL02 |

| | | |
|---|---|---|
| II<br><br>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.<br><br>**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<br><br>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.<br><br>**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<br><br>11 Hours | Meromorphic functions, the argument principle, Rouche's theorem, Mobius transformations and their properties, definition and examples of conformal mappings.<br><br>**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*, 9th 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*, 1stEdition,CRC Publications, 2004.
6. Rajendra Kumar Sharma, Sudesh Kumari Shah and Asha Gauri Shankar, *Complex Numbers and Theory of Equations*, Anthem Press, 2011.
7. Lars V. Ahlfors, An Introduction to the Theory of Analytic Function of one complex variable, 3rd Edition, Tata McGraw-Hill, 2006.
8. Dennis G. Zill& Patrick D. Shanahan, A First Course in Complex Analysis with Application, 3rd Edition, Jones and Bartlett, 2003.
9. S.Kumaresan, *A Pathway to Complex Analysis, 1st Edition, Techno World Publication, 2021.*

**Course Title: Abstract Algebra**

**Course Code: MAT.531**

**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 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<br><br>12 Hours | **Group Theory:** Review of basic concepts of groups, Permutation groups, Alternating groups, Cayley's Theorem, Class equations. Fundamental theorem for finite Abelian groups, Sylow's theorems and their applications.<br><br>**Activity:** Students will work on different examples related to group theory and will explore the use of group theory in real life problems. | CLO1<br><br>CL02 |
| II<br><br>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.<br><br>**Activity:** Students will explore the properties of ring and will solve some problems related to these concepts. | CLO3 |
| III<br><br>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.<br><br>**Activity:** Thestudents will explore the concept of field extension and its applications. The students will solve problems related to these concepts. | CLO4<br><br>CLO5 |
| IV<br><br>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 | CLO6 |

| | | |
|---|---|---|
| | elements of finite fields<br><br>**Activity:** The students will solve problems related to trace and norm functions. Also, they will explore the 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**

**Course Code: MAT.552**

**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 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<br><br>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.<br><br>**Activity:** Exercises depending on unit-I | CLO1<br><br>CL02 |
| II<br><br>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.<br><br>**Activity:** Exercises depending on unit-II | CLO3 |
| III<br><br>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.<br><br>**Activity:** Exercises depending on unit-III | CLO4 |

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|---|---|---|
| IV<br><br>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.<br><br>**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. B. P. Parashar, *Differential and Integral Equations,* 2nd Edition, CBS Publishers and Distributors Pvt Ltd, 2008.
4. M.D. Raisinghania, *Integral equations and boundary value problems,* 9th Edition, S. Chand Publishing, New Delhi, 2016.
5. R. P. Kanwal, *Linear integral equations*, Birkhauser, Boston, 1996.
6. Rakesh Kumar and Nagendra Kumar, *Differential Equations and Calculus of Variations,* CBS Publishers and Distributors Pvt Ltd, 2013.
7. Frederic Wan, *Introduction to the calculus of variations and its applications,* Chapman and Hall/CRC; 2nd Edition, 2019.


**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:** Understand the 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<br>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, Orientation of manifolds, Diffeomorphisms, Partitions of unity and Bump functions.<br>Activity: Exercises on charts, atlases and smooth maps. | CLO1 |
| II<br>11 Hours | Tangent vectors and Tangent space, The Differential of a map, Computations in coordinates, Tangent bundle, Velocity vectors of curves, Maps of constant rank, Embeddings, Submersions, Immersions and Smooth covering maps, Embedded submanifolds, Immersed submanifolds, Restricting maps to submanifolds, Tangent space to a submanifold.<br>Activity: Exercises on Rank of smooth map, submersion, immersion and embeddings. | CLO2 |
| III<br>11 Hours | Topological groups, Lie groups, Lie group homomorphisms, Lie subgroups, Group actions and Equivariant maps, Vector fields, Vector fields and smooth maps, Lie brackets, The Lie algebra of a Lie group, and Induced Lie algebra homomorphisms.<br>**Activity:** Exercises on vector fields, Lie Groups and Lie subgroups and Lie algebra. | CLO3 |
| IV<br>11 Hours | Covectors, The Differential of a function, Pullback of Covector fields. Multilinear algebra, Symmetric and Alternating Tensors, Tensors and Tensor fields on manifolds. The algebra of alternating tensors,, Differential forms on Euclidean n-space, Differential forms on manifolds, Exterior product, Exterior derivative.<br>**Activity:** Exercises on Multilinear algebra, Exterior product,Differential forms and Exterior 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, 2007.
2. S. S. Chern, W. H. Chen and K. S. Lam, *Lectures on Differential Geometry*, World Scientific Publishing Co. Pvt. Ltd., 2022.
3. N. J. Hicks, *Notes of Differential Geometry*, D. Van Nostrand Reinhold Company, New York, 1965.
4. S. Kumaresan, *A Course in Differential Geometry and Lie Groups (Texts and Readings in Mathematics),* Hindustan Book Agency, 2002.
5. J. M. Lee, *Introduction to Smooth Manifolds*, GTM, Vol. 218, Springer, New York, 2012.
6. S. Morita, *Geometry of Differential forms, Translations of Mathematical Monographs*, Vol. 201, American Mathematical Society, 2001.
7. L. W. Tu, *An Introduction to Manifolds*, Second edition, Springer, 2011.


**Course Title: Partial Differential Equations**

**Course Code: MAT.561**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**Total Hours: 45**

**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 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<br>10 Hours | Cauchy Problems for First Order Partial Differential Equations (FOPDEs):method of characteristics, Integral surface passing through given curve. FOPDE's-Initial value problems for Burgers equation, FOPDE's - Conservation laws with a view towards global solutions to Burgers equation<br><br>**Activity:** Students will explore the formation of partial | CLO1 |

| | | |
|---|---|---|
| | differential equations representing some real phenomena. | |
| II<br>11<br>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.<br>**Activity:** Students will explore the formation of second order partial differential equations representing some real phenomena. | CLO2 |
| III<br>12<br>Hours | Fourier Series: Periodic functions and Fourier series, convergence of Fourier series, functions of any period, even and odd functions, half-range expansions.<br><br>Heat equation: initial value problem, fundamental solution, weak and strong maximum principle and uniqueness results.<br><br>**Activity:** Students will explore how the solutions of problems behave if we change the initial and boundary conditions. | CLO3 |
| IV<br>12<br>Hours | Laplace equation: mean value property, weak and strong maximum principle, Green's function,<br>Wave equation: uniqueness, D'Alembert's method<br><br>**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, Birkhauser, 1995.

7. Nakhle H. Asmar,Partial Differential Equations with Fourier Series and Boundary Value Problems, 1st Edition, Dover Publications Inc., 2016.

**Course Title: Measure Theory**
**Course Code: MAT.562**
**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 Product Measure.

| Units/ Hours | Contents | Mapping with CLO |
|---|---|---|
| I<br>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<br><br>**Activity:** Students will find the outer measure of some sets and will apply these concepts in integration. | CLO1<br>CLO2 |
| II<br>11 Hours | Continuity of measure and Borel-Cantelli Lemma, Existence of a non-measurable set, Measurability of Cantor set.<br>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).<br><br>**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. | CLO3 |
| III | Lebesgue integral on R and its properties. Bounded | CLO4 |

| | | |
|---|---|---|
| 11 Hours | convergence theorem, Fatou's lemma, Lebesgue monotone convergence theorem, Lebesgue dominated convergence theorem, countable additivity and continuity of integration.<br><br>**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. | |
| IV<br>11 Hours | Functions of bounded variations: Jordan's theorem, Product Measure: an Introduction, Construction of Product Measures.<br><br>**Activity:** Students will write some functions of bounded variations as the difference of two increasing functions. | 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.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.
7. T. Tao, *An introduction to measure theory*. Vol. 126. American Mathematical Soc., 2021.


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

**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. Find the Fourier series for functions.
6. Eigenvalue Problems and Fourier Series
7. Solution of the wave equation for the associated conditions.
8. Solution of heat equation for the associated conditions.
9. 3D plot of Solutions of Wave and Heat Equations.

**Books Recommended**

1. TynMyint-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, 2022.

**Course Title: Mathematical Statistics**
**Course Code: MAT.512**
**Course type: Discipline Elective Course**
**Total Hours: 45**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**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<br>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.<br><br>**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<br>12 Hours | Expectation, Conditional expectation, Moments, Moment generating function and its properties,,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).<br><br>**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. | CLO2 |
| III<br>11 Hours | Discrete Distributions: Bernoulli, Binomial, Poisson, hyper-geometric, geometric, negative binomial. Continuous Distributions: Uniform, normal, exponential, gamma, Beta.<br><br>**Activity:** Students will explore the use of these discrete and continuous distributions in real life problems. | CLO3 |
| IV<br>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.<br><br>**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. Rohatgi, Vijay K., and AK Md Ehsanes Saleh. *An introduction to probability and statistics*. John Wiley & Sons, 2015.

**Course Title: Numerical Analysis**
**Course Code: MAT.513**
**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 various numerical techniques for a variety of mathematical problems occurring in science and engineering.

**CLO2.** Explain the basic concept of errors .

**CLO3.** Review the numerical techniques for interpolation and approximations with examples.

**CLO4.** Explain the concept of numerical integration and differentiation.

**CLO5.** Explain the concept of numerical solutions of differential equations.

| Units/ Hours | Contents | Mapping with CLO |
|---|---|---|

| | | |
|---|---|---|
| I<br>11 Hours | Error Analysis: Definition and sources of errors, Propagation of errors, Sensitivity and conditioning, Stability and accuracy, Floating-point arithmetic and rounding errors. Numerical Solutions of Algebraic Equations: Bisection method. Fixed- point iteration, Newton Raphson's method, Secant method, Convergence and order of convergence<br><br>**Activity:** Students will try to work on various examples related to the concepts of calculating error and finding numerical solutions of algebraic/transcendental equations | CLO1, CLO2 |
| II<br>12 Hours | Linear Systems of Equations: Gauss elimination and Gauss-Jordan methods, Jacobi and Gauss- Seidel iteration methods.<br><br>Polynomial Interpolation: Interpolating polynomial, Lagrange and Newton divided difference interpolation, Error in interpolation, Finite difference formulas, Hermite Interpolation.<br><br>**Activity:** Students will explore the use of methods of interpolation for fitting a curve or approximating the values of functions at some points. | CLO3 |
| III<br>11 Hours | Numerical Differentiation and Integration: Numerical differentiation with finite differences, Trapezoidal rule, Simpson's 1/3 - rule, Simpson's 3/8 rule, Error estimates for Trapezoidal rule and Simpson's rule, Gauss quadrature formulas.<br><br>**Activity:** Students will explore the use of numerical differentiation and integration in some problems. | CLO4 |
| IV<br>11 Hours | Numerical Solution of Ordinary Differential Equations: Solution by Taylor series, Picard method of successive approximations, Euler's method, Modified Euler method, Runge- Kutta methods. Finite difference method for boundary value problems.<br><br>**Activity:** Students will do the examples applying the | CLO5 |

| | | |
|---|---|---|
| | various methods explained for solving the initial value 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. K. Atkinson, *An Introduction to Numerical Analysis*, 2nd Edition, John Wiley & Sons, 1989.
2. R. L. Burden and J. D. Faires, *Numerical Analysis*, 9th Edition, Cengage Learning, 2011.
3. R. K. Gupta, *Numerical Methods: Fundamentals and Applications*, 1st Edition, Cambridge University Press, 2019.
4. R. S. Gupta, *Elements of Numerical Analysis*, 2nd Edition, Cambridge University Press, 2015.
5. 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.


**Course Title: Dynamical Systems**

**Course Code: MAT.565**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**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 behaviour 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<br>11 Hours | **One-Dimensional Flows**<br><br>**Linear Systems:** linear system theory via eigenvalues and eigenvectors, Fixed Points and Stability, Population Growth, Linear Stability Analysis, Existence and Uniqueness, Impossibility of Oscillations.<br><br>**Activity:** Students will apply some basics of linear algebra in study of dynamical systems. | CLO1 |
| II<br>12 Hours | **Bifurcations:** Saddle-Node Bifurcation, Transcritical Bifurcation, Pitchfork Bifurcation, Insect Outbreak<br><br>**Two-Dimensional Flows**<br><br>Linear Systems, Classification of Linear Systems<br><br>**Activity:** Students will check the stability of some dynamical systems by using the concept of bifurcation. | CLO2 |
| III<br>11 Hours | **Phase Plane:** Phase Portraits, Existence, Uniqueness, and Topological Consequences, Fixed Points and Linearization, Conservative Systems, Reversible Systems, Pendulum, Index Theory<br><br>Limit Cycles: Introduction to Limit Cyclces, Ruling Out Closed Orbits, Poincare-Bendixson Theorem<br><br>Hamiltonian Systems in the Plane, Lyapunov Functions and Stability<br><br>**Activity:** Students will draw the phase portraits of some dynamical systems using some software. | CLO3 |
| IV<br>11 Hours | **Bifurcations Revisited: Saddle-Node,** Transcritical, and Pitchfork Bifurcations, Hopf Bifurcations: Concept of attractors and repellers, limit cycles and torus, Global Bifurcations of Cycles, Homoclinic & Hetero-clinic points and orbits.<br><br>**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. Strogatz, Steven H. *Nonlinear dynamics and chaos with student solutions manual: With applications to physics, biology, chemistry, and engineering*. CRC press, 2018.
6. L. Perko, Differential Equations and Dynamical Systems, Springer Verlag, 1991.
7. S. Lynch, Dynamical systems with applications using Mathematica®. Boston: Birkhäuser, 2007.


**Course Title: Basic Mathematics**

**Course Code: MAT.510**

**Course Tupe: IDC**

| L | T | P | Credits |
|---|---|---|---|
| 2 | 0 | 0 | 2 |

**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<br><br>08 Hours | **Sets**: Basic Definitions, subsets, power set, set operations. Ordered pairs, Cartesian product of sets.<br>**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.<br><br>**Activity:** Students will try to find the applications of functions and relations. | CLO1<br><br>CL02 |
| II<br><br>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.<br><br>**Activity:** Students will solve some problems related to these sequences and series. | CLO3 |
| III<br><br>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.<br><br>**Activity:** Students will solve some problems related to the complex number. | CLO4 |

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|---|---|---|
| IV<br><br>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.<br><br>**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: Vector Analysis (IDC)**

**Course Code: MAT.515**

| L | T | P | Credits |
|---|---|---|---|
| 2 | 0 | 0 | 2 |

**Course Type: IDC**
**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<br>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.<br><br>**Activity:** To check Linearly independent and Linearly dependent set of vectors, exercises on dot and cross product and vector differentiation. | CLO1 |
| II<br>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 in plane.<br><br>**Activity:** Exercises on Gradient, Divergence, Curl and Vector integration. | CLO2 |
| III<br>7 Hours | Transformation of coordinates, orthogonal curvilinear coordinates, arc length and volume elements, Gradient, Divergence and curl in curvilinear coordinates, special orthogonal coordinate systems.<br><br>**Activity:** Exercises on arc-length, volume, Div. and Curl in Curvilinear coordinates. | CLO3 |
| IV<br>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.<br><br>**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, 2021.
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: Numerical Methods (IDC)**

**Course Code: MAT.529**

| L | T | P | Credits |
|---|---|---|---|
| 2 | 0 | 0 | 2 |

**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<br>7 Hours | **Error Analysis:** Relative error, Truncation error, Roundoff error, Order of approximation, Order of convergence, Propagation.<br>**Activity:** Students will explore the use of error analysis and rounding in some daily life problems like measuring. | CLO1 |

| | | |
|---|---|---|
| II<br>8 Hours | **Roots of Nonlinear Equations:** Bisection method, Secant method, Newton Raphson method, Convergence and order of convergence.<br>**Activity:** Students will explore the use of these methods in solving some real life problems. | CLO2 |
| III<br>8 Hours | **Linear Systems of Equations:** Gauss elimination and Gauss-Seidel methods. **Interpolation**: Lagrange's Method, Newton's polynomials.<br>**Activity:** Students will explore the use of these methods in solving some real life problems. | CLO3 |
| IV<br>7 Hours | **Solution of Differential Equations:** Euler's method, Heun's method, Taylor series method, RungeKutta method.<br>**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. S. Mathematics (Semester-III)

**Course Title: Operations Research**

**Course Code: STA.511**

| L | T | P | Credits |
|---|---|---|---|
| 4 | 0 | 0 | 4 |

**Course Type: Compulsory foundation**
**Total Hours: 60**

**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 sequencing, Games and strategies.

| Units/ Hours | Contents | Mapping with CLO |
|---|---|---|
| I<br>15 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. Simplex method, Big-M method, Two phase method, Determination of Optimal solutions, Unrestricted variables.<br>**Activity:** Students will formulate linear programming problems and find solutions with graphical methods. | CLO1<br>CLO2 |
| II<br>15 Hours | Duality theory, Dual linear Programming Problems, Fundamental properties of dual problems, Complementary slackness, Unbounded solution in Primal. Dual Simplex Algorithm. Sensitivity analysis: Discrete changes in the cost vector, requirement vector and coefficient matrix.<br>**Activity:** Students will do problems to find solutions through Simplex method, Big-M method and two phase | CLO3 |

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|---|---|---|
| | method. They will exercise dual linear programming problems. | |
| III<br>15 Hours | 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. Assignment Problems: Mathematical formulation of assignment problem, Hungarian method for solving assignment problems, Traveling salesman problem.<br>**Activity:** Students will do exercises on Sensitivity analysis and transportation problems. | CLO4<br>CLO5 |
| IV<br>15 Hours | Sequencing Problem: General assumptions and basic terms used in sequencing. Processing n jobs through 2 machines, Processing n jobs through 3 machines. Games and Strategies: Two person zero sum games, Maximin - Minimax principle, Saddle points, Graphic and arithmetic solutions.<br>**Activity:** Students will do exercises on Assignment problem and sequencing problem | 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. G. Hadley, *Linear Programming*, Narosa Publishing House, New Delhi, 2002.
2. H. A. Taha, *Operations Research - An Introduction*, Macmillan Publishing Company Inc., New York, 2019.
3. K. Swarup, P. K. Gupta, and M. Mohan, *Operations Research*, Sultan Chand & Sons, New Delhi, 2010.
4. N. S. Kambo, *Mathematical Programming Techniques*, Affiliated East-West Press Pvt. Ltd., 1984, Revised Edition, New Delhi, 2008.
5. S. M. Sinha, *Mathematical Programming, Theory and Methods,* Delhi: Elsevier, 2005.

**Course Title: Functional Analysis**

**Course Code: MAT.571**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**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<br>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.<br>**Activity:** Students will find examples of Banach spaces and normed linear spaces which are not Banach spaces. | CLO1 |
| II<br>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<br>**Activity:** Students will do results related to bounded linear transformations and Dual spaces. | CLO2 |
| III<br>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; normal, unitary and self adjoint | CLO3 |

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|---|---|---|
| | operators.<br>**Activity:** Students will do exercises on Hilbert spaces and examples of inner product spaces which are not Hilbert spaces. | |
| IV<br>12 Hours | Hahn-Banach theorem for real linear spaces and its consequences, Reflexive spaces, Solvability of linear equations in Banach spaces.<br>**Three Main Theorems on Banach Space**: BanachSteinhauns theorem (Uniform boundedness theorem) and some of its consequences, Open mapping and closed graph theorems.<br><br>**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; 2nd edition, 2017.

**Course Title: Advanced Complex Analysis**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**Course Code: MAT.556**

**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<br><br>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.<br><br>**Activity:** Students will do some exercise on Dirichlet problems. | CLO1<br><br>CL02 |

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|---|---|---|
| II<br><br>11<br>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.<br><br>**Activity:** Students will explore the applications of Open mapping theorem, Riemann mapping theorem, Picard's theorem. | CLO3 |
| III<br><br>12<br>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).<br><br>**Acitivity:** students will apply the Weierstrass Zeta functio in solving some problems | CLO4 |
| IV<br><br>11<br>Hours | **Weierstrass Zeta function:**Weierstrass zeta function and their properties, quasi periodicity of (z), Weierstrass sigma function (z) and their properties, associated sigma functions.<br><br>**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.

6. S.Kumaresan, *A Pathway to Complex Analysis,* 1st Edition, Techno World Publication, 2021.

**Course Title: Category Theory**
**Course Code: MAT.564**
**Course type: Discipline Elective Course**
**Total Hours: 45**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**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<br>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.<br><br>**Activity:** Students will do examples/exercises of categories and Functors and explore the presence of other categories and UMPs. | CLO1<br>CLO2 |
| II<br>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.<br>**Activity:** Students will work on the exercises and examples on these topics. | CLO3 |
| III<br>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 terms of equalizers and pullbacks.<br><br>**Activity:** Students will do exercises/examples on these topics. | CLO4 |
| IV<br>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 | CLO5 |

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| | to isomorphism. Order Adjoints and interior operation in Topology as an order adjoint. Preservation of Limits (Co limits) by Right (Left) Adjoints.<br>**Activity:** Students will do examples of Natural Transformations and Explore the occurrence of Adjunctions in Mathematics. | |

**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, 52, Oxford University Press, 2010.

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: Algebraic Topology**

**Course Code: MAT.558**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**Course Type: DE**
**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<br>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.<br>**Activity:** To find fundamental groups of some important topological structures. | CLO 1<br>CLO 2<br>CLO 3<br>CLO 6 |
| II<br>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.<br>**Activity:** To find applications of above important theorems in terms of examples. | CLO 1<br>CLO 2<br>CLO 3<br>CLO 6 |
| III<br>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.<br>**Activity:** Exercises on Abelian groups, free groups and free products. | CLO 4<br>CLO 6 |
| IV<br>11 Hours | Classification of covering spaces: Equivalence of covering spaces, The general lifting lemma, The universal covering space, Covering transformation, Existence of covering spaces.<br>**Activity:** Exercises on covering spaces. | CLO 5<br>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, 2018.

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, *Algebraic Topology: An Introduction,* SPRINGER (SIE), 2010.
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, 2011.
8. E. H. Spanier, *Algebraic Topology (2nd edition*), Springer-Verlag, New York, 2000.

**Course Title: Riemannian Geometry**
**Course Code: MAT.572**
**Course Type: DE**
**Total Hours: 45**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**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 second variation formula 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/ Hours | Content | Mapping with CLO |
|---|---|---|
| I<br>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.<br>**Activity:** Exercises on covariant differentiation, Reiemannian metric and Riemannian connection. | CLO1<br>CLO5<br>CLO6<br>CLO7 |
| II<br>11 Hours | Tensors and tensor fields (Riemannian metric as the most significant example), Tensorial property, Covariant | CLO2<br>CLO5 |

| | | |
|---|---|---|
| | differentiation of tensor fields, Riemann curvature tensor, Ricci tensor, Sectional, Ricci and scalar curvatures, Isometries, Pull-back metrics via diffeomorphisms.<br>**Activity:** Exercises on different curvature tensors and isometries. | CLO6<br>CLO7 |
| III<br>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.<br>**Activity:** Exercises on arc-length, energy, geodesics and exponential map. | CLO3<br>CLO5<br>CLO6<br>CLO7 |
| IV<br>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).<br>**Activity:** Exercises on the application of the above mentioned theorems. | CLO4<br>CLO5<br>CLO6<br>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, 2012.
2. W. M. Boothby, *An Introduction to Differentiable Manifolds and Riemannian Geometry*, 2nd Edition, Academic Press, New York, 2007.
3. S. S. Chern, W. H. Chen and K. S. Lam, *Lectures on Differential Geometry*, World Scientific Publishing, 2022.
4. M. P. Docarmo, *Riemannian Geometry: Theory and Applications*, Birkhausker Boston, 2011.
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 Riemannian Manifolds: 176*, GTM, Springer, 2021.
7. B. O' Neill, *Semi-Riemannian Geometry with Applications to Relativity*, Academic Press, New York, 2011.
8. P. Petersen, Riemannian Geometry: 171 (GTM), Springer, 2016.

9. Sylvestre Gallot, Dominique Hulin, Jacques Lafontaine, *Riemannian Geometry*, University text, Springer, 2004.

**Course Title: Advanced Partial Differential Equations**

**Course Code: MAT.557**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**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<br>12 Hours | **Distribution**: Test functions and distributions, examples, operations on distributions, supports and singular supports, convolution, fundamental solutions, fourier transform, Schwartz space, tempered distributions.<br><br>**Sobolev Spaces**: Basic properties, approximation by smooth functions, extension theorems, compactness theorems, dual spaces, functional order spaces, trace spaces, trace theory, inclusion theorem.<br><br>**Activity:** Students will use smooth functions for approximations. | CLO1 |
| II<br>11 Hours | **Weak solutions of elliptic boundary value problems**: variational problems, weak formulation of elliptic PDE, regularity, Galerkin method, Maximum principles, | CLO2 |

| | | |
|---|---|---|
| | eigenvalue problems, Introduction to finite element methods.<br><br>**Activity:** Students will obtain weak solutions of some elliptic boundary value problems. | |
| III<br>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.<br><br>**Activity:** Students will study scientific evolution equations. | CLO3 |
| IV<br>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).<br><br>**Activity:** Students will check the conditions for existence of minimizers. | 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. 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.
6. Peter J. Costa, *Select Ideas in Partial Differential Equations*. Springer Nature, 2022.

**Course Title: Discrete Differential Geometry**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**Course Code: MAT.560**

**Course Type: DE**
**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<br>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.<br>**Activity:** Exercises on Simplicial complex, simplicial surfaces and curvature of surfaces. | CLO1 |
| II<br>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.<br>**Activity:** Exercises on Wedge product, differential forms and Stoke's theorem. | CLO2 |
| III<br>11 Hours | Curvature of Discrete Surfaces: Vector Area, Area | CLO3 |

| | | |
|---|---|---|
| | 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.<br>**Activity:** Exercises on Gradient, Divergence, Poisson equation and curvature flow. | |
| IV<br>11 Hours | Surface Parameterization: Conformal Structure, The Cauchy-Riemann Equation, Differential Forms on a Riemann Surface, Conformal Parameterization, Eigenvectors, Eigenvalues, and Optimization.<br><br>**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, 2016.
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: Mathematical Modeling**

**Course Code: MAT.532**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**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<br>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.<br><br>**Activity:** Students will study some epidemic models. | CLO1 |
| II<br>11 Hours | Linear system theory, stability analysis, role of eigenvalues & vectors and phase diagrams.<br><br>**Activity:** Students will study some autonomous systems and will check their stability. | CLO2 |
| III<br>11 Hours | Single-species population model, Allee effect, Predator-Prey model, Lotka-Volterra model and SIR model.<br><br>**Activity:** Students will study some population models with available data. | CLO3 |
| IV<br>12 Hours | **I**ntroduction to models in chemical-kinetics, Hopf bifurcation, Poincare-Bendixson theory and index theory.<br><br>**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.
6. AlfioQuarteroni, and GervasioPaola. *A Primer on Mathematical Modelling.* Vol. 121. Springer Nature, 2020.

**Course Title: General Relativity**

**Course Code: MAT.**

| L | T | P | Credits |
|---|---|---|---|
| 3 | 0 | 0 | 3 |

**Total Lectures: 45**

**Learning outcomes**:
The students will be able to
**CLO1**: Find Einstein's field equations and express its physical significance
**CLO2**: Understand Schwarzschild internal and external solutions.
**CLO3**: Determine the Einstein-Maxwell equations, Reissner-Nordstr□m solution and their
applications.
**CLO4**: Derive modified field equations for cosmological models.

| Units/ Hours | Contents | Mapping with CLO |
|---|---|---|

| | | |
|---|---|---|
| I<br><br>10 Hours | Elementary properties of Tensors. Rules of Combination of Tensors, Tensor Algebra, Inner and Outer Product Quotient Rule, Riemannian space, Metric tensor and Conjugate Metric Tensors, Raising and lowering properties.<br><br>Parallel Transport, Christofell symbols of first and second kind, Tranformation properties of Christofell symbols,<br><br>**Activity:** Students will be able to calculate Christofell symbols of first and second kind | CLO1 |
| II<br><br>12 Hours | Covariant Derivative of Tensors, Gradient, Divergence and Curl of Tensors.<br><br>Geodesic Equation, Riemannian Tensor, Ricci Tensor, Bianchi Identities, Scalar Curvature, Einstein Tensor and their properties, Differential Manifolds<br><br>**Activity:** Students will find the applications of Riemannian Tensor, Ricci Tensor, Bianchi Identities, Scalar Curvature, Einstein Tensor. | CLO2 |
| III<br><br>12 Hours | Transition of Special to General Theory of Relativity, Principle of covariance, Equivalence Principle and consequences, Stress Energy Tensor, Einstein Field Equations and Newtonian limit.<br><br>**Activity:** Students will explore the concept of Einstein field equations and its applications. | CLO3 |

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|---|---|---|
| IV<br><br>11 Hours | Spherically symmetric solution to Einstein Field Equation in free space and in matter, Schwarzshild line element. Schwarzschild Singularity, Eddington-Finkelstein co-ordinates, Kruskal-Szekeres co-ordinates.<br><br>**Activity:** Students will explore be able to find the Spherically symmetric solution of Einstein field 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. Narlikar, J.V. An Introduction to Cosmology, 3rd edition (Cambridge University Press, 2002).
2. Adler, R., Bazin M. & Schiffer, M., Introduction to General Relativity (McGraw Hill, 1975).
3. Landau and Lifshitz, Classical Theory of Fields (Pergamon Press, 1975).
4. Dirac, P. A. M. General Theory of Relativity (Prentice Hall of India (reprinted), 2001.


**Course Title: Introduction to Cryptography**

**Course Code: MAT.569**
**Course Type: Discipline Elective**

| L | T | P | Credits |
|---|---|---|---|
| 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/ Hours** | **Contents** | **Mapping with CLO** |
|---|---|---|
| **I**<br><br>**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<br><br>**Activity:** Students will work on different examples related to substitution cipher and will explore cryptography before the computer age. | CLO1<br><br>CL02 |
| **II**<br><br>**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 | CLO3 |

| | | |
|---|---|---|
| | **Activity:** Students will explore the properties of various public key cryptosystems and will solve some problems based on Euler's formula. | |
| **III**<br><br>**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.<br><br>**Activity:** The students will explore the concept of primality testing and applications of prime numbers in different areas of mathematics and computer science. The students will solve problems related to these concepts. | CLO4 |
| **IV**<br><br>**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).<br><br>**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<br><br>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 VYaschenko, 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: Entrepreneurship**

| L | T | P | Credits |
|---|---|---|---|
| 2 | 0 | 0 | 2 |

**Course Code: STA.563**
**Total Hours: 30**
**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.

| Units/Hours | Contents | Mapping with Course Learning Outcome |
|---|---|---|
| I<br>6 Hours | Introduction to entrepreneur and entrepreneurship; Characteristics of an entrepreneur; Characteristics of entrepreneurship; entrepreneurial traits and skills; innovation and entrepreneurship; Types of entrepreneurial ventures; enterprise and society in Indian context.<br><br>**Activities:** Students will understand about the concept of entrepreneur, characteristics of entrepreneurship | CLO1 |

| | | |
|---|---|---|
| II<br>10<br>Hours | Importance of women entrepreneurship, working environment, challenges in the path of women entrepreneurs, empowerment.<br>Role of Statisticians in business, industry and government sector.<br><br>**Activities**: Students will explore the importance of women entrepreneurship and role of statisticians in different domains | CLO2 |
| III<br>8 Hours | Characteristics of successful mathematician, the importance of consistent learning for becoming a successful entrepreneur, how to develop the ability to face challenges in the work environment, and<br><br>**Activities:** Students will hand on experience through case studies on how to develop habits to become a successful statistician and entrepreneur. | CLO3 |
| IV<br>6 Hours | Importance of effective communication skills, publicizing mathematics and ethics consideration, efficient in doing mathematical analysis.<br><br>**Activities:** Students will hand on experience through case studies on how to communicate effectively and publicizing statistics in an efficient manner. | CLO4 |

**Suggested Readings:**


1. Arora, Renu (2008). Entrepreneurship and Small Business, Dhanpat Rai & Sons Publications.
2. Chandra, Prasaaan (2018). Project Preparation, Appraisal, Implementation, Tata Mc-Graw Hills.
3. Desai, Vasant (2019). Management of a Small Scale Industry, Himalaya Publishing House.
4. Jain, P. C. (2015). Handbook of New Entrepreneurs, Oxford University Press.
5. Srivastava, S. B. (2009). A Practical Guide to Industrial Entrepreneurs, Sultan Chand & Sons.
6. Zamiruddin-(2009) Business Mathematics, Sultan Chand & Sons.

**Course Title: Tensor Algebra (VAC)**

**Course Code: MAT.528**
**Total Hours: 30**

| L | T | P | Credits |
|---|---|---|---|
| 2 | 0 | 0 | 2 |

**Learning outcomes:**
The students will be able to
**CLO1:** Explain and use Tensors and operations on Tensors.
**CLO2:** Understand the metric tensor and angle between vectors.
**CLO3:** Understand and use Christoffel symbols and Covariant derivative.
**CLO4:** Understand Curl, Divergence of vectors and applications of covariant derivatives.

| Units/Hours | Content | Mapping with CLO |
|---|---|---|
| I<br>8 Hours | Space of n-dimensions, Transformation of coordinates, Contravariant and Covariant vectors, Tensors of second order, Tensor of higher orders, Invariant or scalar, Algebraic operations on Tensors, Symmetric and Skew symmetric tensors. | CLO1 |
| II<br>7 Hours | Quotient law, Conjugate symmetric tensor, Relative tensor, Metric tensor, Riemannian metric, fundamental contravariant tensor, length of a curve, Associated tensors, Magnitude of a vector, Angle between two vectors and coordinate curves. | CLO2 |
| III<br>8 Hours | Christoffel symbols, Transformation of Christoffel symbols, Covariant differentiation of vectors, Covariant differentiation of tensors,, Intrinsic derivative of tensor, Laws of covariant differentiation of tensors. | CLO3 |

| | | |
|---|---|---|
| IV<br><br>7 Hours | Covariant derivative of a scalar, Ricci's Theorem, Covariant derivative of a scalar, Covariant constants, Divergence and Curl of a vector, Laplacian operator. | 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. D. C. Agrawal, Tensor Calculus and Riemannian geometry, Krishna Prakashan, Meerut, 2003.
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: Mathematical Methods (VAC)**

**Course Code: MAT.534**
**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<br>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.<br><br>**Activity:** Students will learn the basics and applications of Integral Transforms. | CLO1 |
| II<br>7 Hours | Discrete orthogonality and Discrete Fourier transform. Wavelets with examples, wavelet transforms.<br><br>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.<br><br>**Activity:** Students will write some differential equations in the form of integral equations and then will solve them. | CLO2 |
| III<br>7 Hours | Reduction of IVPs BVPs and eigenvalue problems to integral equations. Hilbert Schmidt theorem, Raleigh Ritz and Galerkin methods.<br><br>**Activity:** Students will use Raleigh Ritz and Galerkin methods to solve some scientific problems. | CLO3 |
| IV<br>8 Hours | Regular and singular perturbation methods: Parameter and co-ordinate perturbations. Regular perturbation solution of first and second order differential equations involving constant and variable coefficients.<br><br>**Activity:** Students will obtain the regular perturbation solutions of some first and second order differential 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. I.N. Sneddon – *The use of Integral Transform*s, 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.
4. Quarteroni, Alfio, and Paola Gervasio. *A Primer on Mathematical Modelling.* Vol. 121. Springer Nature, 2020.


**Course Title: Vedic Mathematics and Data Science**

**Course Code: MAT. 535**

**Course type: Value Added Course**

**Total Hours: 30**

| L | P | T | Credits |
|---|---|---|---|
| 2 | 0 | 0 | 2 |

**Learning outcomes:**

The students will be able to

**CLO1:** Apply the knowledge of Vedic mathematics to understand some properties of statistics.
**CLO2:** Illustrate various properties of statistics with the help of Vedic mathematics and Computer programming.
**CLO3:** Explain the basic concepts of data science and linear algebra.
**CLO4:** Apply the Vedic mathematics sutra to solve the problems of linear algebra.
**CLO5:** Apply Vedic techniques in conjunction with data science tools and algorithms to tackle real world data analysis challenges.

| Units/Hours | Contents | Mapping with CLO |
|---|---|---|

| | | |
|---|---|---|
| **Unit I**<br><br>**8 Hours** | Introduction to Vedic mathematics, Vedic mathematics sutras, and their applications in different fields. Basics of statistics, Mean, Median, Mode,Variance, Probability using Vedic techniques. | CLO 1<br><br>CLO2 |
| **Unit II**<br><br>**7 Hours** | **Application of Vedic mathematics in statistics**:CurveFitting,Statistical Modelling, Random Variables and Probability Mass/Density Functions, Hypotheses Testing, Linear Regression. Data visualization and manipulation. | CLO2 |
| **Unit III**<br><br>**8 hours** | **Basics of data Science:**Solving linear equations using Vedic technique, The solution of Simultaneous linear equations using Vedic technique, Solution of quadratic equations using Vedic technique, Evaluation of determinants, Inversion of Matrices. | CLO 3<br><br>CLO 4 |
| **Unit IV**<br><br>**7 hours** | Optimization for data Science using Vedic mathematics, Linear Algebra for Data Science, Halfspaces, Eigenvalues, Eigenvectors, Solving Data Analysis Problems using Vedic techniques. | CLO 5 |

**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. Bharti Krishna Tirtha, Vedic Mathematics, Motilal Banarsi Das, New Delhi, 2015.

2. Bhaskaracharya, Beejganitam, Chokhambba Vidya Bhavan, Varanasi, 2022.

3. S.P. Gupta, Statistical Methods, Sultan Chand & Sons, 2014.

4. RagunathanRengasamy, Shankar Narasimhan, Data Science for Engineers,
Computer Science and Engineering, NPTEL IIT Madras, 2019.

5. John Zelle, Python Programming: An introduction to computer science, Franklin, Beedle & Associates, 2016.

**Course Title: Dissertation Part-I**

| L | T | P | Credits |
|---|---|---|---|
| 0 | 0 | 8 | 4 |

**Course Code: MAT.601**

**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** | | | | |
| **Senior most 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**

| L | T | P | Credits |
|---|---|---|---|

| Course Code: MAT.602 | 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** | - | - | **30** | **10** | **10** | **50** |
| **Senior most faculty member** | - | - | | | | |
| **External expert** | - | - | | | | |

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.