THAPAR INSTITUTE OF ENGINEERING AND TECHNOLOGY, PATIALA

Detailed Scheme
of
M.Sc. (Mathematics)

SCHOOL OF MATHEMATICS

Name of Program: Master of Science (Mathematics)

Mathematics programme is of utmost value to the aspiring graduate students with Mathematics background. Study of mathematics enables students to take up a variety of careers ranging from academic research, education, development and quantitative applications in industry. The course provides students with ability to apply analytical and theoretical skills to model and solve mathematical problems. This programme has been introduced due to the need for sophisticated mathematics for modern scientific investigations and technological developments. The curriculum is designed to provide students with in depth pure as well applied mathematics so that a student become competent to take challenges in Mathematics at National and International levels.

Nature: Full time/ Part time/ Correspondence: Full Time.

Duration: Two Years (4 Semesters).

Eligibility Criteria and Admission Procedure: The candidates seeking admission to M.Sc. (Mathematics) must have a Bachelor degree with Mathematics as a major subject. The qualifying degree must be from a recognized University by the University Grants Commission with minimum duration of three years. The candidate must have at least 60% (55% for SC/ST) marks in qualifying degree. Admissions shall be made by merit which will be made by combining the percentages of marks obtained in 10th, 12th and graduation level. The degree marks will be considered up to second year/four semesters.

Number of Seats: 20

Program Educational Objective: The objectives of the M.Sc. (Mathematics) program are to:

1. develop skills required for sound analytical and practical knowledge to pursue careers in Industries, Banks, Insurance, Educational and Research Institute.
2. prepare students to qualify various national and international competitive examinations.
3. develop mathematical thinking encompassing logical reasoning, generalization, abstraction, and formal proof.

Program Outcomes: At the end of the program, the students will be able to:

1. acquire the knowledge and understanding of pure and applied mathematics and communicate mathematics effectively.
2. innovate, invent and solve complex mathematical problems using the knowledge of pure and applied mathematics.
3. pursue research career in mathematics and inter-disciplinary fields.
4. have the ability to assess and interpret complex situation, enabling them to choose successful career in education and industry.

SCHEME OF COURSES FOR M.Sc. (Mathematics)

First Semester

Sr. No.	Course No.	Course Name	L	T	P	Cr.
1.	PMA107	Real Analysis	3	1	0	3.5
2.	PMA108	Algebra I	3	1	0	3.5
3.	PMA109	Ordinary Differential Equations	3	1	0	3.5
4.	PMA110	Mechanics	3	1	0	3.5
5.	PMA111	Computer Programming	3	0	2	4.0
		Total	**15**	**4**	**2**	**18.0**

Second Semester

Sr. No.	Course No.	Course Name	L	T	P	Cr.
1.	PMA204	Measure theory and Integration	3	1	0	3.5
2.	PMA205	Algebra II	3	1	0	3.5
3.	PMA206	Partial Differential Equations	3	1	0	3.5
4.	PMA207	Complex Analysis	3	1	0	3.5
5.	PMA208	Numerical Analysis	3	1	2	4.5
		Total	**15**	**5**	**2**	**18.5**

Third Semester

Sr. No.	Course No.	Course Name	L	T	P	Cr.
1.	PMA301	Functional Analysis	3	1	0	3.5
2.	PMA302	Topology	3	1	0	3.5
3.	PMA303	Probability and Statistics	3	1	2	4.5
4.	PMA304	Mathematical Programming	3	1	2	4.5
5.		Elective I	3	1	0	3.5
		Total	**15**	**5**	**4**	**19.5**

Fourth Semester

Sr. No.	Course No.	Course Name	L	T	P	Cr.
1.	PMA401	Number Theory	3	1	0	3.5
2.	PMA402	Mathematical Methods	3	1	0	3.5
3.		Elective-II	3	1	0	3.5
4.	PMA491	Dissertation	-	-	-	10.0
		Total	**9**	**3**	**0**	**20.5**

TOTAL CONTACT HOURS: 79 **TOTAL CREDITS: 76.5**

List of Electives: Student can also opt electives from M.Sc. (Mathematics & Computing) provided a particular course is running.

Elective- I

1.	Numerical Methods for Partial Differential Equations (L=3, T=0, P=1)	PMA321
2.	Finite Element Methods (L=3, T=0, P=1)	PMA423
3.	Introduction to Astronomy and Astrophysics	PMA322
4.	Wavelet and Applications	PMA323
5.	Mathematical Biology and Non-Linear Dynamics (L=3, T=0, P=1)	PMA324
6.	Advanced Functional Analysis	PMA325
7.	Enumerative Combinatorics	PMA326
8.	Advanced Complex Analysis	PMA327
9.	Fuzzy Sets and Applications	PMA330
10.	Fluid Mechanics	PMA421
11.	Discrete Mathematics	PMC105

Elective- II

1.	Modelling of Stellar Structure	PMA422
2.	Asymptotic Methods and Perturbation Theory	PMA424
3.	Theory of Elasticity	PMA425
4.	Algebraic Coding Theory	PMA426

5.	Topological Vector Space	PMA427
6.	Fixed Point Theory	PMA428
7.	Statistical Simulation and Computation	PMA429
8.	Financial Mathematics	PMA430
9.	Combinatorial Programming	PMA431
10.	Stochastic Processes	PMA328
11.	Advanced Numerical Optimization Techniques	PMA329

PMA107 Real Analysis

L	T	P	Cr
3	1	0	3.5

Course Objectives: The aim of this course is to introduce the students real number system and metric spaces. In particular, the notion of completeness, compactness, limit, continuity, differentiability, integrability and uniform continuity.

Real Number System and Set Theory: Completeness property, Archmedian property, Denseness of rationals and irrationals, Countable and uncountable sets, Cardinality, Zorn's lemma, Axiom of choice.

Metric Spaces: Open and closed sets, Interior, Closure and limit points of a set, Subspaces, Continuous functions on metric spaces, Convergence in a metric space, Complete metric spaces, Compact metric spaces, Compactness and uniform continuity, Connected metric spaces, Total boundedness, Finite intersection property.

Sequence and Series of Functions: Pointwise and uniform convergence, Cauchy criterion for uniform convergence, Weierstrass M-test, Abel's and Dirichlet's tests for uniform convergence, Uniform convergence and continuity, Uniform convergence and differentiation, Weierstrass approximation theorem.
Riemann-Stieltje's Integral: Definition and existence of Riemann-Stieltjes integral, Properties, Integration and differentiation, Fundamental theorem of calculus.

Course learning outcome(CLO): The student will be able to

1) analyze different properties of R.
2) apply properties viz. convergence, completeness, compactness etc. from the real line to metric spaces.
3) identify the difference between pointwise and uniform convergence and analyze the effect of uniform convergence on the functions with respect to continuity, differentiability and integrability.
4) determine the Riemann-Stieltjes integrability of a bounded functions.

Recommended Books:

12. Rudin, W., Principles of Mathematical Analysis, McGraw-Hill ,3rd edition, 2013.
13. Simmons G. F., Introduction to Topology and Modern Analysis, Tata McGraw Hill, 2008.
14. Malik, S. C. and Arora, S., Mathematical Analysis, Wiley Eastern, 2010.
15. Jain, P. K., Ahmad K., Metric Spaces, Alpha Science Publishers, 2004.

Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA108 Algebra – I

L	T	P	Cr
3	**1**	**0**	**3.5**

Course Objectives: The course intends to impart knowledge in the areas of group theory and linear Algebra with an aim of enabling students to apply the concepts learned to other areas.

Linear Transformations: Review of vector spaces, Linear transformations, Algebra of linear transformations, Matrix representation of linear transformations, Different types of matrices, Change of basis, Rank, trace and determinant of a matrix, Linear equations, Dual and double dual, Transpose of a linear transformation, Linear transformations and their characteristic roots and vectors, Algebraic and geometric multiplicity, Cayley-Hamilton theorem, Minimal polynomial, Quadratic and bilinear forms, Reduction and classification of quadratic forms, Canonical forms, Diagonal form, Triangular form, Rational and Jordan form.

Group Theory: Center, Normalizer, Centralizer, Homomorphism and isomorphism, Cyclic groups, Permutation groups, Cayley's theorem, Conjugate elements, Class equation, Direct product of groups, Structure theorem of finitely generated abelian groups, Cauchy's theorem, Sylow theorems and its applications.

Course learning outcomes (CLO): The students will be able to

1) find characteristic roots, vectors and quadratic forms of matrices.
2) understand various canonical forms of linear transformations.
3) describe the properties of permutation groups and cyclic groups.
4) apply structure theory of abelian groups and Sylow theorems to solve different problems.

Recommended books:

1) Hoffmann K., Kunze R., Linear Algebra, PHI, Second edition, 2014.
2) Herstein, I.N., Topics in Algebra, Wiley Eastern Ltd., 2005.
3) Singh, Surjeet and Zameeruddin, Qazi, Modern Algebra, Vikas Publishing House, 2006.
4) Luthar, S., and Passi, I.B.S., Algebra (Vol. 1 and 2), Narosa Publishing House, 1999.
5) Gallian, J.A., Contemporary Abstract Algebra (8e), Cengage Learning, 2013.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA109 Ordinary Differential Equations

L	T	P	Cr
3	1	0	3.5

Course Objectives: The main objective is to provide mathematics majors with an introduction to the theory of ordinary differential equations (ODEs) through applications and methods of solution. Students will become knowledgeable about system of ODEs and how they can serve as models for physical processes. The course will also develop an understanding of the elements of analysis of ODEs.

Power series method: Ordinary and regular singular points, Legendre and Bessel equations.

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.

Boundary value problems: Two-point boundary value problems, Green's function, Sturm-Liouville theory, Sturm comparison theorems and oscillations, Weyl-Titschmarsh theorem for unbounded interval-limit cycle, limit point cases.

Higher order linear equations and systems: Fundamental solutions, linear system with constant coefficients, fundamental matrices, variation of constants, matrix exponential solution, linear system with periodic coefficients.

Autonomous systems and phase space analysis: Critical points, proper and improper nodes, spiral points and saddle points, asymptotic behaviour: linear and nonlinear stability.

Learning Outcomes: On successful completion of this module, students will be able to:
1) apply power series method to solve certain types of differential equations and able to understand Legendre polynomials and Bessel functions.
2) give examples of differential equations for which either existence or uniqueness of solution fails.
3) solve boundary value problems and Sturm-Liouville problems.
4) state correctly and apply basic facts of systems: fundamental matrices, eigen-values, non-homogeneous systems.
5) sketch the phase portraits and apply standard methods to check the stability of critical points for autonomous system.

Text/References:

1) William E. Boyce, Richard C. DiPrima, and Douglas B. Meade, Elementary Differential Equations and Boundary Value Problems, 11th edition, Wiley, 2017.
2) E. A. Coddington and N. Levinson,Theory of Ordinary differential Equations, McGraw Hill Education, 2017.
3) George F. Simmons and Steven G. Krantz, Differential Equations: Theory, Technique, and Practice, McGraw Hill Education, 2006.
4) L. Perko, Differential Equations and Dynamical Systems, 3rd Edition, Springer, 2008.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (assignments/quizzes/projects)	20

PMA110 Mechanics

	L	T	P	Cr
	3	**1**	**0**	**3.5**

Course objectives: This course is intended to provide a treatment of basic knowledge in mechanics used in deriving a range of important results and problems related to rigid bodies The objective is to provide the student the classical mechanics approach to solve a mechanical problem.

Dynamics of a Particle: Tangential and normal accelerations, Simple harmonic motion, Oscillatory motion projectile motion, Central forces, Apses and apsidal distances, Stability of orbits, Kepler's laws of planetary motion, Disturbed orbits, Simple pendulum, Motion in a resisting medium, Motion of a pendulum in a resisting medium.

Linear and Angular Momentum: Rate of change of angular momentum for a system of particles, Moving origin, Impulsive forces, Moments and products of inertia of a rigid body, Momental ellipsoid, Equimomental system, Principal axes, Coplanar distribution, General equations of motion.

Motion About a Fixed Axis: Compound pendulum, Centre of percussion, Motion in two dimensions, Euler's dynamical equations and simple stability considerations.

Lagrangian and Hamiltonian Mechanics: Constrained motion, D'Alemberts principle, Variational Principle, Lagrange's equations of motion, Generalized coordinates, cyclic coordinates, Hamilton's principles, Principles of least action, Hamilton's equation of motion, Lagendre transformation, Phase, Space, State space examples, Cannonical transformations, Contact transformation, Lagrange's and Poisson brackets invariance, Hamilton-Jacobi Poisson equations.

Course learning outcomes (CLO): The student will be able to

1) describe the dynamics involving a single particle like projectile motion, Simple harmonic motion, pendulum motion and related problems.
2) analyze the path described by the particle moving under the influence of central force.
3) apply the concept of system of particles in finding moment inertia, directions of principle axes and consequently Euler's dynamical equations for studying rigid body motions.
4) obtain the equation of motion for mechanical systems using the Lagrangian and Hamiltonian formulations of classical mechanics.
5) obtain canonical equations using different combinations of generating functions and subsequently developing Hamilton Jacobi method to solve equations of motion.

Recommended Books:

1) Chorlton F., Text book of Dynamics, CBS Publishers, 1985.
2) Synge, J. L., and Griffith, B.A., Principles of Mechanics, Tata McGraw Hill, 1971.
3) Fox C., An Introduction to the Calculus of Variations, Dover Publications, 1992.
4) Goldstein H., Poole C., and Safko J., Classical Mechanics, Addison Wesley, 2002.

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E**valuation Scheme:**

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA111 Computer Programming

L	T	P	Cr
3	0	2	4.0

Course objective: This course is designed to explore computing and to show students the art of computer programming. Students will learn some of the design principles for writing good programs.

Computer Fundamentals: Introduction to computer systems, number system, integer, signed integer, fixed and floating point representations, IEEE standards, integer and floating point arithmetic; CPU organization, ALU, registers, memory, the idea of program execution at micro level.

Algorithms and Programming Languages: Algorithm, flowcharts, pseudocode, generation of programming languages.

C Language: Structure of C Program, life cycle of program from source code to executable, compiling and executing C code, keywords, identifiers, primitive data types in C, variables, constants, input/output statements in C, operators, type conversion and type casting, conditional branching statements, iterative statements, nested loops, break and continue statements.

Functions: Declaration, definition, call and return, call by value, call by reference, showcase stack usage with help of debugger, scope of variables, storage classes, recursive functions, recursion vs Iteration.
Arrays, Strings and Pointers: One-dimensional, two-dimensional and multi-dimensional arrays, operations on array: traversal, insertion, deletion, merging and searching, Inter-function communication via arrays: passing a row, passing the entire array, matrices. Reading, writing and manipulating Strings, Understanding computer memory, accessing via pointers, pointers to arrays, dynamic allocation, drawback of pointers.

Object Oriented Programming Concepts: Data hiding, abstract data types, classes, access control; class implementation, constructors, destructor operator overloading, friend functions; object oriented design (an alternative to functional decomposition) inheritance and composition; dynamic binding and virtual functions; polymorphism; dynamic data in classes.

Laboratory work: To implement Programs for various kinds of programming constructs in C Language.

Course learning outcomes (CLOs):On completion of this course, the students will be able to:

1. comprehend concepts related to computer hardware and software, draw flowcharts and write algorithm/pseudocode.
2. write, compile and debugprograms in C language, use different data types, operators and console I/O function in a computer program.
3. design programs involving decision control statements, loop control statements, case control structures, arrays, strings, pointers, functions and implement the dynamics of memory by the use of pointers.
4. comprehend the key concepts of object-oriented design and programming concepts.

Recommended Books:

1) H. M. Deitel and P. J. Deitel, C++ How to Program, Prentice Hall, 8th Ed, 2011.
2) H. Schildt, C++: The Complete Reference, McGraw-Hill, 4th Ed, 2002.
3) Balaguruswamy E., Object Oriented Programming with C++, McGraw Hill, 2013.
4) Brian W. Kernighan, Dennis M. Ritchie, The C++ Programming Language, Prentice Hall)
5) Kanetkar Y., Let Us C++, BPB Publications, 2nd ed.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	25
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	30

Second Semester

PMA204 Measure Theory and Integration

L	T	P	Cr
3	1	0	3.5

Course Objectives: The aim of the course is to introduce the students Lebesgue measure, measurable sets and their properties, measurable functions and their properties and Lebesgue integral.

Lebesgue Measure: Introduction, Outer measure, Lebesgue measure, measurable sets, Properties of measurable sets, Borel sets and their measurability, non-measurable sets.

Measurable Functions: Definition and properties of measurable functions, step functions, characteristic functions, simple functions, Littlewood's three principles, convergence in measure.

Lebesgue Integral: Lebesgue integral of bounded function, Integration of non-negative functions, General Lebesgue integrals, Integration of series, Comparison of Riemann and Lebesgue integrals.

Differentiation and Integration: Differentiation of monotone functions, functions of bounded variation, Lebesgue differentiation theorem, differentiation of an integral, absolute Continuity.

Course learning outcomes (CLO): The student will be able to

1) define Lebesgue measure on $\mathbb{R}$.
2) describe measurable functions and its properties.
3) apply measures to construct integrals and explain convergence theorems for the Lebesgue integral.
4) analyze the relation between differentiation and Lebesgue integration.

Recommended Books:

1) Royden, H.L. & P. M. Fitzpatrick, Real Analysis, Pearson Education 4th Edition, 2011.
2) Barra, G.de, Measure Theory and Integration, Wiley Eastern Ltd., 2012.
3) Jain, P.K., and Gupta, V.P., Lebesgue Measure and Integration, New Age International Ltd. 2nd Edition, 2010.
4) Rana, I.K., An Introduction to Measure and Integration, Narosa Publication House 2nd Edition, 2010.

Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA205 Algebra – II

L	T	P	Cr
3	1	0	3.5

Course Objectives: The course intends to impart knowledge in the areas of ring theory and field theory with an aim of enabling students to apply the concepts learned to other areas.

Ring Theory: Special kinds of rings, Subrings and ideals, Homomorphism and isomorphism, Quotient rings, Prime and maximal ideals, Integral domain, Units and zero divisors, Unique factorization domain, Principal ideal domain, Euclidean domain.

Field Theory: Polynomials and their irreducibility criteria, Adjunction of roots, Finite and infinite extensions, Algebraic and transcendental extensions, Algebraically closed fields, Splitting fields, Normal extension, Multiple roots, Finite fields, Separable and inseparable extensions, Automorphism groups and fixed fields, Fundamental theorem of Galois theory.

Course learning outcomes (CLO): The students will be able to

1) describe the properties of integral domain, principle ideal domain, Euclidean domain and unique factorization domain.
2) apply different irreducibility criteria to check the irreducibility of a polynomial.
3) describe the concepts of fields, various extensions of fields and splitting fields
4) analyze the properties of finite fields and Galois theory.

Recommended books:

1) Herstein, I. N., Topics in Algebra, Wiley Eastern Ltd., 2005
2) Singh, Surjeet and Zameeruddin, Qazi, Modern Algebra, Vikas Publishing House, 2006.
3) Gallian, J. A., Contemporary Abstract Algebra (8e), Cengage Learning, 2013.
4) Bhattacharya, P.B., Jain, S.K. and Nagpaul, S.R. Basic Abstract Algebra, Cambridge University Press, 1997.
5) Luthar, I.S., and Passi, I.B.S., Algebra (Vol. 4), Narosa Publishing House, 2004.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA206 Partial Differential Equations

L	T	P	Cr
3	1	0	3.5

Course Objectives: Partial Differential Equations (PDEs) are at the heart of applied mathematics and many other scientific disciplines. The primary goal of this course is to provide students the knowledge about fundamental concepts of PDE theory and analytical methods for solving PDEs. Students will become knowledgeable about PDEs and how they can serve as models for physical processes such as Laplace equation, wave equation and transport phenomena including diffusion. The course will also develop an understanding of the elements of analysis of PDEs.

First-Order PDEs: Linear and quasi-linear equations, Cauchy problem, method of characteristics, Monge cone, Cauchy-Kowalewsky theorem, Holmgren's uniqueness theorem.

Second-Order PDEs: Classification and canonical forms, equations with variable coefficients, characteristic, separation of variables method for wave, Laplace and heat equation.

Wave Equation: Well-posedness of Cauchy problems for wave equation, classical and weak solution, spherical means, initial-boundary value problems on bounded domains, uniqueness via energy method, qualitative properties of solutions: causality, non-homogeneous equation and Duhamel's principle.

Heat Equation: Fundamental solution, mean-value formula, energy methods, uniqueness results.

Laplace Equation: Fundamental solution, boundary value problems, maximum principles and mean-value formulas, properties of harmonic functions, Green's function, uniqueness and energy methods.

Nonlinear First-Order PDEs: Complete integrals, envelopes and singular solutions, Hopf-Cole transformation.

Learning Outcomes: On successful completion of this course, students will be able to:

1. state correctly and apply to examples the basic facts about the first order PDEs and method of characteristics.
2. classify second-order partial differential equations and transform them into canonical form.
3. state correctly and apply to examples the basic facts about the Wave equation: energy method, uniqueness, and Duhamel's principle.
4. solve heat equation and can apply mean-value formula and energy methods.
5. state correctly and apply to examples the basic facts about the Laplace equation: maximum principle and energy methods.

Recommended Books:

1) Walter A. Strauss, Partial Differential Equations: An Introduction, Willey, 2nd Edition, 2007.
2) L. C. Evans, Partial Differential Equations, American Mathematical Society, 2nd Edition, 2010.
3) I. N. Sneddon, Elements of Partial Differential Equations, Dover Publications, 2006.
4) F. John, Partial Differential Equations, 4th edition, Springer, 1991.
5) M. Renardy and R. C. Rogers, An Introduction to Partial Differential Equations, Springer, 2nd edition, 2004.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMA207 Complex Analysis

L	T	P	Cr
3	1	0	3.5

Course Objective: The course aims to introduce the theory of complex analysis to graduate students with applications to solve problems in the mathematical sciences and engineering.

Complex numbers: introduction to complex numbers, geometrical interpretation, different representations of complex numbers, mappings and projections (including stereographic projection and bilinear transformation).

Elementary and analytic functions: functions of complex variables, examples of elementary functions like exponential, trigonometric and hyperbolic functions, elementary calculus on the complex plane (limits, continuity, differentiability), Cauchy-Riemann equations, analytic functions, harmonic functions with examples, branch points and branch cuts, multi-valued functions (eg. logarithmic function and its branches, Riemann surfaces).

Complex integration: Cauchy's integral theorem, Cauchy integral formula for higher derivatives, Morera's theorem, Liouville's theorem, maximum-modulus principle, Schwarz lemma.

Series expansion of complex functions: power series, Taylor and Laurent series of complex functions, convergence, definition of holomorphic and meromorphic functions, zeros and poles, classification of singular points, removable singularities, Weierstrass theorems (M test and factor theorem).

Residue calculus: general form of Cauchy's theorem, Cauchy residue theorem, evaluation of definite integrals using residue theorem (principal value integrals and integrals with branch points), argument principle and Roche's theorem (eg. with application to prove the fundamental theorem of algebra), residue at infinity.

Conformal Mappings: elementary conformal mappings (Schwarz-Christoffel transformation), analytic continuation, method of analytic continuation by power series (e.g. application in defining the Riemann-Zeta function).

Course Learning Outcomes (CLO): Upon the completion of this course, the students will be able to:

1) represent complex numbers in Cartesian, polar and matrix form, geometrical interpretation of complex numbers.
2) inspect the analyticity of complex functions including the utility of Cauchy-Riemann equations, evaluation of contour integrals using Cauchy integral formula.
3) represent complex functions as power series (e.g., Taylor and Laurent) and their convergence, classification of singularities.
4) apply residue calculus using Cauchy's residue theorem and method of analytic continuation.
5) have knowledge of conformal maps.

Recommended Books:

1) Ablowitz, M. and Fokas, A. S., *Complex Variables: introduction and applications*, Cambridge University Press, 2003 (2nd edition).
2) Churchill, R.V. and Brown J.W., *Complex Variable and Applications*, McGraw Hill, 2009 (8th edition).
3) Ahlfors, L.V., *Complex Analysis*, Tata McGraw Hill, 1979 (3rd edition).
4) Kasana, H.S., *Complex Variables: Theory and Applications*, Prentice Hall India, 2005 (2nd edition).
5) Ponnuswamy, S., *Foundation of Complex Analysis*, Narosa Publishing House, 2011 (2nd edition).

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA208 Numerical Analysis

L	T	P	Cr
3	1	2	4.5

Course Objectives: The primary goal is to provide mathematics majors with a basic knowledge of numerical methods including: root finding, numerical linear algebra, interpolation, integration, solving systems of linear equations, curve fitting, and numerical solution to ordinary differential equations. MATLAB is the software environment used for implementation and application of these numerical methods. The course will also develop an understanding of the elements of error analysis for numerical methods and certain proofs. The course will further develop problem solving skills.

Mathematical Preliminaries and Error Analysis: Round off errors, Algorithms and convergence, conditioning and stability.

Numerical Solution of Nonlinear Equations: Bisection method, fixed point iterations, secant method, Newton's method and its extensions, convergence analysis, zeros of polynomials and Muller's method, equations in higher dimensions.

Interpolation: Lagrange interpolation, Neville's method, divided differences, Hermite interpolation, Splines, Richardson's extrapolation.

Solutions of Linear Systems: Direct methods, Gauss-elimination method, pivoting, matrix factorization. Iterative methods: Matrix norms, Jacobi and Gauss-Seidel, Relaxation methods and their convergence, error bounds and iterative refinement. Computation of eigenvalues and eigenvectors: power method, Householder's method, QR algorithm.

Numerical Integration: Newton-Cotes formula, Trapezoidal and Simpson's rules, Gaussian quadrature, Romberg integration, Adaptive quadrature methods, multiple integrals.
Numerical Solution of Ordinary Differential Equations: Initial value problems, Euler method, Higher-order methods of Runge-Kutta type, Multi-step methods, Adams-Bashforth, Adams-Moulton and Milne's methods, Convergence and stability analysis, system of ODE's. Boundary value problems: Shooting methods, finite differences, Rayleigh-Ritz methods.
Lab Experiment: Implementation of numerical techniques using MATLAB based on course contents.
Minor Projects: The minor projects will be assigned according the syllabus covered.
Course learning outcomes (CLO): Upon completion of the course, the students will be able to

1) find the source of errors and its effect on any numerical computations and be familiar with finite precision computations.
2) solve an algebraic or transcendental equation using an appropriate numerical method and perform an error analysis for a given numerical method.
3) solve a linear system of equations using an appropriate numerical method which include direct and iterative methods and apply numerical methods to find eigen-values and corresponding eigen-vectors.
4) approximate the given data with an interpolating polynomial and least square approximations.
5) calculate a definite integral numerically and solve initial and boundary value problems using appropriate numerical methods.

Recommended Books:

1) Richard L. Burden, J. Douglas Faires and Annette Burden, Numerical Analysis, Cengage Learning, 10th edition, 2015.
2) K. Atkinson and W. Han, Elementary Numerical Analysis, John Willey and Sons, 3rd edition, 2004.
3) E. Ward Cheney and David R. Kincaid, Numerical Mathematics and Computing, Cengage Learning, 7th edition, 2012.
4) Endre Suli and David F. Mayers, An Introduction to Numerical Analysis, Cambridge University Press, 2003.
5) Curtis F. Gerald and Patrick O. Wheatley, Applied Numerical Analysis, 7th ed, Pearson Education, 2007.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	25
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	30

Third Semester

PMA301 Functional Analysis

L	T	P	Cr
3	1	0	3.5

Course Objectives: Functional analysis is a fundamental area of pure mathematics, with countless applications to the theory of differential equations, engineering, and physics. The students will be exposed to the theory of Banach space, Hilbert spaces, linear transformations and functionals. In particular, the major theorems in functional analysis, namely, Hahn-Banach theorem, uniform boundedness theorem, open mapping theorem and closed graph theorem will be covered.

Course Description:
Review of some basic concepts in metric spaces and topological spaces, completeness proofs and completion of metric spaces.

Normed linear spaces and Banach spaces, examples of Banach spaces, quotient spaces, equivalent norms, finite dimensional Banach spaces and compactness, bounded and continuous linear operators and linear functionals, dual space, Banach fixed-point theorem and applications, Hahn-Banach theorem and applications, uniform boundedness theorem, open mapping and closed graph theorem, weak and weak* convergence.

Inner product spaces and its properties, Hilbert spaces and examples, best approximation in Hilbert spaces, orthogonal complements, orthonormal basis, dual of a Hilbert space.

Operator theory, adjoint of an operator, Riesz representation theorem, self-adjoint operators, normal and unitary operators, projections, compact operators.

Course learning outcomes (CLO): On successful completion of this module, students will be able to:
1) understand the fundamentals of complete metric spaces and normed linear spaces.
2) recognize finite dimensional spaces and associated properties.
3) independently prove and thoroughly explain central theorems.
4) understand thoroughly inner product and Hilbert spaces and can provide approximations in Hilbert spaces.
5) define and thoroughly explain self-adjoint, normal and unitary operators and analyze operators from applications.

Recommended books:
1) Erwin Kreyszig, Introductory Functional Analysis with Applications, Wiley, 2007.
2) John B. Conway, A course in Functional Analysis, Springer, 2nd edition, 1990.
3) G. F. Simmons, Introduction to Topology and Modern Analysis, McGraw Hill Education, 2017.
4) S. Kesavan, Functional Analysis, Hindustan Book Agency, 2014.
5) Peter D. Lax, Functional Analysis, John Wiley & Sons, 2002.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMA302 Topology

L	T	P	Cr.
3	1	0	3.5

Course Objective: To introduce the fundamentals Point Set Topology which is needed in several areas of Mathematics.

Topological spaces: Review of Metric spaces, Definition and Examples of topological spaces, Topology induced by a metric; open and closed sets, Closure, Neighbourhood, Limit point, Derived set; Interior, Exterior and Boundary points.
Bases, Sub-bases and examples, topology generated by sub-bases, Subspaces and relative topology; continuous function and Homeomorphism.

Countability and Separation Axioms: First and second countable spaces, Separable Spaces, Lindeloff spaces. Separation axioms (T_0,T_1, Hausdorff spaces, regular and Normal spaces), Urysohn's Lemma, Metrization Theorem, Tietze extension theorem.

Compactness and Connectedness: Compact spaces and their basic properties; Connected spaces, Connected sets in the real line, Intermediate value theorem, Connected components, Path connected components, Locally connected spaces, Totally disconnected spaces; Continuous functions and connected sets.

Course Learning Outcomes: Upon completion of this course, the student will be able to:
1) define various topologies on a general set.
2) use the concepts of open and closed sets, interior, closure, limit and boundary points.
3) use the concepts of bases, subbases, countability, separation axioms to prove the results and theorems.
4) derive results related to compactness and connectedness.

Recommended Books:

1. Munkres, J. R., topology: a first course, PHI, 2007.
2. Kelley, J. L., General Topology, Springer, 1955.
3. Simmons, G. F., Introduction to topology and Modern Analysis, Tata McGraw hill, 1963.
4. Joshi, K. D., Introduction to General Topology, Wiley, 1983.

Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (may include quizzes/assignments)	25

PMA303 Probability and Statistics

L	T	P	Cr.
3	1	2	4.5

Course Objectives: The course aims to shape the attitudes of learners regarding the field of statistics. Specifically, the course aims to i) motivate students towards an intrinsic interest in statistical thinking, ii) instill the belief that statistics is important for scientific research.

Introduction & Random variables: Axioms of probability, probability space, conditional probability, independence, Baye's rule, Random variable, some common discrete and continuous distributions (Binomial, Poisson, Negative binomial, Geometric, Rectangular, Exponential, Normal, Gamma).

Mathematical Expectation: Moments, Moment generating functions, Characteristic function.

Bi-variate Probability Distribution: Probability distribution of functions of a random variable, joint and marginal distributions, conditional distributions.

Limit Theorems: Modes of convergence; Law of large numbers, Central limit theorem.

Correlation and Regression: Covariance, Karl-Pearson and rank Correlation coefficients; linear regression between two variables.

Hypothesis tests: Introduction to Sampling Distribution (standard normal, chi-square, t & F distributions), Theory of Estimation, Properties of an estimator, Tests for Goodness of fit: Method of maximum likelihood, Neyman-Pearson lemma (without proofs); Critical regions.

Parametric & Non-parametric tests: Based on Chi-square Test, One sample and paired sample tests; Sign Test, Signed-rank Test, Kolmogorov Smirnov Test.

Laboratory Work: Lab work will be based on the programming in MATLAB/ SPSS language of various statistical techniques.

Minor Projects: The minor projects will be set in consonance with material covered in theory and laboratory classes.

Course learning outcomes (CLO): The student will be able to

1) compute probabilities of composite events along with an understanding of random variables and distribution functions.
2) understand the convergence of sequence in probabilities
3) analyze the correlated data and fit the linear regression models.
4) make statistical inferences using principles of hypothesis tests.

Recommended Books:

1) Meyer P. L., Introduction to Probability and Statistical Applications, Oxford & IBH, 2007.
2) Goon, A. M., Gupta, M. K. and Dasgupta, B., An Outline of Statistical Theory, Vol. I the World Press Pvt. Ltd., 2000.
3) Hogg, R. V., and Craig, A. T., Introduction to Mathematical Statistics, Prentice Hall of India, 2004.
4) Anderson, T. W., An Introduction to Multivariate Statistical Analysis, John Wiley, 2003.

5) Walpole, R.E., Myers, R.H., Myers, S.L. and Ye, K., 1993. Probability and statistics for engineers and scientists, Pearson, 2010.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	25
2.	EST	35
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	40

PMA304 Mathematical Programming

L	T	P	Cr
3	1	2	4.5

Course Objectives: Operations research helps in solving problems in different environments that needs decisions. This module aims to introduce students to use quantitative methods and techniques for effective decisions–making; model formulation and applications that are used in solving business decision problems.

Linear programming: Linear programs formulation through examples from engineering / business decision making problems, preliminary theory and geometry of linear programs, basic feasible solution, simplex method, variants of simplex method, like two phase method and revised simplex method; duality and its principles, interpretation of dual variables, dual simplex method, primal-dual method

Integer programming problems: linear integer programs, their applications in real decision making problems, cutting plane and branch and bound methods,

Transportation and Assignment problem: Initial basic feasible solutions of balanced and unbalanced assignment/transportation problems, optimal solutions, time minimization assignment/transportation problem.

Game Theory: Two person zero-sum game, Game with mixed strategies, Dominance property, solution by linear programming.

Nonlinear Programming: Concepts of convexity and its generalizations, Maxima and minima of convex functions, unconstrained optimization problems, constrained programming problems, Lagrange's multiplier rule and Kuhn-Tucker conditions for constrained programming problems. quadratic programs, Wolfe method, applications of quadratic programs in some domains like portfolio optimization and support vector machines, etc.

Laboratory Work: Laboratory experiments will be set in consonance with the materials covered in theory.

Course learning outcomes: Upon completion of this course, the student will be able to:

1) formulate and solve some real life problems as Linear programming problem.
2) use the simplex method to find an optimal vector for the standard linear programming problem and the corresponding dual problem
3) find optimal solution of transportation problem and assignment problem
4) to solve two person zero sum game.
5) solve unconstrained and constrained nonlinear programming problems.

Recommended Books:

1) Chandra, S., Jayadeva, Mehra, A., Numerical Optimization and Applications, Narosa Publishing House, 2013.
2) Cottle, R. W., and Thapa, M.N., Linear and nonlinear optimization, Springer, 2017.
3) Bazaraa, M.S., Jarvis, J.J., and Sherali, H.D., Linear Programming and Network flows, John Wiley and Sons, 1990.
4) Bazaraa, M.S., Sherali, H.D., Shetty, C.M., Nonlinear Programming: Theory and Algorithms, John Wiley and Sons, 1993.

5) Ferris, M., Mangasarian, O., and Wright, S., Linear programming with Matlab, MPS-SIAM series on Optimization, 2007.
6) Hadley, G., Linear Programming, Narosa Publishing House, 2002.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	25
2.	EST	35
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	40

Fourth Semester

PMA401 Number Theory

L	T	P	Cr
3	1	0	3.5

Course Objectives: The purpose of this course is to introduce classical number theory, primes, congruences, solution of congruences, arithmetic functions, quadratic residues and primitive roots. Apart from teaching the theory, stress will be on solving problems and helping students to understand applications of number theory in cryptography and in other fields.

Divisibility and Congruences: Least and greatest common divisor, Fundamental theorem of arithmetic, congruence, residue classes, linear and higher degree congruences, Chinese remainder theorem, congruences with prime moduli, Fermat's theorem, Euler's theorem and Wilson Theorem, applications to cryptography.

Arithmetic Functions: $\varphi(x), d(x), \mu(x), \sigma(x)$, Mobius inversion formula and function [x]. The symbol small "oh", big "oh" and their basic properties. Perfect numbers, Mersenne primes and Fermat numbers.

Polynomial Congruences: Primitive roots, indices and their applications, Quadratic residues, Legendre symbol, Euler's criterion, Gauss's Lemma, Quadratic reciprocity law, Jacobi symbol, Binary quadratic forms and their reduction, sums of two and four squares, positive definite binary quadratic forms.

Diophantine Equations: Equations and Fermat's conjecture for $n = 2$, $n = 4$.

Course learning outcomes (CLO): The student will be able to
1) apply the properties of divisibility and prime numbers to prove results.
2) solve the linear congruences and apply in cryptography.
3) prove results using the properties of arithmetic functions.
4) implement the theory to solve polynomial congruences.
5) analyze the integral solutions of system using Diophantine equations and sum of squares.

Recommended Books:

1) Niven I., Zuckerman S.H. and Montgomary L.H., An Introduction to Theory of Numbers, John Wiley and Sons (1991).
2) Davenport H., Higher Arithmetic, Cambridge University Press, 1999.
3) David M. Burton, Elementary Number Theory, Wm.C.brown Publishers, Dubuque, Ivova 1989.
4) Apostol, T. M., Introduction to Analytic Number Theory, Springer-Verlag, 1998.
5) Hardy and Wright W.H., Theory of Numbers, Oxford University Press, 1979.
6) Dence, J. B, and Dence, T. P., Elements of the Theory of Numbers (Academic Press), 1999.
7) Johannes A. Buchmann, Introduction to Cryptography, Springer Verlag, 2001.

Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA402 Mathematical Methods

L	T	P	Cr
3	**1**	**0**	**3.5**

Course Objectives: This course is intended to prepare the student with mathematical tools and techniques that are required in advanced courses offered in the applied mathematics and engineering programs. The objective of this course is to enable students to apply transforms and variation problem technique for solving differential equations and extremum problems.

Laplace Transform: Review of Laplace transform, Applications of Laplace transform in initial and boundary value problems, Heat equation, Wave equation, Laplace equation.

Fourier Series and Transforms: Definition, Properties, Solutions of differential equations using Fourier series. Fourier integral theorem, Convolution theorem and Inversion theorem, Discrete fourier transforms (DFT), Relationship of FT and fast Fourier transforms (FFT), Linearity, Symmetry, Time and frequency shifting, Convolution and correlation of DFT. Applications of FT to heat conduction, Vibrations and potential problems, Z-transform, Parseval's theorems.

Integral Equations: Linear integral equations of the first and second kind of fredholm and volterra type, Conversion of linear ordinary differential equations into integral equations, Solutions by successive substitution and successive approximation, Neumann series and resolvent kernel methods.

Calculus of Variation: The extrema of functionals, The variation of a functional and its properties, Euler equations in one and several independent variables, Field of extremals, Sufficient conditions for the extremum of a functional conditional extremum, Moving boundary value problems, Initial value problems, Ritz method.

Course learning outcomes (CLO): The student will be able to

1) solve initial and boundary value problems using Laplace transformation.
2) apply Fourier transformation and Z transformation to the relevant problems.
3) solve initial and boundary value problems using Fourier series.
4) find solutions of linear integral equations of first and second type (Volterra and Fredhlom).
5) obtain solution of initial and boundary value problems using theory of calculus of variations.

Recommended Books:

1) Simmons G.F., Differential Equations with Applications and Historical Notes, Tata McGraw Hill, 1991.
2) Gelfand I.M. and Fomin S.V., Calculus of Variations, Prentice Hall, 1963.
3) Kenwal Ram P., Linear Integral Equations: Theory and Techniques, Academic Press, 1971.
4) Sneddon I.N., The Use of Integral Transforms, Tata McGraw Hill, 1985.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

Elective I

PMA321 Numerical Methods for Partial Differential Equations

L	T	P	Cr
3	0	1	3.5

Course Objectives: This course deals with the mathematical theory of numerical methods especially finite difference scheme used to solve second partial differential equations (PDEs) arising in many real world applications. The course covers not only the algorithms and numerical schemes but also deals with the error analysis associated with them. Numerical solution of different kind of physically important PDEs system like Laplace, Poisson, Heat and Wave equations under various environment (initial and boundary conditions) will be discussed and their algorithms will be implemented on computers. The main aim is to give the students the basic understanding of numerical treatment of partial differential equations.
Basic review: Introduction to error analysis, System of linear equations, Interpolation, Integration and numerical differentiation. Classification of PDE.

Parabolic Equations: Finite difference solutions of parabolic equations of second order in one space variable with constant coefficients – two and three levels explicit and implicit difference schemes, Truncation errors and convergence analysis. Numerical solution of second order parabolic equations in two space variable with constant coefficients-improved explicit schemes, Implicit methods, alternating direction implicit (ADI) methods, Difference schemes for parabolic equations with variable coefficients in one and two space dimensions.

Elliptic Equations: Numerical solutions of elliptic equations, Approximations of Laplace operators, Solutions of Laplace and Poisson equations with Dirichlet, Neumann and mixed boundary in rectangular, Circular and triangular regions.

Hyperbolic Equations: Hyperbolic equations in one dimension. Conservation laws, weak forms, Upwind and Lax Wendroff approximations, extension to higher space dimension.

Course learning outcomes (CLO): The student will be able to

1) find numerical solutions of heat conduction diffusion equation in one and two dimension (cartesian and polar space variables) with the aid of explicit scheme, implicit scheme, Crank Nicholson scheme, Du-Fort and Frankel Scheme etc.
2) carry out the stability analysis and truncation error in various aforementioned numerical schemes.
3) solve the Dirichlet, Neumann and mixed type problems with Laplace and Poisson equations in different regions like rectangular, circular and triangular etc.
4) enumerate the numerical solution of hyperbolic equations of second order in one and two space variables with explicit and implicit methods.

Recommended Books:

1) K. W. Morton and D. F. Mayers, Numerical solution of Partial Differential Equations, 2nd Ed. Cambridge press, 2005.
2) John C. Strikewerda, Finite Difference equations, schemes and Partial Differential Equations, 2nd Ed. SIAM, 2004.
3) Langtangen H.P., Computational Partial Differential Equations Springer Verlag, 2003.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	25
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	30

PMA423 Finite Element Methods

L	T	P	Cr
3	1	0	3.5

Course objectives: The objective of the course includes an introduction about different finite element methods in one-, two- and three-dimensions. The course focuses on analyzing variety of finite elements as per the requirements of solutions of differential equations.

Introduction: Finite element methods, History and range of applications.

Finite Elements: Definition and properties, Assembly rules and general assembly procedure, Features of assembled matrix, Boundary conditions.

Continuum Problems: Classification of differential equations, Variational formulation approach, Ritz method, Generalized definition of an element, Element equations from variations, Galerkin's ed residual approach, Energy balance methods.

Element Shapes and Interpolation Functions: Basic element shapes, Generalized co-ordinates, Polynomials, Natural co-ordinates in one- two- and three-dimensions, Lagrange and Hermite polynomials, Two-D and three-D elements for C^o and C^1 problems, Co-ordinate transformation, Iso-parametric elements and numerical integration, Application of finite element methods to heat transfer problems.

Course learning outcomes (CLO): The student will be able to
1) formulate simple problems into finite elements.
2) solve the elasticity and the heat transfer problems.
3) solve the complicated two- and three-dimensional problems.
4) apply finite element methods for solving real life problems arising in various fields of science and engineering.

Recommended Books:

1) Bathe, K. J., Finite Element Procedures, Prentice Hall, 2008.
2) Cook, R. D., Malkus, M.E.P. and Witt, R.J., Concepts and Applications of Finite Element Analysis, 4th Ed. John Wiley and Sons, 2001.
3) Reddy, J. N., An Introduction to the Finite Element Methods, McGraw-Hill, 2006.
4) Thomson E. G., Introduction to the Finite Element: Theory, Programming and applications, Willey, 2004.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMA322 Introduction to Astronomy and Astrophysics

L	T	P	Cr
3	**1**	**0**	**3.5**

Course Objectives: The goal of this course is to familiarize the students with the basic properties of astronomical objects and to provide them the knowledge of basic physics and fundamental properties that govern their structure and formation. This course also familiarizes the students with basic fluid and plasma equations useful for dynamical evolution of astrophysical systems.

Introduction, Distance, Measurement system and devices: Typical physical scales/conditions in astrophysics; order of magnitude estimation, Astronomical observations: earth vs. space based observations, Measurement systems: Distance measurements: Stellar mass measurement: Telescopes.

Fundamentals of radiation and Sun as a star: Radiation: geometric optics, specific intensity, luminosity/flux, radiative transfer equation, extinction and emission of light, opacity, optically thick/thin media, black body radiation, local thermal equilibrium between matter and radiation and its connection with black body radiation, Interstellar medium, Sun as a star (qualitative): Solar spectrum, effective temperature, luminosity, nuclear fusion; energy transport in the sun, X-ray emission, magnetic fields, Sunspots

Elements of Plasma astrophysics: Basic equations of fluid dynamics: Euler equation, continuity equation, Jeans instability, Basic equations of MHD: Flux freezing, Sunspots and magnetic buoyancy, qualitative introduction to dynamo theory, Particle acceleration in astrophysics: synchrotron radiation, Bremsstrahlung

Stellar structure and evolution: Stellar models: hydrostatic equilibrium, gas/radiation pressure; theoretical main sequence, Observed stellar properties: main sequence, luminosity dependence on mass, stellar classification based on spectra, HR diagram; star clusters and distance measurements, Pre-main sequence evolution: Jeans instability, star formation, Hayashi track Post-main sequence evolution: Chandrasekhar mass limit. Type II supernova, neutronization; formation of elements heavier than iron; Neutron stars(NS); NS observed as pulsars, black hole formation for M > NS, Binary system evolution: effective potential in rotating frame, Lagrange points, Roche lobe, mass overflow, Type Ia supernovae, Accretion physics: magnetorotational instability.
Galaxy and Extragalactic astronomy: Types of galaxies: spirals, ellipticals and irregulars, Hubble pitchfork classification, Milky Way components: gas, stars, magnetic field and cosmic rays, satellites, 21cm line, rotation cure, dark matter; HII regions, phases and components of interstellar medium, cosmic rays, Galactic dynamics: orbits in axisymmetric potentials, epicyclic limit; Oort's A & B constants, local differential rotation, Collisionless Boltzmann equation, Active galaxies: observations of active galaxies, quasars, unified model, radio lobes and jets; relativistic apparent superluminnal motion, Sgr A∗, the Galactic centre black hole, Extragalactic distance scale, structure on the largest scales.

Course learning outcomes: After the completion of this course the students will:

1) have knowledge of length scales, masses & timescales in astronomy, celestial co-ordinates and telescopes for astronomical observations
2) have basic knowledge of radiative transfer and inter-stellar medium.
3) have basic knowledge of stellar structure and their evolution, HR diagram and end states of stars.
4) have knowledge of basic components of galaxy, galactic dynamics and extragalactic sources.
5) learn the basic concepts of fluids and basic equations of MHD.

Recommended Books:

1) J. Binney and S. Tremaine: Galactic Dynamics, Princeton, 2008.
2) M. Harwit, Astrophysical Concepts, Springer, 2006.
3) A. Rai Choudhuri: Astrophysics for Physicists, Cambridge University press, 2010.
4) Frank, King, Raine: Accretion power in astrophysics, Cambridge University press, 2001.
5) G. Rybicki and A. Lightman: Radiative Processes in Astrophysics, Wiley, 1979.
6) A. Rai Choudhuri: The Physics of Fluids and Plasmas, Cambridge University press, 1998.

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Evaluation Scheme:

Sr. No.	Component	Weight (%)
1	MST	30%
2	EST	45%
3	Sessional	25%

PMA323 Wavelet and Applications

L	T	P	Cr.
3	1	0	3.5

Course Objectives: The objective of this course is to cover the basic theory of wavelets, multiresolution analysis, construction of scaling functions, bases, frames and their applications in various scientific problems.

Different Ways of Constructing Wavelets: Orthonormal bases generated by a single function, The Balian-low theorem, Smooth projections on L2(R), Local sine and cosine bases and the construction of some wavelets, The unitary folding operators and the smooth projections.

Multiresolution Analysis: Multiresolution analysis and construction of wavelets, Construction of compactly supported wavelets and estimates for its smoothness, Band limited wavelets, Orthonormality, Completeness, First and second generation wavelet transform.

Characterizations in the Theory of Wavelets: Basic equations and some of its applications, Characterizations of MRA wavelets, Characterization of Lemarie-Meyer wavelets and some other characterizations, Franklin wavelets and spline wavelets on the real line, Orthonormal bases of piecewise linear continuous functions for L2(T).

Wavelets in Signal and Image Processing: Signals, Filters, Coding signals, Filters banks, Image analysis, Image compression.

Laboratory Work: Analysis of different wavelet filters, Multiresolution analysis feature of different wavelets, Applications of wavelets in signal and image processing.

Course learning outcome: The student will be able to

1) analyze the properties of various scaling functions and their wavelets.
2) analyze the properties of multiresolution analysis.
3) construct the scaling functions using infinite product formula and iterative procedure.
4) implement wavelets in various problems like image compression, denoising *etc*.

Recommended Books:

1) Eugenio, H. and Guido, W., A First course on Wavelets, CRC Press, New York, 1996.
2) Chui, C. K., An Introduction to Wavelets, Academic Press, 1992.
3) Meyer Y., Wavelets, Algorithms and Applications, SIAM, 1994.
4) Daubechies, I., Ten Lectures on Wavelets, CBS-NSF regional conferences in applied mathematics, 61, SIAM, 1992.
5) Gonzalez, R. C. and Woods, R. E., Digital Image Processing, Pearson Education, 2007.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	25
2.	EST	40
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	35

PMA324 Mathematical Biology and Nonlinear Dynamical systems

L	T	P	Cr
3	0	1	3.5

Course Objectives: The main aim of this course is to see how mathematical ideas and techniques can contribute to the understanding of questions about living things. This course will provide students with skills and knowledge in the process of the mathematical modelling cycle and enable them to formulate and specify a real-life problem.

Mathematical Modelling in Population Biology: Single species models, Exponential, logistic, Gompertz growth, Harvest model, Discrete time and Delay model, Interacting population model, ecological and epidemiological models, competition & mutualism models, Dynamics of exploited populations, Models for interacting populations, Reaction-diffusion equations, Age structured models, sex-structured models, models of spread, two sex models.

Dynamical systems: Central manifold and Normal form, attractors, SIC, 1D map, Logistic map, Poincare maps and Poincare-Bendixson theorem, generalized Baker's map, circle map.

Bifurcations: Saddle-node, Transcritical, pitchfork, Hopf-bifurcation, Global bifurcations.

Course Learning Outcomes: Upon completion of this course, the students will be able to

1) construct appropriate ordinary differential equations associated with real life with relevant parameters and conditions.
2) solve the ordinary differential equations and implement equation in Matlab program to obtain numerical result.
3) analysis and stability of equilibrium of nonlinear systems in more than two variables.
4) analysis of equilibrium and stability of a reaction-diffusion equation.
5) apply Poincare-Bendixson, Central manifold and Normal theorem.

Recommended Books:

1) Strogatz S. H., Nonlinear Dynamics And Chaos: With Applications To Physics, Biology, Chemistry And Engineering, published by Addison Wesley, 1994.
2) Perko L., Differential Equations and Dynamical Systems, published by Springer, 1996.
3) Murray J. D., Mathematical Biology I. An Introduction, 3rd Edition, Springer, 2008.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMA325 Advanced Functional Analysis

L	T	P	Cr
3	1	0	3.5

Course objective: The aim of this course is to deal with the analysis of operators on a Hilbert or Banach space.

Convergence in Normed Linear Spaces: Strong and weak convergence in finite and infinite dimensional normed linear spaces. Weak convergences in Hilbert spaces, weakly compact set in Hilbert spaces.

Finite dimensional spectral Theory: Eigen- values and Eigen vectors, Spectrum of a bounded linear operator, spectrum of self-adjoint, positive and Unitary operators, square root of positive operator, Spectral Theorem for normal operators.

Compact Linear Operators: Compact Linear Operator on normed spaces, properties of compact linear operators, spectral properties of compact linear operators.

Banach algebras: definitions and simple examples. Regular and singular elements. Topological divisors of zero, Spectrum of an element of Banach Algebra, formula for spectral radius.

Course learning outcome(CLO): The student will be able to
1) define strong and weak convergence in Hilbert space.
2) understand bounded linear operators, self adjoint operators, unitary operators etc. and spectral theorems.
3) classify the properties of linear operators.
4) describe Banach algebras and its properties.

Recommended Books:

1) Simmons, G.F.: Introduction to Topology and Modern Analysis, Mc Graw- Hill, 1963.
2) Erwin Kreyszig: Introduction to Functional Analysis with Applications, John Wiley & Sons, 1978.
3) Limaye, Balmohan V.: Functional Analysis, New Age International Limited., 1996.
4) Jain, P.K., Ahuja, O.P & : Functional Analysis, New Age International (P) Khalil Ahmed Ltd. Publishers, 1995.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA326 Enumerative Combinatorics

L	T	P	Cr
3	1	0	3.5

Course Objectives: The objectives of this course is to introduce the fundamentals of mathematical structures that are discrete, deals with integral solutions and enumeration or counting problems. It has applications in other mathematical courses such as coding theory, partition theory, combinatorial optimization or designs problem and also in all fields of computer science especially in data structure algorithms and graph theory.

Inclusion and Exclusion: Two basic counting principles, generalised permutation and combinations, sequences and selections, inclusion-exclusion formula, restricted positions and Rook polynomial, systems of distinct representatives.

Generating Functions and Recurrence Relations: ordinary and exponential generating functions, recurrence relations, algebraic solutions of linear recurrence relations with constant coefficient, solutions of recurrence relation using generating function solutions of inclusion-exclusion principle, recurrence relations and generating functions, bijective methods, generating functions, Fibonacci numbers and Catalan Numbers, q-bionomial theorem, q-gauss theorem, partitions of a positive integer, Ferrers graph, Compositions, zig-zag graphs.

Group Theory in Combinatorics: Symmetric groups, Legendre's Theorem, generators, cyclic indices, equivalence and isomorphism, The Burnside Theorem, Polya's enumeration Theorems.

Course learning outcomes (CLO): The students will be able to

1. solve basic counting problems using concepts of inclusion-exclusion principle.
2. manipulate and derive properties of formal power series
3. derive recursions, generating functions and provide explicit formulas for various combinatorial sequences
4. be able to construct combinatorial proofs of identities and inequalities

Recommended Books:

1. Richard A Brnaldi - Introductory Combinatorics, Pearson Ed. Inc., 2004.
2. G.E. Martin, Counting-the art of enumerative combinatorics, Springer, 2001.
3. A. Tuker, Applied Combinatorics, Wiley, 2017.
4. R.P. Grimaldi, B.V. Ramana, Discrete and Combinatorial mathematics, Pearson Ed. Inc., 2007.
5. V.K. Balakrishnan – Combinatorics including concepts of graph theory, Schaum's outlines, McGraw Hill, 1995.
6. Richard P. Stanley, Enumerative Combinatorics, volume 1, second edition, Cambridge University Press, 2011.

Evaluation Scheme:

Sr. No.	Evaluation Elements	Weightage (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA327 Advanced Complex Analysis

L	T	P	Cr
3	1	0	3.5

Course Objective: The course aims to introduce advanced topics in complex analysis to graduate students. The first part of the course discusses representation of complex numbers in higher dimensions and elementary ideas of hypercomplex analysis. The second part of the course discusses some advanced topics of complex analysis in two dimensions equations.

Hypercomplex numbers and hypercomplex analysis

Complex numbers in higher dimensions (quaternions): introduction to quaternions as hypercomplex numbers, introduction to bi-vectors and correspondence with iota, introduction to geometric algebra for complex analysis in higher dimensions, dilation, contraction, derivations, rotation and reflection in the language of hypercomplex numbers, matrix representation of hypercomplex numbers with examples from basic quantum physics, quaternion operations (conjugate, norm and inverse), rotations in three and four dimensions.

Quaternion calculus and hypercomplex analysis: vector fields, tangential integration and Cauchy's integral formula in higher dimensions, functional calculus of quaternions for dynamical systems (derivatives of quaternions, derivatives of conjugates, quaternion perturbations and rotations in phase space) with several examples of applications from computer graphics and virtual reality, aerospace engineering, electromagnetism, hydrodynamics and quantum physics.

Advanced techniques using complex variables in two dimensions

Differential equations in complex planes: Painleve equations, continuation principle, movable and fixed singular points, ordinary differential equations in punctured disks.

Complex integration and asymptotic methods: Watson's lemma, Laplace method, Method of stationary phase, method of steepest descent, WKB method.

Riemann-Hilbert problems: Introduction to Riemann-Hilbert (RH) problems (discuss examples on scalar RH problems and its applications in Fourier and Radon transform).

Course Learning Outcomes (CLO): Upon completion of this course, the student will be able to:

1) represent complex numbers in higher dimensions and their geometrical interpretation.
2) apply mathematical operations (rotation, reflection, dilation, contraction, differentiation) in higher dimensions using quaternion algebra.
3) use calculus of quaternions to study dynamical systems with examples from engineering and physics.
4) understand differential equations in the complex plane.
5) evaluate integrals using different techniques from complex analysis.

Recommended Books:

1) Ablowitz, M. and Fokas, A. S., *Complex Variables: introduction and applications*, Cambridge University Press, 2003 (2nd edition).
2) Simon, B., *Advanced Complex Analysis*, American Mathematical Society, 2015 (1st edition).
3) Kuipers, J. B., *Quaternions and Rotation Sequences: A Primer with Applications to Orbits, Aerospace and Virtual Reality*, Princeton University Press, 2002 (1st edition).
4) Lounesto, P., *Clifford Algebras and Spinors*, Cambridge University Press, 2003 (2nd edition).

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (may include quizzes/assignments)	25

PMA330 Fuzzy Sets and Applications

L	T	P	Cr
3	1	0	3.5

Course objectives: The objective of this course is to teach the students the need of fuzzy sets, arithmetic operations on fuzzy sets, fuzzy relations, possibility theory, fuzzy logic, and its applications

Classical and Fuzzy Sets: Overview of classical sets, Membership function, α-cuts, Properties of α-cuts, Extension principle.

Operations on Fuzzy Sets: Compliment, Intersections, Unions, Combinations of operations, Aggregation operations.

Fuzzy Arithmetic: Fuzzy numbers, Linguistic variables, Arithmetic operations on intervals and numbers, Fuzzy equations.

Fuzzy Relations: Crisp and fuzzy relations, Projections and cylindric extensions, Binary fuzzy relations, Binary relations on single set, Equivalence, Compatibility and ordering Relations, Morphisms, Fuzzy relation equations.

Possibility Theory: Fuzzy measures, Evidence and possibility theory, Possibility versus probability theory.

Fuzzy Logic: Classical logic, Multivalued logics, Fuzzy propositions, Fuzzy qualifiers, Linguistic hedges.

Applications of Fuzzy Logic : Control systems engineering, Power engineering and Optimization.

Course learning outcomes (CLO): The student will be able to

1) construct the appropriate fuzzy numbers corresponding to uncertain and imprecise collected data.
2) explain the problems having uncertain and imprecise data.
3) find the optimal solution of mathematical programming problems having uncertain and imprecise data.
4) deal with the fuzzy logic problems in real world problems.

Recommended Books:

1) Klir G.J. and Folger T. A., Fuzzy Sets, Uncertainty and Information, PHI, 1988.
2) Klir G. J. and Yuan B., Fuzzy Sets and Fuzzy logic: Theory and Applications, PHI, 1995.
3) Zimmermann H. J., Fuzzy Set Theory and its Applications, Allied Publishers, 1991.
4) Mohan, C., An introduction to Fuzzy Set Theory and Fuzzy Logic, Viva Publishers, 2009.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMA421 Fluid Mechanics

L	T	P	Cr
3	1	0	3.5

Course objectives: This course is intended to provide a treatment of topics in fluid mechanics to a standard where the student will be able to apply the techniques used in deriving a range of important results and in research problems. The objective is to provide the student with knowledge of the fundamentals of fluid mechanics and an appreciation of their application to real world problems.

Kinematics: Lagrangian and Eulerian methods, Equation of continuity, Stream lines, Path lines and streak lines, Velocity potential and stream function, Irrotational and rotational motions.

Dynamics: Euler's equation, Bernoulli's equation, Equations referred to moving axes, Impulsive actions, Vortex motion and its elementary properties, Motions due to circular and rectilinear vortices, Kelvin's proof of permanence.

Potential Flow: Irrotational motion in two-dimensions, Complex-velocity potential sources, Sinks, Doublets and their images, Conformal mapping.

Laminar Flow: Stress components in a real fluid, Navier-Stokes equations of motion, Plane poiseiuille and couette flows between two parallel plates, Flow through a pipe of uniform cross section in the form of circle, Annulus, Theory of lubrication.

Boundary Layer Flows: Boundary layer thickness, Displacement thickness, Prandit's boundary layer, Boundary layer equations in two dimensions, Blasius solution, Karman integral equation, Separation of boundary layer flow.

Course learning outcomes (CLO): The student will be able to

1) describe the basic principles of fluid mechanics, such as Lagrangian and Eulerian approach, conservation of mass etc.
2) apply Euler and Bernoulli's equations and the conservation of mass to determine velocity and acceleration for incompressible and inviscid fluid.
3) explain the concept of rotational and irrotational flow, stream functions, velocity potential, sink, source, vortex etc.
4) analyse simple fluid flow problems (flow between parallel plates, flow through pipe etc.) with Navier - Stoke's equation of motion.
5) analyse the phenomenon of flow separation and boundary layer theory.

Recommended Books:

1) Yuan S. W., Foundations of Fluid Mechanics, Prentice Hall of India Private Limited, 1976.
2) Chorlton F., Textbook of Fluid Dynamics, C.B.S. Publishers, 2005.
3) Besant W. H., and Ramsay A. S., Treatise of Hydro Mechanics, Part II, CBS Publishers, 2004.
4) Rathy R. K., An Introduction to fluid Dynamics, Oxford and IBH Publishing Company, 1976.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMC105 Discrete Mathematical Structures

L	T	P	Cr
3	1	0	3.5

Course Objectives: Prepare students to develop mathematical foundations to explain and create mathematical arguments, require in learning many mathematics and computer sciences courses. To motivate students how to solve practical problems using discrete mathematics

Mathematical Logic: Statement and notations, Connectives, Statement formulas and truth table, Conditional and bi-conditional statements, Tautology and contradiction, Equivalence of formulas, Tautological implications.

Theory of inference: Validity using truth table, Rules of inference, Consistency of premises and indirect method of proof, Predicates, Statement function, Variables, Quantifiers, Free and bound variables, Universe of discourse, Inference of the predicate calculus.

Relation: Review of binary relations, equivalence relations, Compatibility relation, Composition of binary relations, Composition of binary relations and transitive closure, Partial ordering and partial ordered set.

Function: Review of functions and their enumeration, Pigeonhole principle.

Recurrence Relation: Iteration, Sequence and discrete functions, Recurrence relations, Generating function.

Lattice and Boolean Algebra: Lattice and algebraic system, Basic properties of algebraic systems, Special types of lattices, Distributed, Complemented lattices, Boolean algebra, Boolean expressions, Normal form of boolean expressions, Boolean function and its applications to LOGIC GATES.

Course learning outcomes (CLO): The student will be able to

1) construct mathematical arguments using logical connectives and quantifiers.
2) validate the correctness of an argument using statement and predicate calculus.
3) apply lattices and Boolean algebra as tools in the study of network.
4) explain some of the discrete structures which include sets, relations, functions, graphs and recurrence relation.

Recommended Books:

1) Tremblay, J.P., and Manohar, R., A First Course in Discrete Structures with Applications to Computer Science, McGraw Hill, (1987).
2) Kenneth, H. Rosen, Discrete Mathematics and its Applications, WCB/ McGraw Hill.
3) Liu, C.L., Elements of Discrete Mathematics, McGraw Hill, New York, (1978).
4) Grimaldi, R.P. and Ramana, B.V., Discrete and Combinatorial Mathematics – An Applied Introduction, Pearson education (2004)

Evaluation Scheme

Sr.No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

Elective II

PMA422 Modeling of Stellar Structure

L	T	P	Cr
3	1	0	3.5

Course Objectives: The goal of this course is to familiarize the students with the basic observed properties of stars and to provide them the knowledge of basic physics and fundamental properties that govern stars and their structures. The aim of this course is also to explain mathematical techniques to solve the stellar structure equations and apply the basic theory of stellar structures on analytical models.

Observed Properties of the Stars: Introduction to stars**,** Measurement of stellar distances, Luminosities, Temperatures, Masses and radii, The Hertzsprung-Russell diagram.
Fundamental Equations of Stellar Structure: Time scales, Fundamental equations: Mass conservation, Hydrostatic equilibrium, Energy transport, The virial theorem. Radiative transport and convection.
Boundary Value Problems: Shooting method and relaxation method, Applications to stellar structure with detailed discussion of Henyey scheme and EZ – Code**.**
Stellar modelling and Numerical Calculations: Russell-Voigt theorem, Limits to the mass, solving the coupled equations, Simple analytic stellar models: Polytropes and other relations, Numerical models, The Edington luminosity, Dimensional analysis and mass-radius relations, The HR diagram.
Superdense Objects: Use of polytropic models for completely degenerate stars, Mass-radius relation, Non-degenerate upper layers and abundance of Hydrogen, Stability of white dwarfs.
Course learning outcomes (CLO): The student will be able to

1) describe the various properties of stars.

2) obtain the basic physics and fundamental properties that govern star and their structure.

3) apply the mathematical methods to solve stellar structure equations.

4) develop mathematical methods of stellar structures and their solution techniques.
5) explain the various properties of super dense objects like white dwarf stars.

Recommended Books:

1) Chandrasekhar, S., An introduction to the Study of Stellar Structure, University of Chicago Press, Reprinted by Dover, 1939.

2) Kippenhahn, R and Weigert, A., Stellar Structure and Evolution, Springer-Verlag, 1990.

3) Schwarzschild, M., Structure and Evolution of stars, Princeton University Press, 1958.

4) Evolution of the Stars, Princeton University Press, Reprinted by Dover, 1958.
5) Prialnik, D., An Introduction to the Theory of Stellar Structure and Evolution, CUP, 2000.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMA424 Asymptotic Methods and Perturbation Theory

L	T	P	Cr
3	1	0	3.5

Course Objective: The course aims to introduce asymptotic methods and perturbation theory to graduate students which have wide applications in solving linear and nonlinear differential equations especially those which model multi scale phenomena.

Prerequisites: Undergraduate level knowledge of calculus and differential equations, and basic complex analysis.

Review of elementary differential equations: introduction to differential equations in the complex plane (Painleve equations)

Approximate solutions to linear differential equations: classification of singular points of homogeneous linear differential equations, local series expansion about regular singular points (Taylor and Fuch's series), local solutions around irregular singular points (method of dominant balance, basic ideas of asymptotic series expansion).

Approximate solutions to nonlinear differential equations: spontaneous singularities, approximate solutions (Painleve transcendent, Thomas-Fermi equation, phase-space interpretation of nonlinear autonomous systems, classification of critical points).

Asymptotic expansion of integrals: integration by parts, Laplace's method and Watson's lemma, method of stationary phase, method of steepest descents.

Perturbation theory: regular and singular perturbation theory, asymptotic matching (method of matched asymptotic expansions to solve differential equations), basic ideas of boundary layer theory, WKB approximation to solve differential equations with dissipative and dispersive behaviour, examples of the one-Turning-point problem and tunneling via the Schrodinger equation.

Multiple scales analysis: resonance and secular behaviour, Fredholm alternative, examples of multiple scales analysis through models of damped oscillators, Duffing equation and elementary ideas of stability.

Course Learning Outcomes (CLO): Upon the completion of this course, the students will obtain conceptual skills to practise the following mathematical techniques.

1) Find approximate solutions of differential equations as power series (asymptotic series) around different singular points.
2) Compute approximate solutions to integrals.
3) Find approximate solutions of differential equations using perturbation theory.

Recommended Books:

1) Bender, Carl and Orszag, Steven, *Advanced Mathematical Methods for Scientists and Engineers*, Springer, 1st ed., 1999.
2) Hinch, E. J., Perturbative Methods, Cambridge University Press, 1st ed., 1991.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals* (may include quizzes/assignments)	25

* Sessionals will be mini projects where students will have to either discuss a research paper on a given topic or present a proof of an important theorem and/or a solution to an advanced problem not covered in the lectures. The topics will be pre-assigned based on an individual student's interest and will require prior approval from the instructor.

PMA425 Theory of Elasticity

L	T	P	Cr
3	1	0	3.5

Course objectives: This course is intended to provide a basic treatment of the formulation of linear elasticity theory and its application to problems of stress and displacement analysis. The objective is to provide the student knowledge of fundamentals of theory of elasticity and an appreciation of their application to the different fields of research.

Tensor Algebra: Scalar, Vector, Matrix and tensor definition, Index notation, Kroneckor delta and alternating symbol, Coordinate-transformation, Cartesian tensor of different order, Properties of tensors, Isotropic tensors of different orders and relation between them, Symmetric and skew-symmetric tensors, Covariant, Contra variant and mixed tensors, Sum and product of tensors.

Analysis of Stress: Stress vector, Stress components, Stress tensor, Symmetry of stress tensor, Stress quadric of Cauchy, Principal stress and invariants, Maximum normal and shear stresses.

Analysis of Strain: Affine transformations, Infinitesimal affine deformation, Geometrical interpretation of the components of strain, Strain quadric of Cauchy, Principal strains and invariants, General infinitesimal deformation, Finite deformations, Examples of uniform dilatation, Simple extension and shearing strain.

Equations of Elasticity: Generalized Hooke's law, Hooke's law for Homogeneous isotropic media, Elastic moduli for isotropic media, Equilibrium and dynamic equations for an isotropic elastic solid, Beltrami-Michell compatibility equations, Strain energy function.

Elastic Waves: Simple harmonic progressive waves, Scalar wave equation, Progressive type solutions, Plane waves, Propagation of waves in an unbounded elastic solid media, P, SV and SH waves, Elastic surface waves as Rayleigh waves, Love waves. Applications to different elastic models.

Course learning outcomes (CLO): The student will be able to

1) describe the notation and properties of different types of tensor.
2) explain various terms related to stress tensor like normal and shear stress, stress quadric of cauchy, Principal stress and invariants.
3) explain affine transformations and geometrical interpretation of the components of strain and terms related to strain tensor.
4) apply the generalized Hooke's law, reduction of elastic constants to different elastic models from the most general case.
5) develop equilibrium and dynamical equations of an isotropic elastic solid.
6) obtain some important aspects of wave propagation in the infinite and semi-infinite solids.

Recommended Books:

1) I. S. Sokolnikoff, Mathematical Theory of Elasticity, Tata McGraw Hill Publishing Company Ltd., New Delhi, 1977.
2) D. S. Chandrasekharaiah, and L. Debnath, Continuum Mechanics, Academic Press, 1990.

3) K. F. Graff, Wave Motion in Elastic Solids, Dover, New York, 1991.
4) A. A. Shaikh, U. C. De. and J. Sengupta, Tensor Calculus, Narosa Publishing House, 2nd ed., 2008.
5) Shanti Narayan, Text Book of Cartesian Tensor, S. Chand & Co., 1956.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMA426 Algebraic Coding Theory

L	T	P	Cr
3	1	0	3.5

Course Objectives: The objective of the course is to introduce basic topics of algebraic coding theory like error correction and detection, linear codes, Hamming codes, finite fields and BCH codes, dual codes and the distribution, cyclic codes, generator polynomial and check polynomial.

Introduction to Coding Theory: Code words, Distance and function, Nearest-neighbour decoding principle, Error detection and correction, Matrix encoding techniques, Matrix codes, Group codes, Decoding by coset leaders, Generator and parity check matrices, Syndrom decoding procedure, Dual codes.

Linear Codes: Linear codes, Matrix description of linear codes, Equivalence of linear codes, Minimum distance of linear codes, Dual code of a linear code, distribution of the dual code of a binary linear code, Hamming codes.

BCH Codes: Polynomial codes, Finite fields, Minimal and primitive polynomials, Bose-Chaudhuri-Hocquenghem codes.

Cyclic Codes: Cyclic codes, Algebraic description of cyclic codes, Check polynomial, BCH and Hamming codes as cyclic codes.

MDS Codes: Maximum distance separable codes, Necessary and sufficient conditions for MDS codes, distribution of MDS codes.

Algebraic Coding Theory: Overview of coding theory, Error detecting and correcting codes.

Course learning outcomes (CLO): The student will be able to

1) apply basic techniques of algebraic coding theory like matrix encoding, polynomial encoding, and decoding by coset leaders etc.
2) analyze different types of codes like linear, BCH, cyclic and MDS codes.
3) apply algebraic coding theory is applicable to solve the real world problems.

Recommended Books:

1) Vermani L R, Elements of Algebraic Coding Theory, Chapman and Hall, 1996.
2) Vera P.**,** Introduction to the Theory of Error Correcting Codes, John Wiley and Sons, 1998.
3) Roman Steven, Coding and Information Theory, Springer Verlag, 1992.
4) Garrett Paul, The Mathematics of Coding Theory, Pearson Education, 2004.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMA427 Topological Vector Spaces

L	T	P	Cr
3	1	0	3.5

Course objective: The aim of this course is to deal with topological vector spaces with their properties.

Definition and examples of topological vector spaces. Convex, balanced and absorbing sets and their properties.

Minkowski's functional. Subspace, product space and quotient space of a topological vector space.

Locally convex topological vector spaces. Normable and metrizable topological vector spaces. Complete topological vector spaces and Frechet space.

Linear transformations and linear functional and their continuity. Finite dimensional topological vector spaces. Hahn-Banach Theorem.

Uniform bounded Principle, Open mapping theorem and closed graph theorem for Frechet spaces.

Course learning outcome (CLO): The student will be able to

1) define topological vector spaces and their properties.
2) understand subspace, product , quotient space, normable and metrizable topological vector spaces.
3) define linear transformation and related theorems.

Recommended Books:

1) Walter R., Functional Analysis, TMH Edition, 1974.
2) Schaefer, H.H.: Topological Vector Spaces, Springer, N.Y., 1971.
3) John Horvath, Topological Vector Spaces and Distributions, Addison-Wesley, 1966.
4) G. Kothe, Topological vector spaces , Vol. I, Springer, New York, 1969.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes)	20

PMA428 Fixed Point Theory

L	T	P	Cr
3	1	0	3.5

Course objective: The aim of this course is to deal with fixed point theory with their applications.

Metric Contraction Principles: Banach's Contraction Principle, Extensions of Banach's Principle, The Caristi-Ekeland Principle, Equivalents of the Caristi-Ekeland Principle, Set-valued contractions.

Banach Spaces and Continuous Mappings: Banach Spaces, Brouwer's Theorem, Comments on Brouwer's Theorem, Schauder's Theorem, Banach Algebras: Stone Weierstrass Theorem, Condensing mappings.

Fixed Point Theory: Contraction mappings, Basic theorems for non-expansive mappings, A closer look at l_1, Stability results in arbitrary spaces, The Goebel-Karlovitz Lemma, Orthogonal Convexity, Structure of the fixed point set, Asymptotically regular mappings.

Applications of Fixed Point Theory: Application to System of Linear Equations, Differential Equations and Integral Equations.

Course learning outcome(CLO): The student will be able to
1) understand contraction principles such as Banach contraction principle and their extensions.
2) explain fixed point theorems for various abstract spaces.
3) classify contractive and non-expansive mappings.
4) apply fixed point theorems to many problems like system of linear equations, differential and integral equations.

Recommended Books:
1) R. P. Agarwal, M. Meehan and D. O'Regan, Fixed Point Theory and Applications, Cambridge University Press, 2004.
2) K. Goebel and W. A. Kirk, Topics in Metric Fixed Point Theory, Cambridge University Press, 1990.
3) V. I. Istratescu, Fixed Point Theory: An Introduction, Springer, 2001.
4) M. A. Khamsi and W. A. Kirk, An Introduction to Metric Spaces and Fixed Point Theory, John Wiley & Sons, 2001.
5) E. Zeidler. Nonlinear Functional Analysis and its Applications I: Fixed-Point Theorems, Springer, 1986.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes)	20

PMA429 Statistical Simulation and Computation

L	T	P	Cr.
3	1	0	3.5

Objective: This course introduces statistical simulation. Students learn Pattern Recognition using statistical concepts.

Simulation: Introduction, Systems, Models, types of models, need of simulation, Monte Carlo method, physical versus digital simulation, Buffen's needle problem.

Random Number Generation: Mid square method, Congruential generators, Shift generator, statistical tests for pseudo random numbers.

Pattern Recognition: Introduction, Basic Concepts, Fundamental problems, Design concepts and methodologies, Examples of automatic systems, Pattern Recognition model, and Pattern classification by likelihood functions.

Random Variate Generation: Inverse transformation method, Acceptance-Rejection method, Composition method. Simulation of Random vectors, Multivariate transformation method, Generation from Multinormal distribution, Generating random variates from continuous distributions.

Monte Carlo integration: Hit or miss Monte Carlo method,sample mean Monte Carlo method, Efficiency of Monte Carlo method.

Variance Reduction Techniques: Introduction, Importance sampling, Correlated sampling, Control variates, Stratified sampling.

Course learning outcomes (CLO): The student will be able to
1) understand the fundamental knowledge of statistical simulation and computation.
2) apply Monte Carlo and other types of numerical methods for analyzing complex models where the simple numerical methods cannot be applied.
3) understand the Mid square method, Congruential generator, shift generator etc. for pseudo random numbers.
4) evaluate Monte Carlo integrations.

Recommended Books:

1. Reuven Y. Rubinstein, Dirk P. Kroese, Simulation and the Monte Carlo Method, 3rd Edition, Willey, 2016.
2. Frank L. Severance, System Modeling and Simulation: An Introduction, Willey, 2001.
3. W. A. Lewis and Ed McKenzie, Simulation Methodology for Statisticians, Operations Analysts, and Engineers, Chapman and Hall/CRC, 1989.
4. T.T. Julius and R. C. Gonzalesz, Pattern Recognition Principles, Addison-Wesley, 1977.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes)	20

PMA430 Financial Mathematics

L	T	P	Cr
3	1	0	3.5

Course Objectives: This is an introductory course in finance to equip with a framework and basic techniques necessary for financial engineering. The main focus is on valuation of financial assets and more specifically derivative products. The course will introduce the concept of risk and relation between risk and return. The knowledge of risk and valuation will be integrated in optimal decision-making. The models will be studied in discrete-time scenario.

Basics of Financial Mathematics: Financial markets, terminologies, basic definitions and assumptions, Interest rate, present value, future value, NPV, annuity and perpetuity. Market structure, no arbitrage principle, derivative products, forwards, futures– their valuation, dividend and non divided cases, options, swap, valuation concept, purpose and working of these products.

Theory of Option Pricing: Options-calls and puts, pay-off, profit diagrams, hedging and speculation properties of options, valuation of options using pricing and replication strate- gies, mathematical properties of their value functions, put-call parity. Risk neutral probability measure (RNPM) (discrete case), existence of RNPM, Binomial lattice model, Binomial formula for pricing European style and American style options, dividend and non-divided cases. CRR model, Black-Scholes formula derivation, Examples. Greeks and their role in hedging, delta-neutral portfolio, delta-gamma neutral portfolio.

Portfolio Optimization: Portfolio optimization: introduction, risk, return, two-assets portfolio, Markowitz curve, efficient frontier, Multi-assets all risky portfolio, mean-variance Markowitz model, two fund theorem. Portfolio with one risk free asset, one fund theorem, CAPM, market line, beta, systematic and unsystematic risks, factor models, other risk measures, stochastic dominance and portfolio optimization. Risk neutral probability measure (RNPM) (discrete case), existence of RNPM, Binomial lattice model, Binomial formula for pricing both European style and American style options, dividend and non-divided cases.

Course learning outcomes (CLO): The student will be able to
1) understand basic quantities that are reported in everyday life such as interest rates, periodic payments of money, dividends, shares, bonds, forwards, futures etc.
2) evaluate call and put option prices using binomial and CRR models.
3) construct a portfolio which is optimal in a given market scenario.

Recommended Books:
1) D.G. Luenberger, Investment Science, Oxford University Press, 2014.
2) S. Chandra, S. Dharmaraja, A. Mehra, R. Khemchandani, Financial Mathematics: An Introduction, Narosa, 2014.
3) M. Capinsky and T. Zastawniak, Mathematics for Finance: An Introduction to Financial Engineering, Springer, 2010.
4) J. C. Hull, Options, Futures and other Derivatives, Prentice Hall, 10th edn, 2018.
5) J. H. Cochrane, Asset Pricing, Princeton University Press, 2005.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals(May include assignments/quizzes/Lab Evaluation)	25

PMA431 Combinatorial Programming

L	T	P	Cr
3	1	0	3.5

About this course: The course is a comprehensive introduction to the theory, algorithms and applications of integer optimization and is organized in four parts: formulations and relaxations, algebra and geometry of integer optimization, algorithms for integer optimization, and extensions of integer optimization.

Polyhedral Combinatorics (1) Basic polyhedral theory (2) Linear Programming: - Quick overview of duality, algorithms for LP - Equivalence of optimization and separation (3) Integer Programming : - Integer hull of a polyhedron - Cutting plane algorithms and bounds - Branch and bound, branch and cut algorithms - Totally unimodular matrices (TUM), Total Dual Integrality (TDI)

Combinatorial algorithms for classic discrete optimization problems
(1) Quick Overview of flow problems: Maximum flow, Minimum Cut, Minimum cost flow, Multicommodity flows
(2) Matching theory: Matching and alternating paths
(3) Set covering

Other techniques for Combinatorial Optimization
(1) Matroid Theory, Greedy Algorithms
(2) Lattice, Lattice basis reduction, Lenstra's algorithm

Course learning outcomes: After completion of the course, students will be able to
1) formulate and analyze mathematical models of some classical combinatorial optimization problems.
2) implement cutting plane algorithms to integer programs.
3) use various algorithms to solve network flow problems.

Recommended Books:

1) G. L. Nemhauser and L.A. Wolsey, Integer and combinatorial optimization, John Wiley, 1988.
2) W. J. Cook, W. H. Cunningham, W. R. Pulleyblank, A. Schrijver, Combinatorial Optimization, John Wiley and Sons, 1998.
3) A. Schrijver, Combinatorial Optimization-Polyhedra and efficiency, Springer-Verlag, 2003.
4) M. Conforti, G. Cornuejols and G. Zambell, Integer Programming, Springer, 2014.
5) R. K. Ahuja, T.L. Manganti and J.B. Orlin, Network flows: Theory applications and Algorithms, Prentice Hall, 1993.
6) L. R. Foulds, Combinatorial Optimization for Undergraduates, UTM, Springer Verlag, 1984.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	45
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	25

PMA328 Stochastic Processes

L	T	P	Cr.
3	1	0	3.5

Course Objective: This course explanations and expositions of stochastic processes concepts which they need for their experiments and research. It also covers theoretical concepts pertaining to handling various stochastic modeling. This course provides classification and properties of stochastic processes, stationary processes, discrete and continuous time Markov chains and simple Markovian queueing models.

Course Outlines: Probability Review and Introduction to Stochastic Processes(SPs): Probability spaces, random variables and probability distributions, transforms and generating functions, convergence, Definition, examples and classification of random processes according to state space and parameter space.

Stationary Processes: Weakly stationary and strongly stationary processes, moving average and auto regressive processes.

Discrete-time Markov Chains (DTMCs): Transition probability matrix, Chapman-Kolmogorov equations; n-step transition and limiting probabilities, ergodicity, stationary distribution, random walk and gambler's ruin problem, applications of DTMCs.

Continuous-time Markov Chains (CTMCs): Kolmogorov differential equations for CTMCs, infinitesimal generator, Poisson and birth-death processes, stochastic Petri net, applications to queueing theory and communication networks.

Martingales: Conditional expectations, definition and examples of martingales, applications in finance.

Brownian Motion: Wiener process as a limit of random walk; process derived from Brownian motion, stochastic differential equation, stochastic integral equation, Ito formula, some important SDEs and their solutions, applications to finance.

Renewal Processes: Renewal function and its properties, renewal theorems, cost/rewards associated with renewals, Markov renewal and regenerative processes, non Markovian queues, applications of Markov regenerative processes.

Branching Processes: Definition and examples branching processes, probability generating function, mean and variance, Galton-Watson branching process, probability of extinction.

Course Learning Outcomes: The students will able to:

1. give examples and classification of random processes and stationary processes.
2. identify and analyze discrete-time Markov chains.
3. solve Kolmogorov differential equations for continuous-time Markov chains.
4. provide examples and applications of martingales.
5. give examples and application of renewal and branching processes.

Recommended Books:

1. J. Medhi, Stochastic Processes, 3rd Edition, New Age International, 2009.
2. S.M. Ross, Stochastic Processes, 2nd Edition, Wiley, 1996.
3. Liliana Blanco Castaneda, Viswanathan Arunachalam and S. Dharmaraja, Introduction to Probability and Stochastic Processes with Applications, Wiley, 2012
4. S. E. Shreve, Stochastic Calculus for Finance, Vol. I & Vol. II, Springer, 2004.

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Evaluation Scheme:

Sr. No.	Evaluation Elements	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20

PMA329 Advanced Numerical Optimization Techniques

L	T	P	Cr
3	1	0	3.5

Introduction: Review of the basic concepts of convex functions and Linear programming theory and KKT conditions.

Unconstrained optimization methods: Line search, trust region methods, gradient descent, conjugate gradient, Newton and Quasi-Newton methods, Davidon-Fletcher-Powell (DFP) method, least square problems

Constrained Optimization methods: Frank and Wolfe's method, Rosen's gradient projection method, penalty function method, barrier function method and interior point method

Semi-definite programming: Formulation of semi-definite programming problems and applications. Formulations of dual problems and duality theorems

Nonlinear programming techniques: Separable programming, Linear fractional programming and Complementary pivoting algorithm.

Course learning outcomes: Upon completion of this course, the student will be able to:

1) use various techniques to solve unconstrained optimization problems.
2) solve constrained optimization problem by using Newton method and its variants.
3) solve semi-definite programming problem
4) apply vertex search algorithms to nonlinear programming problems.

Recommended Books:

1) Chandra, S., Jayadeva, Mehra, A., Numerical Optimization and Applications, Narosa Publishing House, 2013.
2) Cottle, R. W., and Thapa, M.N., Linear and nonlinear optimization, Springer, 2017.
3) Bazaraa, M.S., Sherali, H.D., Shetty, C.M., Nonlinear Programming: Theory and Algorithms, John Wiley and Sons, 1993.
4) Nocedal, J., and Wright, S., Numerical Optimization, Springer series in Operations research and Financial engineering, 2006.
5) Ruszczynski, A., Nonlinear Optimization, Princeton University Press, 2006.

Sr. No.	Evaluation Scheme	Weight (%)
1.	MST	30
2.	EST	50
3.	Sessionals (May include assignments/quizzes/Lab Evaluation)	20