Department of Mathematics
Central University of Tamil Nadu, Thiruvarur

Course Structure for Integrated M.Sc. Mathematics

(The syllabus finalized in the BoS meeting held on 04.03.2022)

Semester	Course code	Course title	Type	Credits
I	MAT111	Mathematics I	Core	4
I	–	*Physics 1**	Core	5
I	–	*Chemistry 1**	Core	5
I	–	*English 1**	AECC	3
I	–	*AECC 1**	AECC	2
II	MAT121	Mathematics II	Core	4
II	–	*Physics 2**	Core	5
II	–	*Chemistry 2**	Core	5
II	–	*English 2**	AECC	3
II	–	*AECC 2**	AECC	2
III	MAT211	Mathematics III	Core	4
III	MAT212	Scientific Computing Lab I	Core	2
III	–	*Physics 3**	Core	5
III	–	*Chemistry 3**	Core	5
III	–	*II Language 1**	AECC	3
III	–	*AECC 3**	AECC	2
IV	MAT221	Probability and Statistics	Core	4
IV	MAT222	Scientific Computing Lab II	Core	2
IV	–	*Physics 4**	Core	5
IV	–	*Chemistry 4**	Core	5
IV	–	*II Language 2**	AECC	3
IV	–	*AECC 4**	AECC	2
V	MAT311	Algebra I	Core/DSE**	4
V	MAT312	Analysis I	Core/DSE**	4
V	MAT313	Ordinary Differential equations	Core/DSE**	4
V	MAT314	Linear Programming	Core/DSE**	4
V	MAT315	Number theory	Core/DSE**	4
VI	MAT321	Algebra II	Core/DSE**	4
VI	MAT322	Elementary Complex Analysis	Core/DSE**	4
VI	MAT323	Basic Graph Theory	Core/DSE**	4
VI	MAT324	Numerical analysis I	SEC	2
VI	MAT325	Numerical analysis - Lab	SEC	2
VI	MAT326	Numerical analysis II	SEC	2
VI	MAT327	LaTeX Hands-on-training (Lab)	SEC	2

Semester	Course code	Course title	Type	Credits
VII	MAT411	Analysis II	Core	5
VII	MAT412	Linear Algebra	Core	5
VII	MAT413	Probability theory	Core	5
VII	–	Elective 1*	Elective	4
VII	–	Elective 2*	Elective	4
VIII	MAT421	Measure and Integration	Core	5
VIII	MAT422	Topology	Core	5
VIII	MAT423	Partial Differential Equations	Core	5
VIII	–	Elective 3*	Elective	4
IX	MAT511	Advanced Complex Analysis	Core	5
IX	MAT512	Functional Analysis	Core	5
IX	MAT51R	Reading course*	Elective	2
X	–	Elective 4*	Elective	5
X	–	Elective 5*	Elective	5
X	MAT52P	Project	Elective	12

* The course titles and course codes will be given based on the choice.
** For Int M.Sc. programme, types of these papers will be Core. For B.Sc. degree by exit option, type of these papers will be considered as DSE.

Credits/Programmes	**B.Sc.**	**Int M.Sc.**	**Core**	**Elective**	**AECC**	**SEC**
Range of credits by CBCS/UGC	*Min 120*	*Min 196*	*124 - 132*	*36 - 48*	*20*	*4 - 8*
Actual credits	120	196	132	36	20	8

List of elective courses.

Sl.No.	Course code	Course title	Credits
1	MAT01E	Computational Mathematics	3+2
2	MAT02E	Mathematical Methods	4
3	MAT03E	Fluid Dynamics	4
4	MAT04E	Transformation Groups	4
5	MAT05E	Design & Analysis of Algorithms	5
6	MAT06E	Number Systems	4
7	MAT07E	Nonlinear Programming	4
8	MAT08E	Introduction to Lie Algebras	5
9	MAT09E	Algebraic Number Theory	4
10	MAT10E	Non-linear Partial Differential Equations	5
11	MAT11E	Advanced Partial Differential Equations	5
12	MAT12E	Differential Geometry	4
13	MAT13E	Delay Differential equations	4
14	MAT14E	Foundations of Geometry	4
15	MAT15E	Commutative algebra	5
16	MAT16E	Discrete Mathematics	5
17	MAT17E	Advanced graph theory	4
18	MAT18E	Hyperbolic Geometry	4
19	MAT19E	Topics in Graph Theory	5
20	MAT20E	Mechanics	4

Generic electives.

Sl.No.	Course code	Course title	Credits
1	MAT01G	Python for Sciences	4
2	MAT02G	Game theory	4
3	MAT03G	History of Mathematics	3

Value added course(s)

Sl.No.	Course code	Course title	Credits
1	MATVA1	Advanced LaTeX	2

Semester I

Subject Code: MAT111 **Credits: 4**

Mathematics I

0. Review of Systems of linear equations as matrix equations, row-reduced echelon matrices, row-rank.

1. Inverse of a Matrix. Equivalence of row and column ranks. Equivalence and canonical form. Determinants. Eigenvalues, Eigenvectors, and the characteristic equation of a matrix. Cayley-Hamilton theorem and its applications.

2. (Review of differential calculus), related rate problems, implicit differentiation, tangent of a curve (given in parametric form and in implicit form), motion on a Straight Line, local extremums, Increasing, Decreasing Functions.

3. Limit of a function motivation and examples, L'Hospital's rule, problems on limits, convergent sequences and their properties, bounded, Cauchy, monotonic sequences (Theorems, proofs, and problems on sequences); Convergent series, Tests for convergence of series (problems).

4. Higher order derivatives, Taylor's series expansion of $\sin x, \cos x, e^x, \log(1+x), (1+x)^m$ (with m is a negative integer or a rational number), Leibnitz rule and its applications to problems of type $e^{ax+b}\sin x$, $e^{ax+b}\cos x$, $(ax+b)^n \sin x$, and $(ax+b)^n \cos x$, convex and concave functions, curve tracing.

5. (Review of Integral Calculus: Area Under Curves, Applications of integrals to find Area, Reduction formulae for powers of trigonometric functions.) Gamma function and Beta function, relation between beta and gamma integrals.

References.

1. G.B. Thomas and R.L. Finney, Calculus and Analytic Geometry, Ninth International Edition, Addison Wesley, 2002.

2. E. Kreyszig, Advanced Engineering Mathematics, Eighth Edition, John Wiley & Sons, Singapore, 2006.

3. G.F. Simmons, Calculus with analytic geometry, Second Edition, The McGraw-Hill Companies, Inc., 1996.

Semester II

Subject Code: MAT121 **Credits: 4**

Mathematics II

1. Vector Spaces and its properties; Examples; Subspaces; Smallest Subspace containing a given subset; Span and Linear Independence; Bases; Dimension.

2. Differentiability, total differential, chain rule. Directional derivative, gradient of a scalar field, geometrical meaning, tangent plane, Hessian matrix, extreme values and saddle point for function of two variables.

3. Divergence and curl of a vector field, solenoidal field, irrotational field and conservative field, scalar and vector potentials, Laplacian of a scalar field, standard identities involving curl, divergence, gradient and Laplacian operators.

4. Surface Area and Volumes of Surface of Revolution, Differentiation under integral sign by Leibnitz rule, Double integrals, Change of order of integration, Double integrals in polar form, Jacobian determinant, Change of variables.

5. Triple integrals in rectangular, cylindrical and spherical coordinates, Verification of Gauss, Green and Stokes theorems.

References.

1. K. Hoffman and R. Kunze, Linear Algebra, Second edition, Prentice Hall of India, 2003.

2. G.B. Thomas and R.L. Finney, Calculus and Analytic Geometry, Ninth Edition, Pearson, Noida, 2019.

3. E. Kreyszig, Advanced Engineering Mathematics, 8th Edition, John Wiley & Sons, Singapore, 2006.

Semester III

Subject Code: MAT211 **Credits: 4**

Mathematics III

0. Review: Formation of Ordinary Differential Equations (ODEs), separation of variables
1. *ODES - First order*. Exact equations, Integrating factors (Theory and problems), Orthogonal trajectories.
   Second order ODE with constant coefficients (Theory and problems): Homogeneous: Solution space. Non-homogeneous: Complimentary solution and particular solutions, method of variation of parameters.
2. Laplace transform: Laplace transforms of standard functions, properties of Laplace transforms, inverse Laplace transform and its properties. Dirac delta function, Convolution integral. Applications of Laplace transform in solving linear ODE with constant coefficients, ODEs with discontinuous right-hand sides, system of linear ODEs with constant coefficients.
3. *Partial differential equations (PDEs)*: Introduction, formation of PDEs, Theory and problems on First order PDEs: classification of integrals, Lagrange's method, Pfaffian differential equations, compatible system, Charpit's method, Jacobi's method. Linear PDEs with constant coefficients: Higher order.
4. Fourier Series, half range series, applications to boundary value problems - vibration of strings, one dimensional heat equation, steady state two dimensional heat equation.
5. Fourier transform and its properties, applications of Fourier transform to PDEs.

References.

1. E. Kreyszig, Advanced Engineering Mathematics, Ninth Edition, John Wiley and Sons, Singapore, 2006.
2. K.A. Stroud, Advanced Engineering Mathematics, Fourth Edition, Palgrave, London, 2003.
3. M. Braun, Differential Equations and their applications, Fourth Edition, Springer, 1993.
4. I.N. Sneddon, Elements of Partial Differential Equations, Dover, 2006.
5. T. Amaranath, An elementary course in partial differential equations, Narosa Publishing House, 2003.
6. T. Myint-U. L. Debnath, Linear Partial Differential Equations for Scientists and Engineers, Birkhäuser, Boston, 2014.

Subject Code: MAT212 **Credits:2**

Scientific Computing Lab I

0. (Review) Linux commands: File management and permissions; Using VI editor; Introducing a programming language, syntax, basic tools, simple programmes, etc.

1. Basic Tools: First Program file; Handling complex numbers; Functions and loops; Standard math functions; Conditionals; Python keywords and function names; Defining Names;

2. Lists in Python: Defining and accessing lists; Loops with lists; Range function; for loop with lists for sorting; Built-in sort functions; else class in loops; slicing lists; lists as stacks; using lists as queues; new lists from old;

3. Data types: Numeric Types; Tuples; Accepting tuple inputs; sorting iterables; the lambda function; Sets; Dictionaries;

4. Input and output: Output formatting; Format specifiers; align, sign, width, precision, type; File operations; Functions from Numpy and Scipy libraries.

5. Some math problems for practice (is not limited to the following):
   (a) Finding GCD of two or more integers;
   (b) Primality checking; Finding primes up to a given integer;
   (c) Plotting curves;
   (d) Area of a triangle;
   (e) Angle between vectors;
   (f) Convert a number in decimal to a given base n.
   (g) Transpose of a matrix; Product of two matrices;
   (h) Finding the mean; median; mode; standard deviation etc., of a given data;

References.

1. M. Lutz and D. Ascher, Learning Python: Powerful Object-Oriented Programming, Fourth edition, O'Reilly, 2009.

2. R. Thareja, Python Programming: Using Problem Solving Approach, Oxford HED, 2017.

3. H.P. Langtangen, A Primer on Scientific Programming with Python, Springer-Verlag, Berlin, 2016.

4. Y. Zhang, An Introduction to Python and Computer Programming, Springer, Singapore, 2015.

5. K.V. Namboothiri, Python for Mathematics Students, Version 2.1, March 2013. (https://drive.google.com/le/d/0B27RbnD0q6rgZk43akQ0MmRXNG8/view)

Semester IV

Subject Code: MAT221 **Credits: 4**

Probability and Statistics

1. Probability: Random experiment; Sample point, Event and Probability; Rules of Probability; Conditional Probability; Independence of Events; Bayes' Rule. Applications.

2. Discrete Random variables: Definition; sum and linear composite of random variables; Mean and variance; Bernoulli, Binomial, geometric and negative binomial distributions; hypergeometric distribution; Poisson distribution. Applications.

3. Continuous Random Variables: Definition; Uniform and exponential distributions; Normal distribution and its properties; Standard normal distribution; Transformation from a general normal distribution to standard normal; Checking for normality of data; Applications.

4. Point Estimation and Confidence Intervals: Point estimation of the population mean and standard deviation of a normal distribution; Estimation of proportion; Confidence intervals; Large sample methods; Applications.

5. Hypothesis Testing: simple and composite; Null and alternative; Test of Hypothesis; Type I and Type II errors; Level and power of a test; p-value; Tests for mean and standard deviation; Test for proportion; one tail or two tails. Applications.

References

1. A.D. Aczel, and J. Sounderpandian Complete Business Statistics, Seventh Edition, McGraw-Hill, Irwin, 2008.

2. S.C. Gupta, V.K. Kapoor, Fundamentals of Mathematical Statistics (A Modern Approach), Tenth Edition, Sultan Chand and Sons, 2000.

3. M.L. Samuels, and J.A. Witmer , Statistics for the life sciences, Third Edition, Prentice Hall, 2003.

4. H.E. Van Emden, Statistics for terrified Biologists, Blackwell Publishing, 2008.

5. R. Barlow, Statistics - A guide to the use of statistical methods in the Physical Sciences, Wiley, 1999.

Subject Code: MAT222 **Credits: 2**

Scientific Computing Lab II

0. Review of Python commands, Python variables, Symbolic Variables, First computations; Elementary functions and Usual constants; Auto completion; Simple plotting.

1. Symbolic Expressions and Simplification; Transforming expressions; Usual Mathematical functions; Assumptions and pitfalls; Explicit solving of Equations; Equation with no explicit solution; Sums; Limits; Sequences; Power Series Expansions; Series; Derivatives; Partial Derivatives; Integrals; Solving linear systems; Vector Computations; Matrix Computations; Reduction of a Square Matrix

2. Programming with Sage; Python language keywords; Sage Keywords; Special symbols in Sage and their uses; Function Calls; Algorithms - Loops; Approximation of Sequence Limits; Conditionals; Procedures and functions; Iterative and recursive methods; Input and Output

3. Lists and Other Data Structures; List creation and access; Global list operations; Main methods on lists; Examples of list manipulations; Character Strings; Shared or Duplicated Data Structures; Mutable and Immutable Data Structures; Finite sets; Dictionaries;

4. 2D Graphics - Graphical representation of a function; Parametric Curve; Curves in Polar Coordinates; Curve Defined by an implicit function; Data Plot; Displaying solutions of differential equations; Evolute of a curve; 3D Graphics

5. Statistics with SageMath: Basic functions - random, mean, median, mode, moving average, std, variance; C Int Stats - stats.IntList, min, max, plot, histogram, product, sum; Distributions - norm, uniform, expon, bernoulli, poisson; Statistical functions - stats.gmean, stats.hmean, stats.skew, stats.histogram2, stats.kurtosis, stats.linregress; Statistical model - linear fit - stats.glm

References.

1. P. Zimmermann et.al., Mathematical Computation with Sage, SIAM, Philadelphia, 2018. (http://sagebook.gforge.inria.fr/english.html)

2. R. A. Mezei, An Introduction to SAGE Programming: With Applications to SAGE Interacts for Numerical Methods, John Wiley & Sons, 2015.

3. G.A. Anastassiou, R.A. Mezei, Numerical Analysis Using Sage, Springer, 2015.

4. R. A. Beezer, A First Course in Linear Algebra, University Press of Florida, 2009.

5. A. Kumar & S. G. Lee, Linear Algebra with Sage, Kyobo Books, 2015. (http://matrix.skku.ac.kr/2015-Album/Big-Book-LinearAlgebra-Eng-2015.pdf)

6. https://docs.scipy.org/doc/scipy/reference/stats.html

Semester V

Subject Code: MAT311 **Credits: 4**

Algebra I

1. Groups: definition and examples: finite, infinite, abelian, cyclic groups; Subgroups, existence of smallest subgroups of a group G containing a subset $S \subset G$; order of an element; Cosets of subgroups; Lagrange's theorem.

2. Normal subgroups - properties, the subgroup of the form HK and $O(HK)$ - quotient groups, homomorphisms of groups, kernel, image, fundamental theorem of homomorphism.

3. Automorphisms, Cayley's theorem, permutation groups.

4. Rings, commutative ring, integral domain, division ring, field (definitions), finite integral domain is a field, ring homomorphism, ideals, quotient rings, maximal ideals & prime ideals and their characterizations, quotient field of an integral domain.

5. Euclidean rings, division algorithm, GCD and unique factorization theorem in an Euclidean ring, Principal Ideal domain and Unique factorization domain, Polynomial rings.

References.

1. I.N. Herstein, Topics in Algebra, Second Edition, John-Wiley & Sons, 1975.

2. J.B. Fraleigh, A First course in Abstract Algebra, 7th edtion, Pearson Education, 2003.

3. D.S. Dummit and R.M. Foote, Abstract Algebra, Third edition, Wiley, 2004.

4. M. Artin, Algebra, Prentice-Hall of India, 1994.

5. C. Lanski, Concepts in Abstract Algebra, American Math. Society, Indian Edtion, by Universities Press, 2010.

Subject Code: MAT312 **Credits: 4**

Analysis I

1. Ordered set, Ordered field, infimum and supremum, least upper bound property, Archimedian property in $\mathbb{R}$, $\mathbb{Q}$ is dense in $\mathbb{R}$, existence of n^{th}root of unity (without proof).

2. Metric space, interior point, limit point, open set, closed set, interior, closure, perfect set, Cantor set, compact set, Bolzano's theorem, Heine Borel theorem, connected set, characterization of connected subsets of $\mathbb{R}$.

3. Subsequential limits, limit infimum and limit supremum, and their properties, convergent series, examples, series of non-negative terms, the number e, Root test and ratio test, power series, summation by parts, absolute convergence, addition and multiplication of series, rearrangements of series, Riemann mapping theorem (without proof).

4. Limits of functions between metric spaces, continuous functions, uniformly continuous functions, examples of continuous but not uniformly continuous functions, continuity and compactness, continuity and connectedness, discontinuities, monotone functions, infinite limits and limit at infinity.

5. Differentiable functions, local extremums, mean-value theorems, continuity of derivatives, L'Hospital's rule, Derivatives of higher order and Taylor's theorem, derivatives of vector valued functions.

References.

1. W. Rudin, Principles of Mathematical Analysis, Wiley International Edition, 1985.

2. T. Apostol, Mathematical Analysis, Second Edition, Narosa Publishing House, 1985.

3. R.G. Bartle and D.R. Sherbert, Introduction to Real Analysis, Third Edition, Wiley International Student edition, 2001.

4. A. Kumar, S.Kumaresan, A Basic Course in Real Analysis, CRC Press, 2014.

5. K.A. Ross, Elementary Analysis: The theory of Calculus, Springer International Edition, Indian Reprint, New Delhi, 2004.

6. R.R. Goldberg, Methods of real analysis, Second Edition, John-Wiley & Sons, New York, 1976.

Subject Code: MAT313 **Credits: 4**

Ordinary Differential Equations

1. First order differential equations: Existence and uniqueness theorem, Picard's iteration (Theory and problems). Second order Linear equations with variable coefficients, Wronskian theory, Non-homogeneous equations: Method of variations of parameters (Theory and problems), Method of judicious guessing (or method of undetermined coefficients).

2. Series solution: Singular points, regular singular points - the method of Frobenius, Equal roots, and roots differing by an integer: Bessel equation, Legendre equation, Laguerre equation, Hermite equation, Chebschev equations. Higher order equations.

3. System of differential equations: The eigenvalue-eigenvector method of finding solutions, Complex roots, Equal roots, Fundamental matrix solutions, the non-homogeneous equations: variation of parameters, method of judicious guessing.

4. Qualitative theory: Stability of linear system of ODEs, Stability of equilibrium solutions, the phase-plane, qualitative properties of orbits, Phase portraits of linear systems.

5. Sturm-Liouville problems, orthogonality of characteristic functions, the expansion of a function in series of orthonormal functions.

References.

1. M. Braun, Differential Equations and their applications, Fourth Edition, Springer, 1993.

2. S.L. Ross, Differential Equation, Fourth Edition, John Wiley & Sons, 1984.

3. A.K. Nandakumaran, P.S. Datti and R.K. George, Ordinary Differential Equations: Principles and Applications, Cambridge University Press, 2017.

4. T. Myint-U, Ordinary Differential Equations, Elsevier, North-Holland, 1978.

5. G.F. Simmons, Differential Equations with Applications and Historical Notes, Tata Mc-Graw Hill, 1979.

6. G.F. Simmons & S.G. Krantz, Differential Equations: Theory, Technique, and Practice, Tata Mc-Graw Hill, 2012.

7. E.A. Coddington, An Introduction to Ordinary Differential Equations, Dover, 1961.

8. L. Perko, Differential Equations and Dynamical Systems, Third Edition, Springer, 2006.

9. M.W. Hirsch, S. Smale, R.L. Devaney, Differential Equations, Dynamical Systems, and an Introduction to Chaos, Third edition, Academic Press, 2013.

Subject Code: MAT314 **Credits: 4**

Linear Programming

1. The Linear programming problem. Problem formulation. - Graphical Method - Definitions of bounded, unbounded and optimal solutions, Linear programming in matrix notation. Definitions of Basic, non-basic variables - basic solutions - slack variables, surplus variables and optimal solution, Simplex method of solution of a linear programming problem, Big M-technique.

2. Two phase simplex method. Degeneracy and Cycling. Revised Simplex Method, Duality Theory Formulation of Dual Problem. Duality theorems. Primal Dual Method and Dual Simplex Method. Sensitivity Analysis.

3. Balanced and unbalanced Transportation problems. Feasible solution- Basic feasible solution - Optimum solution - degeneracy in a Transportation problem. - Mathematical formulation - North West Corner rule - Vogell's approximation method, Method of Matrix minima - algorithm of Optimality test.

4. Balanced and unbalanced assignment problems -restrictions on assignment problem - Mathematical formulation -formulation and solution of an assignment problem (Hungarian method) - degeneracy in an assignment problem.

5. Sequencing problem - n jobs through 2 machines - n jobs through 3 machines - two jobs through m machines - n jobs through m machines. Definition of network, event, activity, critical path, total float and free float - difference between CPM and PERT - Problems.

References.

1. K. Swarup, P.K. Gupta, Man Mohan, Operations Research, Ninth edition, Sultan Chand & Sons, Chennai, 2001.

2. S.I. Gauss, Linear Programming, Second Edition, McGraw-Hill Book Company, New York, 1964.

3. A. Ravindran, D.T. Phillips, and J.J. Solberg, Operation research: Principles and Practice, Second Edition, John Wiley & Sons, 1987.

4. F.S. Hillier and G.J. Lieberman, Introduction to Operations Research , McGraw-Hill, Eighth Edition, 2001.

Subject Code: MAT315 **Credits: 4**

Number Theory

1. Divisibility, greatest common divisor and its properties, Euclidean algorithm, primes, Unique factorization theorem. Mobius function μ and Euler's totient function φ, relation between μ and φ, product formula for φ, properties of φ.

2. Dirichlet product of arithmetical functions, Dirichlet inverses, and Mobius inversion formula, Mangoldt function and its properties, multiplicative functions and Dirichlet product, inverse of completely multiplicative function.

3. Liouville's function $\Lambda(n)$, divisor functions $d_\alpha(n)$, Generalized convolution, Generalized Mobius inversion formula, Bell series of arithmetic function, Bell series and Dirichlet product, Derivative of arithmetic function, Selberg identity.

4. Definition and basic properties of congruences, residue classes and complete residue system, linear congruences, reduced residue systems, Euler-Fermat theorem, Little Fermat theorem, Polynomial congruence modulo p, Lagrange's theorem, Applications of Lagrange's theorem, Wilson's theorem, Wolstenholme's theorem.

5. Simultaneous linear congruences, Chinese remainder theorem, Applications of Chinese remainder theorem, polynomial congruences with prime power moduli, Principle of cross classification and its applications.

References.

1. T. M. Apostal, Analytic Number Theory, Springer Verlag, New York, 1976.

2. I. Niven, H.S. Zukerman, H.L. Montgomery, An Introduction to Theory of Numbers, Fifth Edition, John Wiley & Sons inc., New York, 1991.

3. D. M Burton, Elementary Number Theory, Sixth Edition, McGraw-Hill, New York, 2007.

4. S.G. Telang, Number Theory, Tata McGraw-Hill, 2003.

Semester VI

Subject Code: MAT321 **Credits: 4**

Algebra II

1. Conjugacy classes, class equations, Cauchy's theorem for abelian groups, Sylow's theorem for abelian groups, Cauchy's theorem, number of conjugacy classes in S_n, conjugate of a subgroup.

2. Sylow's theorem, three parts of Sylow's theorem, applications of Sylow' theorem, Structure theorem for finite abelian groups (without proof).

3. Fields, Field extensions, finite extension, algebraic extension, roots of polynomials, splitting field.

4. More about roots, simple extension, splitting field of a polynomial, Galois theory, Galois group, fixed field, theorem on symmetric polynomials, normal extension,

5. Fundamental theorem of Galois theory, Solvable group, solvable by radicals, Abel's theorem.

References.

1. I.N. Herstein, Topics in Algebra, Second Edition, John-Wiley & Sons, 1975.

2. D.S. Dummit and R.M. Foote, Abstract Algebra, Third edition, Wiley, 2004.

3. N. Jacobson, Basic Algebra I, Second Edition, Dover, 2009.

4. M. Artin, Algebra, Prentice Hall India, 1996.

5. J. Rotman, Galois Theory, Springer, 1998.

Subject Code: MAT322 **Credits: 4**

Elementary Complex Analysis

1. (Quick Review: Complex numbers and geometrical representations - Cauchy-Schwarz Inequality - principal argument of a complex number -nth root of a complex number) - Sequences and series of complex numbers, limit and continuity of complex valued functions of a complex variable, Extended complex numbers and stereographic projection.

2. Complex and partial differentiability - Cauchy-Riemann equations -Harmonic function - Harmonic conjugate - Problems on finding harmonic conjugates, finding analytic functions from a given harmonic function as its real (or imaginary) part.

3. Radius of convergence of a Power series, differentiability and uniqueness of power series -problems on finding radius convergence of power series - Polynomial and rational functions, Lucas' theorem, existence of partial fraction expansion of rational functions - Linear fractional transforms / Mobius transforms - Mobius transform maps circles and lines to circles and lines - Cross ratios - Symmetric points with respect to circle or straight line.

4. Piece-wise smooth curve - Line Integrals and their properties - Cauchy's theorem (without proof)- Cauchy's integral formula - Evaluation of integrals using Cauchy's integral formula (problems only), Types of singularities, characterization of removable singularity - Taylor's theorem - Laurent series (without proof)- Zeros, poles and singularities-problems on expanding Laurent series - characterization of singularities using Laurent series.

5. Residue definition -Problems on finding residues of functions at isolated singularities - Cauchy's residue theorem (without proof) - Evaluation of integrals using Cauchy's residue theorem- Evaluation of real integrals (problems only) - Evaluating number of zeroes of polynomials using Rouche's theorem.

References.

1. J.W. Brown and R.V. Churchill, Complex Variable and Applications, McGraw Hill, 2008.

2. S. Ponnusamy, Foundations of Complex Analysis, Second edition, Narosa Publishing House, 2005.

3. B.P. Palka, An Introduction to Complex Function Theory, Springer, 1995.

Subject Code: MAT323 **Credits: 4**

Basic Graph theory

1. Graphs - Subgraphs - Isomorphism of graphs - Degrees of Vertices - Paths and Connectedness - Trees- Counting the Number of Spanning Trees - Cayley's Formula.

2. Vertex Cuts and Edge Cuts - Connectivity and Edge-connectivity - Blocks - Eulerian Graphs.

3. Hamilton graphs - Necessary conditions - Dirac's theorem - closure of a graph-A criterion for Hamilton graphs using closure of a graph-Chvatal's theorem.

4. Edge colourings - Vertex colourings - critical graph - properties of critical graphs - Chromatic polynomials.

5. Planar and Nonplanar Graphs - Euler's Formula and its Consequences - K_5 and $K_{3,3}$ are Nonplanar graphs - Dual of a Plane Graph - The Four Color Theorem (without proof) and the Heawood Five-Color Theorem - Kuratowski's Theorem (without proof).

References.

1. R. Balakrishnan and K. Ranganathan, A Textbook of Graph Theory, Second Edition, Springer, 2012.

2. J.A. Bondy and U.S.R. Murty, Graph Theory with Applications, North-Holland, 1982.

3. G. Chartrand, L. Lesniak and P. Zhang, Graphs and Digraphs, Fifth Edition, CRC press, 2011.

4. D.B. West, Introduction to Graph Theory, Second Edition, PHI Learning Private Ltd, New Delhi, 2011.

Subject Code: MAT324 **Credits: 2**

Numerical Analysis I

1. Algebraic and transcendental equations: Bisection method, Iteration method, Regula-Falsi method, Secant method, Newton-Raphson's method, Error analysis, Rate of convergence.

2. System of Equations: Linear system (Direct methods): Gauss elimination, Pivoting strategies, Vector and matrix norms, Error estimates and condition number, LU decomposition. Linear system (Iterative methods): Gauss-Jacobi and Gauss-Seidel - Convergence analysis; Eigenvalue problem: Power method - Jacobi for a real symmetric matrix.

3. Interpolation: Lagrange's interpolation - Error analysis - Newton's divided differences - Newton's finite difference interpolation - Optimal points for interpolation - Piecewise polynomial Interpolation: Piecewise linear and Spline interpolation.

References.

1. K.E. Atkinson, An Introduction to Numerical Analysis, Wiley, 1989

2. R.L. Burden, J.D.Faires, Numerical Analysis, Ninth Edition, Cengage Learning, 2011.

3. S.D. Conte, and C. de Boor, Elementary Numerical Analysis, Third Edition, McGraw-Hill Book Company, 1983.

4. B. Bradie., A Friendly Introduction to Numerical Analysis, First Edition, Pearson Education, New Delhi, 2007.

Subject Code: MAT325 **Credits: 2**

Numerical Analysis - Lab

Laboratory Assignments (not limited to):

1. Finding the roots of the Algebraic and Transcendental equations using Bisection method, Regula-Falsi method, Newton-Raphson method, Secant method and Iterative method
2. Solving the system of linear equations using Gauss elimination method, Gauss Jacobi method, Gauss-Seidal method and Gauss Jordan method
3. Determining the Eigenvalues and Eigenvectors of a Square matrix.
4. Finding the largest eigenvalue of a matrix by power method.
5. Implementing Numerical Integration using Trapezoidal rule.
6. Implementing Numerical Integration using Simpson 1/3 rule.
7. Implementing Numerical Integration Simpson 3/8 rule
8. Implementing Newton's Forward/Backward Interpolation formula
9. Implementing Gauss Forward/Backward Interpolation formula
10. Implementing Newton's Divided Difference formula
11. Implementing Langrange's Interpolation formula
12. Finding numerical solution of ordinary differential equations by Euler's method, Runge-Kutta method and Adams-Bashforth method

References.

1. A. Quarteroni, F. Saleri and P. Gervasio, Scientific computing with MATLAB and Octave, Springer, 2006.
2. S. L. Campbell, J.-P. Chancelier and R. Nikoukhah, Modeling and Simulation in Scilab/Scicos with ScicosLab 4.4, Springer, 2009.
3. S. Linge and H.P. Langtangen, Programming for Computations - MATLAB/Octave: A Gentle Introduction to Numerical Simulations with MATLAB/Octave, Springer Open, 2016.
4. J. Kiusalaas, Numerical methods in engineering with Python 3, Cambridge University Press, 2013.
5. R.A. Mezei, An introduction to SAGE programming with applications to SAGE interacts for Numerical Methods, John Wiley & Sons, 2016.
6. K.E. Atkinson, An Introduction to Numerical Analysis, Wiley, 1989.

Subject Code: MAT326 **Credits: 2**

Numerical Analysis II

1. Numerical differentiation and Integration: Numerical differentiation based on interpolation, finite differences. Numerical integration: Newton Cotes formulae, Gaussian quadrature, Trapezoidal and Simpson's rules, Error analysis. Quadrature rules for Multiple integrals.

2. Ordinary Differential Equations: Single-Step methods: Euler's method and Modified Euler's method, Taylor series method - Runge-Kutta method of fourth order - Multistep methods: Adams-Bashforth - Moulton methods - Stability analysis- Boundary value problems: Finite Difference method.

References.

1. K. Atkinson, W. Han, D. Stewart, Numerical Solution of Ordinary Differential Equations, John Wiley & Sons, 2009.

2. K.E. Atkinson, An Introduction to Numerical Analysis, Wiley, 1989

3. R.L. Burden, J.D.Faires, Numerical Analysis, Ninth Edition, Cengage Learning, 2011.

4. S.D. Conte, and C. de Boor, Elementary Numerical Analysis, Third Edition, McGraw-Hill Book Company, 1983.

5. B. Bradie., A Friendly Introduction to Numerical Analysis, First Edition, Pearson Education, New Delhi, 2007.

Subject Code: MAT327 **Credits: 2**

LaTeX- Hands-on-training (Lab)

1. Command names and arguments - environments and declarations - length - special characters - fine-tuning text.

2. Document class - page style - parts of the document - table of contents

3. Changing fonts - centering and indenting - lists - generalized lists -theorem-like declarations - tables.

4. Mathematical environments - main elements of math mode - mathematical symbols - additional elements - fine-tuning mathematics - user defined commands.

5. Processing parts of documents - In-text references - bibliographies - keyword index.

References.

1. H. Kopka and P.W. Daly, A Guide to LaTeX and electronic publishing, Fourth Edition, Addison-Wesley, 2004.

2. G. Grätzer, Math Into Latex, Third Edition, Birkhäuser Boston, 2000.

3. L. Lamport, A Document Preparation System, Second Edition, Addison-Wesley, 1994.

4. D.F. Griffiths and D.J. Higham, Learning LaTeX, SIAM, 1997.

Semester VII

Subject Code: MAT411 **Credits: 5**

Analysis II

1. Riemann integration, Riemann - Stieltjes integration, equivalence of Riemann integrablity, examples, properties of Riemann-Stieltjes integration, Differentiation and integration, total variation of rectifiable curves.

2. Point-wise and uniform convergence of sequence and series of functions, Examples to illustrate the disadvantages of point-wise convergence, Properties of uniform convergence.

3. Partial derivatives and total derivative of differentiable scalar valued (and vector valued) functions on $\mathbb{R}^n$, Chain rule, Mean-value theorem and applications, Higher order derivatives, interchanging order of derivatives; Taylor's theorem for scalar valued valued functions, Inverse mapping theorem, Implicit mapping theorem.

4. Multiple integrals, Properties of integrals, Existence of integrals, iterated integrals, change of variables.

5. Curl, Gradient, divergence, Line integrals, surface integrals, Proofs of theorems of Green, Gauss and Stokes.

References.

1. W. Rudin, Principles of Mathematical Analysis, Wiley International Edition, 1985.

2. T.M. Apostol, Calculus Vol.2, Multi-Variable Calculus and Linear Algebra with Applications to Differential Equations and Probability, Second Edition, John Wiley & Sons, 1969.

3. T. Apostol, Mathematical Analysis, Second Edition, Narosa Publishing House, 1985.

4. R.G. Bartle and D.R. Sherbert, Introduction to Real Analysis, Third Edition, Wiley International Student edition, 2001.

5. K.A. Ross, Elementary Analysis: The theory of Calculus, Springer International Edition, Indian Reprint, 2004.

Subject Code: MAT412 **Credits: 4**

Linear Algebra

0. *Recall.* Vector Spaces and its properties; Examples; Subspaces; Smallest Subspace containing a given subset; Span and Linear Independence; Bases; Dimension.

1. Linear Maps; Null spaces and Ranges; Rank-Nullity Theorem; Matrix of a Linear Map; Invertibility; Review of polynomials with complex and real coefficients; Eigenvalues and Eigenvectors; Existence of eigenvalue; Triangularization and Diagonalization of linear transformations; Invariant subspaces.

2. Inner-product spaces; Pythagorean Theorem; Triangle Inequality; Parallelogram Law; Orthonormal Basis - Gram-Schmidt process; Orthogonal Projections and its properties; Definition of adjoint operator and its properties.

3. Linear operators on inner-product spaces; Self-adjoint and Normal operators; Spectral Theorem.

4. Operators on complex vector spaces; Generalized eigenvectors; Characteristic polynomial and Cayley-Hamilton Theorem; Minimal polynomial;

5. Jordan Form; Rational Canonical Form.

References

1. S. Axler, Linear Algebra Done Right, Second edition, Springer, 1997.

2. S. Kumaresan, Linear Algebra - A Geometric Approach, Twelvth reprint, Prentice Hall of India, 2011.

3. G. Strang, Linear Algebra and its applications, 8th Indian reprint Indian edition, Cengage Learning, 2011.

4. S.H. Friedberg and A.J. Insel, L.E. Spence, Linear Algebra, Fourth edition, Prentice-Hall of India, 2003.

5. K. Hoffman and R. Kunze, Linear Algebra, Second edition, Prentice Hall of India, 2003.

Subject Code: MAT413 **Credits: 5**

Probability Theory

1. Random Experiments and Probability: Sample space; Sample points; Events; Axioms of Probability; Probability of union of events; Sample spaces with equally likely outcomes; Probability as a continuous set function.

2. Conditional Probability and independence of events: Motivation for conditional probability; Shrinking of sample space when it is known that a certain event occurred; Conditional probability; Independence of events; independent events and disjoint events; Bayes' Theorem and posterior probabilities.

3. Discrete Random Variables: Definition; Distribution; Examples; Probability mass function and distribution function; Properties of a distribution function; Expected value; Variance of a random variable; Poisson random variable as an approximation of Binomial random variable.

4. Continuous random variables: Probability density function and Distribution function; Examples; Expectation and variance of continuous random variables; Normal approximation of Binomial distribution; Exponential distribution; Gamma, Chi-square, Beta and F distributions; Weibull and Cauchy distributions; Chebychev's inequality and its applications.

5. Joint distribution of two or more random variables; Joint distribution functions; Examples; Covariance between two random variables; Independence of random variables; Uncorrelatedness and independence; pairwise independence and mutual independence; Sums of independent random variables; Marginal and Conditional distributions; Conditional distribution: discrete and continuous cases; Bivariate normal distributions, Weak law of Large Numbers; Statements of Central Limit Theorem.

References.

1. S. Ross, A first Course in Probability, Sixth Edition, Pearson Education, 2006.

2. A. Dasgupta, Fundamentals of Probability: A First Course, Springer, 2010.

3. W. Feller, An introduction to Probability Theory and its Applications, Volume 1, Second Edition, Wiley, 1969.

4. R.V. Hogg, J. McKean and A.T. Craig, Introduction to Mathematical Statistics, Pearson Education, sixth edition, 2005.

Semester VIII

Subject Code: MAT421 **Credits: 5**

Measure and Integration

0. *Recall.* Riemann integration and its properties.
1. Definition of Lebesgue outer measure of a subset of $\mathbb{R}$ and its properties - Definition of a Lebesgue measurable set - The sigma-algebra of Lebesgue measurable sets. Every interval is Lebesgue measurable - Cantor (ternary) set - The inner and outer regularity of Lebesgue measurable sets - Borel sigma algebra.
2. Lebesgue Measurable functions on $\mathbb{R}$ - $\liminf$ and $\limsup$ of measurable functions - simple functions - any non-negative measurable function is the limit of an increasing sequence of simple functions - Existence of non-measurable sets, Lebesgue integrals of simple functions, non-negative measurable functions, any real valued measurable function, complex valued functions on $\mathbb{R}$ and their properties.
3. Fatou's lemma, Monotone convergence theorem, Dominated and bounded convergence theorems, integral of series, Necessary and sufficient condition for Riemann integrability - Riemann integrability implies the Lebesgue integrability.
4. Abstract measure theory: σ-algebra $\mathscr{B}$ of subsets of a set X, measurable space, measure space, integral of measurable functions over abstract measure space. Signed measure, Hahn decomposition, Jordan decomposition, Lebesgue decomposition theorem - Radon-Nykodim theorem
5. L^p spaces, for $1 \leq p \leq \infty$-Holder's inequality, Minkowski's inequality - L^p spaces as metric spaces - completeness of L^p-spaces, for $1 \leq p \leq \infty$ - Product measure - monotone class and sigma-algebra- Fubini's Theorem.

References.

1. G. de Barra, Measure theory and integration, Wiley Eastern Ltd., 1981.
2. H.L. Royden and P. Fritzpatric, Real Analysis, Fourth Edition, Pearson Education, 2010.
3. C.D. Aliprantis and O. Burkinshaw, Principles of Real Analysis, Third Edition, Academic Press, 1998.
4. G.B. Folland, Real Analysis - Modern Techniques and their applications, Second Edition, Wiley,1999.
5. I.K. Rana, Measure theory and Integration, Second edition, Narosa Publishing, 2000.

Subject Code: MAT422 **Credits: 5**

Topology

1. Topological space definitions and examples, Basis and subbasis, order topology, continuous functions, product topology, subspace topology, closed sets, closures, limit points, cluster (accumulation) points, interior and boundary of a set, metric topology, quotient topology.

2. Connectedness, components, Locally connectedness, and path-connectedness and locally path-connectedness.

3. Compactness, tube lemma, compact subspaces of real line, characterization of compact metric spaces, locally compactness.

4. Countability axioms, T_1-spaces, Hausdorff spaces, regular spaces, completely regular spaces, Normal spaces, one-point compactification, Urysohn's lemma and Tietze extension theorem.

5. Urysohn Metrization Theorem, Tycknoff's theorem, Stone-Čech Compactification.

References.

1. J. R. Munkres, Topology, Second Edition,Prentice Hall of India, 2000.

2. G.F. Simmons, Introduction to Topology and Modern analysis, McGraw-Hill, 1963.

3. S. Kumaresan, Topology of Metric Spaces, Second Edition, Narosa Publishing, 2011.

4. K. D. Joshi, Introduction to General Topology, Second Edition, New Age International Publishers, 1983.

5. M.A. Armstong, Basic Topology, Springer International Edition, 2005.

6. S. Willard, General Topology, Dover Publications, 2004.

Subject Code: MAT423 **Credits: 5**

Partial Differential Equations

1. First order PDEs: Classification of PDEs into linear, semi-linear, quasilinear, and fully nonlinear equations. Well-posed problems in the sense of Hadamard. Geometrical Interpretation of a First-Order Equation. Solution of first order PDEs: Cauchy problem, Method of characteristics. Non-linear first order PDEs. Initial value problems.

2. Second order PDE: Classification of second order PDEs in to hyperbolic, elliptic and parabolic PDEs. Canonical forms.

3. Wave Equation : d'Alembert's formula, uniqueness and stability of solutions to the initial value problem for one dimensional wave equation. Parallelogram identity, domain of dependence, range of influence, finite speed of propagation. Method of spherical means. Hadamard's method of descent. Duhamel's principle for solutions of non-homogeneous wave equation. Uniqueness using energy method.

4. Laplace equation: Green's identities. Uniqueness of solutions to Dirichlet, Neumann, and mixed boundary value problems. Fundamental solutions. Mean value property. Properties of harmonic functions: Maximum principle and uniqueness, Regularity, Liouville's theorem. Green's function for Dirichlet boundary value problem on upper half-space and ball. Energy method: Uniqueness, Dirichlet principle.

5. Heat equation : Fundamental solution. Method of eigenfunction expansion for solutions. Cauchy problem for homogeneous heat equation, infinite speed of propagation. Duhamel's principle for non-homogeneous heat equation. Maximum principle and uniqueness. Energy method: Uniqueness, backward uniqueness

References.

1. L.C. Evans, Partial Differential Equations, AMS, Second Edition, 2010.

2. T. Amaranath, An elementary course in partial differential equations, Narosa Publishing House, 2003.

3. R. Mc Owen, Partial Differential Equations: Methods and Applications, Pearson Education, 2002.

4. F. John, Partial differential equations, Fourth Edition, Springer-verlag, New York, 1991.

5. Q. Han, A Basic Course in Partial Differential Equations, AMS, 2011.

6. T. Myint-U, and L. Debnath, Linear Partial Differential Equations for Scientists and Engineers, Fourth Edition, Birkhauser, 2007.

7. Y. Pinchover and J. Rubinstein, An Introduction to Partial Differential Equations, Cambridge University Press, 2005.

Semester IX

Subject Code: MAT511 **Credits: 5**

Advanced Complex Analysis

0. Quick review of complex derivative, partial derivative, C-R equations, power series.

1. Branch of a multivalued function and examples, Cauchy's theorem for rectangle, Rectangle theorem with exceptional points, exact differentiable form, Cauchy's theorem for disc, Winding number, Cauchy's theorem for disc with exceptional points, Cauchy's integral formula, Higher order derivatives.

2. Morera's theorem, Liouville's theorem, fundamental theorem of algebra, Removable singularities, Taylor's theorem, zeroes and poles, essential singularity, algebraic order of isolated singularity, local correspondence theorem, open mapping theorem, maximum modulus principle.

3. Simply connected region, Cauchy's theorem for simply connected region, homology, Cauchy's theorem for multiply connected region, Residues, Argument principle, Rouche's theorem, evaluation of definite integrals (theory with proof).

4. Harmonic function, mean-value property of harmonic function, Poisson's formula, Schwartz theorem, Reflection principle, Weierstrass theorem, Taylor's series and Laurent series.

5. Partial fractions, Mittag-Leffler theorem, expansion of $\frac{\pi}{\sin \pi z}$, infinite products, canonical products, Gamma function, infinite product expressions for $\pi \cot \pi z$ and $\sin \pi z$, Jensen's formula, Poisson-Jensen's formula.

References.

1. L.V. Ahlfors, Complex Analysis, Third edition, McGraw-Hill Inc., 1979.

2. J. Bak and D.J. Newmann, Complex analysis, Second edition, Springer Indian Edition (SIE), 2009.

3. H.A. Priestley, Complex analysis, Second edition, Oxford University Press, Indian Edition, 2006.

4. J.B. Conway, Functions of one complex variable, Second edition, Springer-Verlag, 1978.

5. T.W. Gamelin, Complex analysis, Springer, 2004.

6. R.E. Greene and S.G. Krantz, Function Theory of One Complex Variable, Third edition, American Mathematical Society, 2006.

Subject Code: MAT512 **Credits: 5**

Functional Analysis

1. Normed Linear spaces, Banach spaces, X is complete iff $\{x : \|x\| \leq 1\}$ is complete, direct sum of Banach spaces, quotient space, ℓ_p^n and ℓ_p spaces (including the proof of Holder's and Minkowski's inequalities), $\|\cdot\|_p \to \|\cdot\|_\infty$ as $p \to \infty$, the spaces of continuous bounded functions $C(X,\mathbb{R})$ and $C(X,\mathbb{C})$.

2. Bounded linear transformations, equivalences of continuity, norm of a bounded linear transformation and its properties, the space $\mathscr{B}(X,Y)$ bounded linear transformations, completeness of $\mathscr{B}(X,Y)$, equivalence of different norms on a linear space - Every linear transformation from a finite dimensional normed linear space is continuous - dual space (the space of continuous linear functionals) - examples: duals of ℓ^p and ℓ_n^p- Hahn-Banach extension theorem (for both real and complex cases) - applications of Hahn-Banach theorems.

3. Natural imbedding of X in X^{**} - reflexive spaces - ℓ_p^n are reflexive, weak topology on X^*, strong topology on X^*- a Banach space is reflexive iff its closed unit sphere is compact in the weak topology - weak*-topology on X^* - closed unit ball in a normed linear space is always compact Hausdorff in the weak*-topology, Open mapping theorem, projections on Banach spaces, direct sums and projections, closed graph theorem, conjugate of an operator and its properties.

4. Inner product spaces, Hilbert spaces, Cauchy-Schwarz inequality - ℓ_2^n and ℓ_2 spaces, parallelogram law - closed convex set has a unique vector of minimum norm - polarization identity - Pythogorean theorem - orthogonal complement and its properties- best approximation in a closed subspace - orthogonal complement - $H = M \oplus M^\perp$, for any closed subspace M - orthonormal sets - examples, Bessel's inequality, equivalences of orthonormal basis- Fourier series - Riezs representation theorem - Gram-Schmidt's orthogonalization process - Conjugate space H^*

5. Adjoint of an operator and its properties - self adjoint operator - positive operators and inequality on self adjoint operators - normal and unitary operators - projections - spectral theorem for finite dimensional Hilbert spaces.

References.

1. G.F. Simmons, Introduction to Topology and Modern analysis, McGraw-Hill, 1963.

2. B.V. Limaye, Functional Analysis, Third edition, New Age international, 2017.

3. B. Bollabas, Linear Analysis, an introductory course, Cambridge University Press, 1994.

4. E. Kreyzig, Introductory Functional Analysis with applications, Wiley Classics Library, 2001.

5. M. Thamban Nair, Functional Analysis: A First Course , Prentice-Hall of India, 2002.

6. K. Saxe, Beginning Functional Analysis, Springer, 2002.

Electives

Subject Code: MAT01E **Credits: 3+2**

Computational Mathematics

- FINITE DIFFERENCE METHOD

  1 Parabolic equations: Explicit and Crank-Nicolson Schemes for - weighted average approximation - derivative boundary conditions - Truncation errors - Consistency, Stability and convergence- Lax Equivalence theorem- eigenvalues of a common tridiagonal matrix - Gerischgorin's theorems - stability by matrix and Fourier-series method - A.D.I. method.

  2 Hyperbolic Equations: First order quasi-linear equations and characteristics - numerical integration along a characteristic - Lax-Wendroff explicit method - second order quasi - linear hyperbolic equation - characteristics - solution by the method of characteristics - Explicit method for linear hyperbolic equations.

  3 Elliptic Equations: Solution of Laplace and Poisson equations in a rectangular region using standard five point finite difference formula - five point finite difference formula with non uniform grid - Finite difference in Polar coordinate - Discretization error - Mixed Boundary value problems.

- FINITE ELEMENT METHODS

  4 Weak formulation of Boundary Value Problems, Ritz-Galerkin approximation, Error Estimates, Piecewise polynomial spaces, Finite Element Method, Relationship to Difference Methods, Local Estimates.

  5 Finite element methods for elliptic problems, error analysis for the finite element method, Galerkin methods for time-dependent problems, error estimates, two-dimensional problems.

- Laboratory Assignments (not limited to):

  1. Explicit and Crank-Nicholson schemes with prescribed and derivative boundary conditions
  2. ADI method for two space dimensional parabolic PDE
  3. Method of numerical integration along characteristics for first order hyperbolic PDE
  4. Lax-Wendroff method
  5. Finite difference method for Laplace and Poisson's equations
  6. Finite element method for Two point BVP
  7. Finite element method for one dimensional parabolic PDE
  8. Finite Element method for Poisson's equation.

References.

1. G.D. Smith, Numerical Solution of P.D.E., Oxford University Press, New York, 1995.
2. A.R. Mitchel and S.D.F. Griffiths, The Finite Difference Methods in Partial Differential Equations, John Wiley and sons, New York, 1980.
3. K.W. Morton, and D.F. Mayers, Numerical Solutions of Partial Differential Equations, Cambridge University Press, Cambridge, 2002.
4. S. Brenner and R. Scott, The Mathematical Theory of Finite Elements Methods, Springer-Verlag, New York 1994.
5. C. Johnson, Numerical Solutions of Partial Differential Equations by the Finite Element Method, Cambridge University Press, Cambridge 1987.

Subject Code: MAT02E **Credits: 4**

Mathematical Methods

1. Integral equation: Introduction- Types of Integral equations - Integral equations with separable kernels - Reduction to a system of algebraic equations, Fredholm alternative, an approximate method, Fredholm integral equations of the first kind, method of successive approximations - Iterative scheme, Volterra integral equation, some results about the resolvent kernel, classical Fredholm theory - Fredholm's method of solution - Fredholm's first, second, third theorems (without proof).

2. Applications of Integral Equations: Application to ordinary differential equation - Reduction of Initial value problems and boundary value problems to integral equations - Green's function Approach - Singular integral equations - Abel integral equation

3. Symmetric Kernels: Introduction, Fundamental Properties of Eigenvalues and Eigenfunctions for symmetric kernels, Solution of a symmetric integral equation, Rayleigh-Ritz Method. (if time permits)

4. Calculus of Variations: Functionals. Variation of a functional - Euler-Lagrange equation - Necessary and sufficient conditions for extrema - Functional dependent on higher-order derivatives, functional dependent on the function of several independent variables, variational problems in parametric form. Sufficient condition for weak/storing extremum.

5. Direct Methods in Variational Problems: Direct Methods, Euler's finite difference methods, The Ritz method, Kantorovich's method.

References.

1. I.M.Gelfand and S.V. Fomin, Calculus of Variations, Prentice Hall, New Jersey, 1963.

2. F.B. Hildebrand, Methods of Applied Mathematics, Dover, New York, 1992.

3. F.G. Tricomi, Integral Equations, Dover Publications, 1985

4. L. Elsgolts, Differential Equations and the Calculus of Variations, MIR Publishers, Moscow, 1970.

5. R. Weinstock, Calculus of Variations, with Applications to Physics and Engineering, McGraw-Hill, New York, 1952.

6. R.P.Kanwal, Linear Integral Equations: Theory & Technique, Second Edition, Birkhäuser, 2013.

Subject Code: MAT03E **Credits: 4**

Fluid Dynamics

1. KINEMATICS OF FLUIDS IN MOTION
   Real and ideal fluids. Coefficient of viscosity. Steady and unsteady flows. Isotropy. Orthogonal curvilinear coordinates. Velocity of a fluid particle. Material local and convective derivative. Acceleration. Stress. Rate of strain. Vorticity and vortex line. Stress analysis. Relation between stress and rate of strain, Streamline. Path lines. Streak lines. Velocity potential. Eulerian and Lagrangian forms of Equation of continuity. Boundary conditions and boundary surfaces.

2. EQUATIONS OF MOTION OF A FLUID
   Pressure at a point in a fluid. Euler's equations of Motion. Momentum equations in cylindrical and spherical polar coordinates. Conservative field of force. Flows involving axial symmetry. Equations of motion under impulsive forces. Potential theorems.

3. INVISCID FLOWS
   Energy equation. Cauchy's Integrals. Helmholtz equations. Bernoulli's equation and applications. Lagrange's hydro-dynamical equations. Bernoulli's theorem and applications. Torricelli's theorem. Trajectory of a free jet. Pitot tube. Venturi meter.

4. TWO DIMENSIONAL AND IRROTATIONAL MOTION
   Two-dimensional flows. Stream function. Complex potential. Irrotational and incompressible flow, Complex potential for standard two-dimensional flows. Cauchy Riemann equations in polar form. Magnitude of velocity. Sources and sinks in two dimensions. Problems. Kinetic energy of liquid. Theorem of Blasius. Complex potential due to source. Doublet in two dimensions. Milne-Thomson circle theorem. Flow and circulations. Stoke's theorem. Kelvin circulation theorem. Kinetic energy of infinite liquid. Kelvins minimum energy theorem. Permanence if irrotational motion. Vortex motion. Dynamical similarity. Boundary layer theory.

References.

1. G.K. Batchelor, An Introduction to Fluid Dynamics, Cambridge University Press, 1993.

2. F. Chorlton, Text book of Fluid Mechanics, CBS Publishers, New Delhi, 1985.

3. F. White, Viscous Fluid Flow, McGraw -Hill, 1991.

4. M.D. Raisinghania, Fluid Dynamics, S Chand, New Delhi, 2000.

5. L.M. Milne-Thomson, Theoretical Hydrodynamics, Dover Publications, 1996.

Subject Code: MAT04E **Credits: 4**

Transformation Groups

1. Revision of Group Theory: Homomorphism, Quotient group, Groups presented by generators and relations, Group actions and orbits.
2. Affine transformations, Isometries in $\mathbb{R}^2$, translation, rotation, reflection, and glide reflection.
3. Projective space, projective transformations, affine and projective coordinates.
4. Symmetries of Differential Equation: Ordinary differential equations, Change of variables, The Bernoulli equation, Point transformations, One-parameter groups, Symmetries of differential equations, Solving equations by symmetries.

References.

1. S.V. Duzhin and B.D. Chebotarevsky, Transformation Groups for beginners, AMS, 2004.
2. T. T. Dieck, Transformation Groups, Walter de Gruyter, 1987.
3. N.V. Efimov, Higher Geometry, Mir publications, 1980.

Subject Code: MAT05E **Credits: 5**

Design & Analysis of Algorithms

1. Introduction to Algorithms, examples, Recurrent relations and closed form solution, Tools and techniques for summation, Manipulation of sum, floor and ceiling functions, Finite and infinite calculus, Problem solving using the tools.

2. Number theory an applied perspective, Divisibility, Introduction to relations and functions, Mod and congruence relation, Application of congruence, Independent Residues.

3. Permutation, Permutation of Multi sets, Combination, Application of Permutation and combination, Combinatorial properties of permutations.

4. Design and analysis of algorithms with examples like Euclid algorithm etc..,

5. Sorting - Insertion sort - Divide and Conquer approach -Merge sort - Quick sort. Asymptotics and analysis. Complexity Theory. Polynomial time - Complexity classes - class P, NP, NPC - reducibility - NP Completeness problems.

6. Scientific computing with open source R.

References.

1. T.H. Cormen, C.E. Leiserson, R.L. Rivest, Introduction to Algorithms, Prentice Hall of India, New-Delhi, 2004.

2. S. Basse, Computer Algorithms: Introduction to Design and Analysis, Addison Wesley, 1993.

3. A. Levitin, Introduction to the Design and Analysis of Algorithms, Pearson Eduction Pvt. Ltd, New Delhi, 2003.

4. S. Sedgewick, Algorithms, Addison Wesley, 2011.

Subject Code: MAT06E **Credits: 4**

Number Systems

1. Axioms of set theory, Russell's paradox, Foundation axiom, ordered pair, relation, function, Peano's postulates and natural numbers, definition and properties of addition on $\mathbb{N}$, definition and properties of multiplication on $\mathbb{N}$, order relation on $\mathbb{N}$ and its properties. Equivalence of principle of induction and well ordering property on $\mathbb{N}$, finite and infinite sets, pigeon-hole principle, characterization of finite sets, Schörder-Bernstein theorem, countable sets and their properties.

2. Definition of integers as equivalence classes of pairs of natural numbers, addition, multiplication, order relation, subtraction and their properties on $\mathbb{Z}$, proof of the fact that $\mathbb{Z}$ is an integral domain, definition of rational numbers , operations on rational numbers and their properties, $\mathbb{Q}$ is an ordered field satisfying Archimedian property, justification for $\mathbb{Q}$ is not having least upper bound property, absolute value on $\mathbb{Q}$.

3. Dedekind's construction of real numbers through cuts, addition, multiplication, and order relation on $\mathbb{R}$, $\mathbb{R}$ is an ordered Archimedian field with least upper bound property.

4. Cantor's construction of real numbers through equivalence classes of Cauchy sequences of rational numbers, addition, multiplication, field structure, order relation, completeness of $\mathbb{R}$, least upper bound property of $\mathbb{R}$ in Cantor's construction of real numbers, uniqueness of real number system, decimal expansion of a real number, when do two different decimal expansion represent a same real number? When does a decimal expansion represent a rational number?

5. Uncountable set, properties of uncountable sets, $\mathbb{R}$ is equinumerous with every interval having at least two points, $\mathbb{R}$ is equinumerous with $\mathbb{R}^n$, definition of cardinality, arithmetic on cardinalities, Aleph naught, aleph and their arithmetic, [ordinals, equivalence of axiom of choice (if time permits)]

References.

1. A. G. Hamilton, Numbers, Sets and Axioms: The Apparatus of Mathematics, Cambridge University Press, Cambridge, 1983.

2. E. Hewitt and K. Stromberg, Real and Abstract Analysis, Springer, New York , 1975.

3. E. Kamke, Theory of Sets, Dover Publications Inc., New York, 1950.

4. W. Rudin, Principles of Mathematical Analysis, McGraw-Hill Inc., New York, 1976.

Subject Code: MAT07E **Credits: 4**

Nonlinear Programming

1. Introduction to Optimization problems.(real life examples, constrained and unconstrained, convex and non-convex etc.,) Convex sets, convex hull, Caratheodory's theorem, Separation theorem and Farka's lemma. (Standard fixed point theorems without proof after teaching Farka's lemma).

2. Convex functions, first and second derivative convexity characterizations, Euclidean(metric) projection on a convex set. Necessary and sufficient conditions for local and global optimality of a feasible point, Weierstrass Theorem.

3. Definition of descent direction and a sufficient condition for descent direction. Optimality conditions: Definitions of normal cone, cone of feasible directions and tangent cone. Relationship between these cones. Optimality conditions based on these cones.

4. Fritz John optimality conditions and KKT optimality conditions. Different constraint qualifications(Abadie's CQ, Mangasarian-Fromovitz CQ, Slater CQ, Linear independence CQ) and their relationship with KKT optimality conditions.

5. Lagrangian Duality: Lagrangian dual problem, Examples to find the dual of a linear as well as nonlinear programming problems, Lagrange multipliers and its relation to global optimality. Convexity of dual problem. Duality gap and existence of Lagrange multipliers, Global optimality conditions in the absence of duality gap. Saddle point and global optimality. Weak and strong duality theorems for convex programs.

References.

1. O. Mangasarian, Nonlinear programming, McGraw-Hill Inc., 1969.

2. M.S. Bazaraa, H.D. Sherali and C.M. Shetty, Nonlinear programming, Wiley-Blackwell, 2006

3. N. Andreasson, A. Evgrafov and M. Patriksson, An Introduction to Continuous optimization, Springer, 2013.

Subject Code: MAT08E **Credits: 5**

Introduction to Lie Algebras

1. Review of the following: exponential and logarithmic functions of real and complex variables; inverse function theorem; triangularizability, diagonalizability and simultaneous diagonalizability of matrices; Jordan Canonical Form; topology: Hausdorff topology, continuity, compactness and connectedness; Groups: Normal groups, homomorphism between groups, nilpotent and solvable groups; total derivatives and chain rule.

2. Topological Groups; The group $GL(n,\mathbb{R})$; Examples of subgroups of $GL(n,\mathbb{R})$; Polar decomposition in $GL(n,\mathbb{R})$; The orthogonal group; Gram decomposition.

3. Exponential and Logarithm of a matrix; total derivative of the exponential.

4. Linear Lie Groups: One parameter semigroups and subgroups; Lie algebra of a linear Lie group; Linear Lie groups as submanifolds; Campbell-Hausdorff formula.

5. Lie algebras: Definitions and examples; nilpotent and solvable Lie algebras; semi-simple Lie algebras.

References.

1. J. Faraut, Analysis on Lie Groups, Cambridge Studies in Advanced Mathematics, Cambridge University Press, Cambridge, 2008.

2. B. Hall, Lie Groups, Lie Algebras, and Representations, Springer International Publishing, Switzerland, 2015.

3. A. Baker, Matrix Groups: An Introduction to Lie Group Theory, Springer-Verlag, London, UK, 2002.

4. N. J. Higham, Functions of Matrices, SIAM, Philadelphia, 2008.

Subject Code: MAT09E **Credits: 4**

Algebraic Number Theory

1. Introduction: A quick review on concepts like Integral domain, prime ideal, maximal ideal, prime number theorem(without proof), various estimates on $\pi(x)$, module theory and finitely generated module theory.

2. Number fields: Algebraic numbers, Algebraic integers, transcendental numbers, Algebraic Number Fields, Liouville's Theorem, finite extension of $\mathbb{Q}$, Dedekind domain, primitive element theorem.

3. Primitive roots, semi-primitive roots, Sophie Germain prime, Gauss's conjecture, Artin's generalized conjecture, various estimates around the conjecture.

4. abc conjecture, non-wieferich primes, estimates on the number of primes $p \le x$ such that $2^{p-1} \not\equiv 1 \mod p^2$, Fermat's last theorem, Erdős' conjecture on square full natural numbers, Connecting these conjectures with Fermat's last theorem

5. Analytic methods, The Riemann zeta function, Dedekind Zeta Function, Zeta Functions of Quadratic Fields.

References.

1. D. Burton, Elementary Number Theory, 7th ed. Tata McGraw-Hill, 2012.

2. G. H. Hardy and E. M. Wright, An Introduction to the Theory of Numbers, Clarendon Press, Oxford, Fifth edition, 1979.

3. J. Stopple, A primer of analytic number theory: from Pythagoras to Riemann, Cambridge University Press, 2003

4. R. Gupta, M. Ram Murty, A remark on Artin's conjecture, Inventiones Mathematicae, vol. 78, pp. 127-130 (1984).

5. M.E. Harold *Fermat's Last Theorem: A Genetic Introduction to Algebraic Number Theory*, Graduate Texts in Mathematics, Springer, 2000.

Subject Code: MAT10E **Credits: 5**

Non-linear Partial Differential Equations

1. Nonlinear first-order PDEs: complete integral, new solutions from envelopes; characteristics.

2. Introduction to Hamilton-Jacobi equations: calculus of variations: First variation, Euler-Lagrange Equation, second variation, Hamilton's ODE, Legendre transform, Hopf-Lax formula, weak solutions, uniqueness.

3. Introduction to Conservation laws: shocks, entropy condition, Lax-Oleinik formula, weak solutions, uniqueness, Riemann's problem, long time behaviour.

4. Representation of solutions: separation of variables; similarity of solutions; transform methods: Fourier, Laplace.

5. Converting nonlinear PDE into ODE: Hopf-Cole transform, Asymptotics; Power series: non-characteristic surfaces, real analytic functions, Cauchy-Kovalevskaya theorem.

References.

1. L.C. Evans, Partial Differential Equations, AMS, Second Edition, 2010.

2. F. John, Partial differential equations, Fourth Edition, Springer, 1991.

3. R. Mc Owen, Partial Differential Equations: Methods and Applications, Pearson Education, 2002.

4. J.D. Logan, Applied Partial Differential Equations, Second Edition, Springer, 2004.

5. T. Myint-U, L. Debnath, Linear Partial Differential Equations for Scientists and Engineers, Fourth Edition, Birkhauser, 2007.

Subject Code: MAT11E **Credits: 5**

Advanced Partial Differential Equations

1. Elliptic Equation: Weak Solution, Lax-Milgram Theorem, Energy estimates, Regularity, Maximum principles.
2. Parabolic Equation: Weak Solution, Existence and uniqueness, Regularity, Maximum principles .
3. Hyperbolic Equation: Weak Solution, Existence and uniqueness, Regularity, Propagation of disturbances.
4. Calculus of variation: Basic ideas, First variation, Euler-Lagrange equation, Second variation, Systems: Null Lagrangians, Brouwer's fixed point theorem.
5. Existence of Minimizers: coercivity, lower semi-continuity, convexity, weak solutions of Euler-Lagrange equations, systems.

References.

1. L.C. Evans, Partial Differential Equations, Second Edition, AMS, Providence, 2010.
2. S. Salsa, Partial Differential Equations in Action: From Modelling to Theory, Springer, New Delhi, 2008.
3. S. Kesavan, Topics in Functional Analysis and Applications, New Age International, New Delhi, 2008.
4. H. Brezis, Functional Analysis, Sobolev Spaces and PDEs, Springer, New York, 2011.

Subject Code: MAT12E **Credits: 4**

Differential Geometry

1. Plane curves and Space curves- Frenet-Serret Formulae. Global properties of curves- Simple closed curves, The isoperimetric inequality, The Four Vertex theorem.

2. Surfaces in three dimensions- Smooth surfaces, Tangents, Normals and Orientability, Quadric surfaces.

3. The First Fundamental form- The lengths of curves on surfaces, Isometries of surfaces, Conformal mappings of surfaces, Surface area, Equiareal Maps and a theorem of Archimedes.

4. Curvature of surfaces- The Second Fundamental form, The Curvature of curves on a surface, Normal and Principal Curvatures.

5. Gaussian Curvature and The Gauss' Map - The Gaussian and The mean Curvatures, The Pseudo sphere, Flat surfaces, Surfaces of Constant Mean Curvature, Gaussian Curvature of Compact surfaces, The Gauss' Map.

References.

1. A. N. Pressley, Elementary Differential Geometry, Springer, 2010.

2. T. J. Willmore, An Introduction to Differential Geometry, Oxford University Press, 1997.

3. D. Somasundaram, Differential Geometry: A First Course, Narosa, 2005.

Subject Code: MAT13E **Credits: 4**

Delay Differential Equations

1. Review of system of ODEs, Solution of nonlinear system as given by groups of operators,. stability and asymptotic stability.

2. Solution of Parabolic/hyperbolic equations as semi-groups / groups. Backward Euler method as a motivation for Hille-Yoshida theorem without proof, Existence for DDEs.

3. Models involving DDEs: Population Model, Predator Model with Delay, Logistics Equations, Pantograph Equations.

4. Asymptotic stability of linear DDEs, Spectral Theorem for compact linear maps, Compact semi-groups, Growth Bounds.

References.

1. J. Hale, Theory of Functional Differential Equations,Springer-Verlag, New York, 1997.

2. V. J. Arnold, Ordinary Differential Equations,Springer-Verlag, Berlin, 1982.

3. S. Kesavan, Topics in Functional Analysis and Applications, John Wiley & Sons, 1989.

Subject Code: MAT14E **Credits: 4**

Foundations of Geometry

1. The elements of geometry and the five groups of axioms, Group I: Axioms of connection Axioms of Order, Consequences of the axioms of connection and order, Axiom of Parallels (Euclid's axiom), Axioms of congruence, Consequences of the axioms of congruence, Axiom of Continuity (Archimedes's axiom).

2. Compatibility of the axioms, Independence of the axioms of parallels. Non-euclidean geometry, Independence of the axioms of congruence, Independence of the axiom of continuity. Non-archimedean geometry.

3. Complex number-systems, Demonstration of Pascal's theorem, An algebra of segments, based upon Pascal's theorem, Proportion and the theorems of similitude, Equations of straight lines and of planes.

4. Equal area and equal content of polygons, Parallelograms and triangles having equal bases and equal altitudes, The measure of area of triangles and polygons, Equality of content and the measure of area.

5. Desargues's Theorem, its demonstrations and applications.

References.

1. D. Hilbert, The Foundations of Geometry, MJP Publishers, 1902.

2. S. Kumaresan and G. Santhanam, An Expedition to Geometry, Hindustan Book Agency, 2011.

3. N.V. Efimov, Higher Geometry, Mir publications, 1980.

Subject Code: MAT15E **Credits: 5**

Commutative Algebra

1. Commutative ring with unity, Zero-divisors, Nilpotent elements, Nilradical Jacobson radical, Modules, Module homomorphism,.
2. Submodules, Quotient modules, Operations on submodules, Direct sum, Finitely Generated modules, Nakayama's lemma, Exact sequences.
3. Rings and Modules of Fractions, local properties.
4. Chain Conditions, Noetherian A-module and its characterization, Artinian A-modules and its characterization.
5. Noetherian rings, Hilbert's Basis Theorem, Artinian rings.

References.

1. M.F. Atiyah and I.G. MacDonald, Introduction to Commutative Algebra, Addison- Wesley, Reading (1969).
2. N.S. Gopala Krishnan, Commutative Algebra, Second Edition, University Press, 2015.
3. D.S. Dummit and R.M. Foote, Abstract Algebra, Third edition, Wiley, 2004.

Subject Code: MAT16E **Credits: 4 or 5**

Discrete Mathematics

1. Mathematical induction - Strong induction and well ordering principle, Recurrence Relations and Generating Functions, Some number sequences, Linear homogeneous recurrence relations, Non-homogeneous recurrence relations, Generating functions, Recurrences and generating functions, Exponential generating functions.

2. Statements Symbolic Representation and Tautologies, Quantifiers, Predicates and validity, Prepositional Logic, Connectives, Truth table, Normal form, PCNF, PDNF.

3. Lattices as partially ordered sets, their properties, Lattices as Algebraic systems. Sub lattices, Direct products and Homomorphism, Some special lattices e.g. complete, Complemented and Distributive Lattices.

4. Boolean Algebras as Lattices, Various Boolean Identities, The switching Algebra. Example, Subalgebras, Direct Products and Homomorphism, Joint-irreducible elements, Atoms and Minterms, Boolean forms and their equivalence, Minterm Boolean forms, Sum of Products, Canonical forms, Minimization of Boolean functions, Applications of Boolean Algebra to Switching Theory (using AND, OR and NOT gates.) The Karnaugh method.

5. Finite state Machines and their Transition table diagrams, Equivalence of Finite State, Machines, Reduced Machines, Homomorphism, Finite automata, Acceptors, Non-deterministic, Finite Automata and equivalence of its power to that of deterministic Finite automata, Moore and Mealy Machines.

References.

1. J.P. Tremblay and R. Manohar, A First Course in Discrete Structures with Applications to Computer Science, McGraw Hill, 1987.

2. K.H. Rosen, Discrete Mathematics and its Applications, Seventh edition, McGraw Hill, 2011.

3. C.L. Liu, Elements of Discrete Mathematics, McGraw Hill, New York, 1978.

4. R.P. Grimaldi and B.V. Ramana, Discrete and Combinatorial Mathematics- An Applied Introduction, Pearson education, 2004.

5. T. Sengadir, Discrete Mathematics, Pearson Education India, 2009.

6. J.E. Hopcraft and J.D. Ullman, Introduction to Automata Theory, Languages and Computation, Second Edition, Addison Wesley, 2001.

Subject Code: MAT17E **Credits: 4**

Advanced Graph Theory

1. Matching-maximum matching-Berge theorem in maximum matching-Hall's theorem-Perfect matching-Tutte theorem.
2. Eulerian graphs and its characterization - Vizing's theorem in edge colourings - independent sets - Gallai's theorem - Ramsey theory.
3. Turan's theorem - Brook's theorem in vertex colourings - Hajo's conjecture - subdivision of graphs - Mycielski's construction for triangle free graphs.
4. Kuratowski's theorem - face colouring - characterization of face colouring - Tait colouring - nonhamiltonian planar graphs.
5. Directed graphs - existence of directed path - tournament - disconnected tournament - Moon theorem - Networks - Max-flow min-cut theorem.

References.

1. J.A. Bondy and U.S.R. Murty, Graph Theory with Applications, North-Holland, 1982.
2. G. Chartrand, L. Lesniak and P. Zhang, Graphs and Digraphs, Fifth Edition, CRC press, 2011.
3. D.B. West, Introduction to Graph Theory, Second Edition, PHI Learning Private Ltd, New Delhi, 2011.
4. R. Balakrishnan and K. Ranganathan, A Textbook of Graph Theory, Second Edition, Springer, 2012.

Subject Code: MAT18E **Credits: 4 or 5**

Hyperbolic Geometry

1. A model for the hyperbolic plane, Riemann sphere, Boundary at infinity of the upper half plane, the group of Mobius transformations Mob^+,the transitivity properties of Mob^+ and Cross ratio.

2. Classification of elements in Mob^+, matrix representations, reflections, conformality of elements of Mob^+, transitivity properties and the geometry of action of Mob^+.

3. Paths and elements of arc-length, the element of arc-length on $\mathbb{H}$, path metric spaces, arc-length to metric, formulae for the hyperbolic distance in $\mathbb{H}$ and isometries.

4. Metric properties of $(\mathbb{H}, d_{\mathbb{H}})$, Poincare disc model, a general construction, convexity and hyperbolic polygons.

5. Definition of hyperbolic area, Gauss-Bonnet formula with applications and trigonometry in the hyperbolic plane.

References.

1. J.W. Anderson, Hyperbolic geometry, second edition, Springer Undergraduate Mathematics Series, Springer-Verlag London, Ltd., London, 2005.

2. L. Keen and N. Lakic, Hyperbolic geometry from a local view point, London Mathematical Society Student Texts, Cambridge University Press, Cambridge, 2007.

Subject Code: MAT19E **Credits: 5**

Topics in Graph Theory

1. Triangulated Graphs (Chordal graph), Perfect Graphs, Characterization of Triangulated Graphs, Interval Graphs, Characterization of Interval graphs, Bipartite Graph B(G) of a Graph G, Circular Arc Graphs.

2. Domination in Graphs, bounds for the Domination Number, Bound for the Size m in terms of order n and Domination Number of G, Independent Domination Number and Irredundance, Domination number of Cartesian product graphs.

3. Vizing's Conjecture, 2-packing number of graphs, Decomposable graphs, Barcalkin-Greman (B-G) graphs, Domination number in Direct product graphs.

4. The Spectrum of a Graph, Examples of Spectrum of graphs (the Complete Graph Kn, the Cycle Cn), Coefficients of the Characteristic Polynomial, The Spectra of Regular Graphs, The Spectrum of the Complement of a Regular Graph, Line Graphs of Regular Graphs,the Complete Bipartite Graph $K_{p,q}$,

5. The Determinant of the adjacency Matrix of a Graph. The Energy of a Graph, Maximum Energy of k-Regular Graphs, Hyper energetic graphs, Energy of the Mycielskian of a Regular Graph.

References.

1. M.C. Golumbic, Algorithmic Graph Theory and Perfect Graphs. Academic Press, New York (1980).

2. T.A. McKee and F.R. McMorris, Topic in Intersection Graph Theory, Siam (1999).

3. R. Balakrishnan and K. Ranganathan, A text book of graph theory, Second edition, Springer (2012).

4. T.W. Haynes, S.T. Hedetniemi, P.J. Slater, Fundamentals of Domination in Graphs, Marcel Dekker, (1998).

5. T.W. Haynes, S.T. Hedetniemi, P.J. Slater, Domination in Graphs: Advanced Topics, Marcel Dekker, (1998).

6. D.M. Cvetković, M. Doob, M., H. Sachs, Spectra of Graphs-Theory and Application, third revised and enlarged edition. Johann Ambrosius Barth Verlag, (1995).

7. R.B. Bapat, Graph and Matrices, Second edition, Springer (2014).

8. A.E. Brouwer and W.H. Haemers, Spectra of Graphs, Springer (2012).

Subject Code: MAT20E **Credits: 4**

Mechanics

1. Mechanics of system of particles, Conservation theorems, conservative forces with examples, Constraints, Generalized co-ordinates. D'Alembert's principle, Lagrange's equations of motion. The forms of Lagrange's equations of motion for non conservative systems and partially conservative and partially non conservative systems. Kinetic energy as a homogeneous function of generalized velocities. Simple applications of the Lagranian formulation.

2. Cyclic co-ordinates and generalized momentum conservation Theorems, Calculus of variation, Euler Lagrange's equation, First integrals of Euler Lagrange's equation, the case of several dependent variables, Geodesics in a plane, the minimum surface of revolution, Brachistochrome problem. Isoperimetric problems, problems of maximum enclosed area.

3. The central force Problem - Reduction to the equivalent one body problem - The equation of moion and the first integrals - The equivalent one dimensional problem and classification of orbits - The virial theorem.

4. The differential equation of the orbit - the integrable power law potentials - conditions for closed orbit - Betrands theorem - The Kepler problem - The inverse square law of force - The motion in time in the Kepler problem - Lapace Runge Lenz vector.

5. Legendre transformation and the Hamilton equations of motion - cyclic coordinates and conservation theorem - Hamiltonian canonical equations of motion - derivation of Hamilton's equation from variational problem - The principle of least action - Jacobi's form of the least action principle.

References.

1. H. Goldstein, Classical Mechanics, Addison Wesley, 2001.

2. J.R. Taylor, Classical Mechanics, University Science Books, 2005.

3. T.W.B. Kibbie, F.H. Berkshire, Classical Mechanics, Imperial College Press, 2004.

Generic electives.

Subject Code: MAT01G **Credits: 4**

Python for Sciences

1. Introduction to linux commands and Vi Editor. Overview of installing and running Python. Python interpreter and IDLE, one more text editor GEANY. Simple commands to use Python as a calculator. Python 2.x vs Python 3.x. Variables, Statements, Getting input from the user, Functions, Modules, Running Python scripts from a Command Prompt. Strings, Concatenating strings, String representation; repr and str; input vs raw input. String Conversions; Methods find, join, lower, replace, split, strip, translate.

2. Lists, Tuples and Dictionaries; Lists Indexing, Slicing, Adding Sequences, Multiplication, Membership, Length, Minimum and Maximum. List operations and methods. Tuple operations. Creating and using Dictionaries; Dictionary operations, String formatting with Dictionaries, Dictionary methods.

3. Conditionals and Loops, Importing libraries, Assignment, Blocks, if statement, else and elif clauses, Nesting Blocks. While loops, for loops, Iteration, Breaking, else clauses in Loops. Printing and Output formatting. Format specifiers like align, sign, width, precision, type etc.,. File operations. Python shell error handling. Python exceptions: Try and Except function.

4. Various programs related to basic mathematics followed by Bisection Method, Newton Raphson Method, Regula Falsi Method, Trapezoidal Rule for integration, Simpsons 1/Third rule, Euler's method for ODE, RK method of ODE etc.,

5. Numpy and Scipy. Obtaining Numpy and Scipy libraries. Using Ipython. Numpy basics, Array creation, Printing Arrays, Basic operations, Universal functions, Indexing, Slicing and iterating. Changing shapes, stacking and splitting of arrays. Matplotlib and plotting. Scipy: scipy.special, scipy.integrate, scipy.optimize, scipy.interpolate, scipy.fftpack, scipy.linalg, scipy.stats.

References.

1. M. Dawson, Python programming for the absolute beginner, Third Edition, Course Technology, 2010.

2. K.V. Namboothiri, Python for Mathematics Students, Version 2.1, March 2013. (https://drive.google.com/open?id=0B27RbnD0q6rgZk43akQ0MmRXNG8).

3. Numpy tutorial - https://www.numpy.org/devdocs/user/quickstart.html

4. Beginner's Guide to matplotlib - https://matplotlib.org/users/beginner.html

5. Scipy tutorial - https://docs.scipy.org/doc/scipy/reference/tutorial/index.html

Subject Code: MAT02G **Credits: 4**

Game theory

1. Linear algebra: vectors, scalar product, matrices, linear inequalities, solution of linear equations, real vector spaces of finite dimensions, linear transformations.

2. Convex sets and polytopes, convex cones, extreme vectors and extreme solutions for linear inequalities.

3. Linear programming: Example problems, formulation of linear programming problem, primal and dual problem; simplex method and its variations for solving linear programming problems, duality theorem.

4. Two-person games: Examples, definitions and elementary theory; solutions of games, pure and mixed strategies, value of the game and optimal strategies; saddle point and minimax theorem; symmetric games; proof of fundamental theorem of games.

5. Solutions to matrix games: Relation between matrix games and linear programming; solving games by the simplex method; optimal strategies and solutions.

References.

1. D. Gale, The Theory of Linear Economic Models, McGraw Hill Book Company, London, 1990.

2. V. Chvatal, Linear Programming, W.H. Freeman and Company, 1983.

Subject Code: MAT03G **Credits: 3**

History of Mathematics

1. Development of Euclidean Geometry and Non-Euclidean Geometries.
2. The Stories of π, e and i.
3. Mathematics in Different Cultures, Sumeria, Egypt, Arab, (with special emphasize on Indian Astronomy).
4. Indian Mathematics - Study of Kanakkathikaram and Lilavathi, Ramanujan's contributions; Women Mathematicians - Emmy Noether.
5. Development of Modern Mathematics: Hilbert's 23 problems, Gödel's incompleteness theorem, Turing Machine.

References.

1. G.G. Joseph, The Crest of the Peacock, Third Edition, Princeton University Press, 2010.
2. E.T. Bell, Men of Mathematics, Touchstone; Reissue edition, 1986 .
3. G. Gamow, One, Two, Three...Infinity: Facts and Speculations of Science, Dover Publications Inc., 1989.

Value Added Course

Subject Code: MATVA1 **Credits: 2**

Advanced LaTeX

1. Recall basic LaTeX - invoking $\mathcal{AMS}$ LaTeX, standard features of $\mathcal{AMS}$ LaTeX , further $\mathcal{AMS}$ LaTeX packages, $\mathcal{AMS}$ fonts, other packages.

2. Preparation of research articles, project reports/thesis, slides, books, etc.

3. BibTeX program, creating, bibliographic data base, customizing bibliographic styles.

4. Picture environment in LaTeX , drawing packages, inserting images, graphics packages, adding color.

5. Structure of error messages, some sample errors, Warnings.

References.

1. H. Kopka and P.W. Daly, A Guide to LaTeX and electronic publishing, Fourth Edition, Addison-Wesley, 2004.

2. G. Grätzer, Math Into Latex, Third Edition, Birkhäuser Boston, 2000.

3. L. Lamport, A Document Preparation System, Second Edition, Addison-Wesley, 1994.

4. D.F. Griffiths and D.J. Higham, Learning LaTeX, SIAM, 1997.