MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR
DEPARTMENT OF MATHEMATICS
CURRICULUM WORKSHOP
8-9 May 2017

PROPOSED SYLLABUS
May 2017

M.Sc. in MATHEMATICS

I Semester

Course Number	Course Name	**Subject Area Code**	L	T	P	C	**CWS**	**MTE**	**PRE**	**ETE**	Total
MAT-811	Linear Algebra	**DC**	3	1	-	4	20	40	-	40	100
MAT-812	Real Analysis	**DC**	3	1	-	4	20	40	-	40	100
MAT-813	Discrete Mathematics	**DC**	3	1	-	4	20	40	-	40	100
MAT-814	Ordinary Differential Equations	**DC**	3	1	-	4	20	40	-	40	100
MAP-815	Computer Language	**DC**	2	-	4	4	20	20	20	40	100
HST-603	Comprehensive English Dynamics of Communication (for tech. eng. Communication skills)	**IDC**	2	1	-	3	40	30	-	30	100
	Total		16	5	4	23	140	210	20	230	600

II Semester

Course Number	Course Name	**Subject Area Code**	L	T	P	C	**CWS**	**MTE**	**PRE**	**ETE**	Total
MAT-821	Abstract Algebra	**DC**	3	1	-	4	20	40	-	40	100
MAT-822	Topology	**DC**	3	1	-	4	20	40	-	40	100
MAT-823	Partial Differential Equations	**DC**	3	1	-	4	20	40	-	40	100
MAT-824	Complex Analysis	**DC**	3	1	-	4	20	40	-	40	100
MAT-825	Multivariable Calculus	**DC**	3	1	-	4	20	40	-	40	100
	Total		15	5	-	20	100	200	-	200	500

III Semester

Course Number	Course Name	**Subject Area Code**	L	T	P	C	CWS	MTE	PRE	ETE	Total
MAT-831	Numerical Analysis	**DC**	3	1	-	4	20	40	-	40	100
MAT-832	Measure Theory	**DC**	3	1	-	4	20	40	-	40	100
MAT-833	Statistics & Probability Theory	**DC**	3	1	-	4	20	40	-	40	100
MAD-834	Project Stage I	**PRJ**	-	-	-	4	-	-	-	40	40
	Elective I	**DE**	3	1	-	4	20	40	-	40	100
	Elective II	**DE**	3	1	-	4	20	40	-	40	100
	Total		15	5	-	24	100	200	-	240	540

IV Semester

Course Number	Course Name	**Subject Area Code**	L	T	P	C	CWS	MTE	PRE	ETE	Total
MAT-841	Functional Analysis	**DC**	3	1	-	4	20	40	-	40	100
MAT-842	Integral Transforms	**DC**	3	1	-	4	20	40	-	40	100
	Elective III	**DE**	3	1	-	4	20	40	-	40	100
	Elective IV	**DE**	3	1	-	4	20	40	-	40	100
MAD-843	Project Stage II	**PRJ**	-	-	-	6	-	-	-	60	60
	Total	**-**	12	4	-	22	80	160	-	220	460
	Grand Total of all Semesters	**-**	58	19	4	89	420	770	20	890	2100

M. Sc. Electives I to IV Semester

S.No.	Course Code	Course Name	L	T	P	C
1.	MAT-911	Number Theory	3	1	-	4
2.	MAT-912	Applied Stochastic Processes	3	1	-	4
3.	MAT-913	Advanced Matrix theory	3	1	-	4
4.	MAT-914	Special Functions	3	1	-	4
5.	MAT-915	Introduction to Graph Theory	3	1	-	4
6.	MAT-916	Fractional Calculus & its Application	3	1	-	4
7.	MAT-917	Computational Fluid Dynamics	3	1	-	4
8.	MAT-918	Queueing Theory and Applications	3	1	-	4
9.	MAT-919	Optimization Algorithms for Networks	3	1	-	4
10.	MAT-920	Analytic Function Theory	3	1	-	4
11	MAT-921	Mathematical Modelling	3	1	-	4
12	MAT-922	Operation Research	3	1	-	4
13	MAT-923	Fluid Mechanics	3	1	-	4
14	MAT-924	Integral Equations	3	1	-	4
15	MAT-925	Information Theory and Coding	3	1	-	4
16	MAT-926	Calculus of Variation and Tensor Calculus	3	1	-	4
17	MAT-927	Fractional Differential Equations	3	1	-	4
18	MAT-928	Lie Group and Lie Algebra	3	1	-	4
19	MAT-929	Differential Geometry	3	1	-	4
20	MAT-930	Algebraic Geometry	3	1	-	4
21	MAT-931	Finite Element Method	3	1	-	4
22	MAT-932	Fourier Analysis	3	1	-	4
23	MAT-933	Commutative Algebra	3	1	-	4
24	MAT-934	Fields Theory and Galois Theory	3	1	-	4
25	MAT-935	Algebraic Number Theory	3	1	-	4
26	MAT-936	Orthogonal Polynomials	3	1	-	4
27	MAT-937	Viscous Fluid Dynamics	3	1	-	4
28	MAT-938	Measure Theoretic Probability	3	1	-	4
29	MAT-939	Numerical Methods for Partial Differential Equations	3	1	-	4
30	MAT-940	Classical Mechanics	3	1	-	4
31	MAT-941	Analytic Number Theory	3	1	-	4

MAT-811 Linear Algebra 3L+1T Credits: 4

Review of fields, definition and basic examples.
Vector spaces, sub spaces, linear combinations, spanning sets, dimension and basis, linear transformations. Rank and nullity of linear transformation. Representation of transformations by matrices. Duality and transpose of a linear transformation. Linear functional, dual space.
Eigen values and eigen vectors, characteristics polynomials, minimal polynomials. Cayley Hamilton's theorem, triangularization, diagonalization. Inner product spaces. Orthogonality, Gram–Schmidt orthonormalization. Orthogonal projections. Linear functionals and adjoints. Unitary and normal operators. Spectral theorem for normal operators.
Bilinear forms, symmetric and skew symmetric bilinear forms, matrix of a bilinear form.

Text and reference books:

1. Hoffman K. and Kunze R., *Linear Algebra*, 2nd edition, PHI Learning, 2009.
2. Lang S., *Introduction to Linear Algebra*, 2nd Edition, Springer India, 2005.
3. Artin M., *Algebra*, 2nd Edition, Pearson education, 2011.
4. Herstein I. N., *Topics in Linear Algebra*, 2nd Edition, Wiley India Pvt. Ltd., 2006.

MAT-812 Real Analysis 3L+1T Credits:4

Real numbers: Basic properties, supremum and infimum, Archimedean property, denseness of rationals and irrationals.

Sequences: Definition and examples, convergent sequences, boundedness, monotonicity, subsequences, Cauchy sequences, Cauchy criterion, Cauchy's general principle of convergence.

Point set topology: Metric spaces, Cauchy Schwarz inequality, accumulation point, Bolzano-Weierstrass Theorem, Cantor Intersection Theorem, Cover of a set, Lindelof Covering Theorem, Heine-Borel Covering Theorem, Compact Set.

Series : Convergence tests. Absolute and conditional convergence. Addition, Multiplication and rearrangements.

Functions: Function, limit, continuity, composite function, inverse function, bounded function, homeomorphism, connectedness, two valued function, components of a metric space, uniform continuity, contraction, fixed point theorem, monotonic function, continuity of derivatives, Taylor's theorem, mean value theorems, compactness.

Riemann-Stieltjes integral: Partition, Riemann-Stieltjes sum, Riemann-Stieltjes integral, properties, step function as integrator, reduction of RS integral to a finite sum, upper and lower Stieltjes sums, upper and lower integrals, Riemann condition, comparison theorem, mean value theorems, second mean value theorem for RS integrals.

Sequences of Functions: Pointwise and uniformly convergence, Cauchy condition for uniform convergence, series of functions, Cauchy condition for uniform convergence of series, functions of bounded variation, uniform convergence, boundedly convergent sequences.

Fourier series: Bessel's inequality. Localization theorem. Parseval's theorem.

Text and reference books:

1. Rudin, W., *Principles of Mathematical Analysis*, Mc Graw Hill, Singapore, 1976.
2. Apostol, T.M., *Mathematical Analysis*, Narosa Publishing House, 1985.
3. Natanson, I. P., *Theory of Functions of a Real Variable*, Volume I, Frederick Pub. Co., 1964.
4. Ghorpade, S. R., Limaye B. V., *A Course in Calculus and Real Analysis*, Springer, 2006.
5. Royden, H.L., *Real Analysis*, McMillan Publication Co. Inc. New York, 1988.

MAT-813 Discrete Mathematics 3L+1T Credits: 4

Logic: Propositional Logic, language of propositional logic, truth table, natural deduction, predicate logic: language of predicate logic, Logical inference with Quantifiers. Proof techniques: Introduction to different standard proof techniques.

Set Theory: Review of basic set operations, cardinality of a set. Countable and uncountable sets. Relations, Types of relations, operations of relations and applications, Poset, Congruence arithmetic. Partially ordered sets and Lattices, Hasse Diagrams, lattices as algebraic systems sub-lattices, direct product and Homomorphisms, Complete lattices**.**

Combinatorics: Counting techniques: Pigeon Hole principle, inclusion exclusion principle, recurrence relation and generating function.

Graphs: Complete graphs, regular graphs, bipartite graphs, Vertex degree, subgraphs, paths and cycles, the matrix representation of graphs, fusion, trees and connectivity, bridges, spanning trees, chromatic number, connector problems, shortest path problems, cut vertices and connectivity.

Text and reference books:

1. Liu C. L. and Mohapatra D., *Elements of Discrete Mathematical*, 4th Ed., Tata McGraw-Hill, 2012.
2. Rosen K. H., *Discrete Mathematics and Its Applications with Combinatorics and Graph Theory*, 7th Edition, Tata McGraw-Hill Edu. 2012.
3. West D. B., *Introduction to Graph Theory*, Second Edition, Pearson, 2001.
4. Kolman B., Busby R. and Ross S. C., *Discrete mathematical structures*, 4th edition. Prentice Hall of India, 2002.
5. Wilson R. J., *Introduction to Graph Theory*, Fourth Edition, Prentice Hall of India, 1996.
6. Bondy J. A. and Murty U. S. R., *Graph Theory,* Springer, 2008.
7. Sane S. S., *Combinatorial Techniques*, Hindustan Book Agency, 2013.

MAT-814 Ordinary Differential Equations 3L+1T Credits: 4

Ordinary differential equations: System of simultaneous linear differential equations with constant and variable coefficients. Pfaffian Equation, Solution in series, Bessel's, and Legendre polynomial, linear difference equations.

Existence and Uniqueness of Initial Value Problems: Picard's and Peano's Theorems. **Boundary Value Problems for Second Order Equations:** Green's function, Sturm comparison theorems and oscillations, Eigen Value Problems and Sturm Liouville Problems, Stability of Linear and Non Linear Systems.

Text and reference books:

1. Raghvendra D. et al., *Ordinary Differential Equations*, Tata McGraw Hill, 2015.
2. Chakrabarti A., *Elements of Ordinary Differential Equations and Special Functions*, Wiley, 1990.
3. Mondal C.R., *Text book of Ordinary Differential Equations*, PHI Learning, 2008.
4. Simmons G., *Differential Equations with Applications and Historical Notes*,MHE , 2012.
5. Earl A., Coddington, *An Introduction to Ordinary Differential Equations*, Dover Publications, 1990.

MAT-815 Computer Language 2L-0T-4P

Credits: **4**

Programming in 'C': Need of Programming Languages, algorithms and flowcharts, constants, variables, data types, declarations, operators and expressions, operator precedence and associativity, input and output operations, formatting, decision making, branching, looping, arrays, character arrays and strings, user-defined functions.

Pointers: pointer expressions, pointers and arrays.

Introduction to C++ (optional).

Text and reference books:

1. Balagurusamy E., *Programming in ANSI C*, Mc Graw Hill, 7^{th} Edition, 2016.
2. Kernighan B. W. and Ritchie D. M., *The C Programming Language* (Ansi C Version), PHI Learning, 2012.

MAT-821 Abstract Algebra 3L+1T Credits: 4

Groups: Normal subgroups, quotient groups, homomorphism and isomorphism theorems of groups. Maximal subgroups. Composition series of a group, group actions, orbits and stabilizers, direct product. Cauchy's and Sylow's theorems for finite groups. Simple groups, solvable groups, structure theorem of finite abelian group.

Rings: Subrings and Ideals. Principal and Maximal Ideals. Quotient rings, isomorphism of rings, characteristic of a ring. Imbedding of a ring into another ring. Polynomial rings. Irreducible polynomials. Division algorithm for polynomials over a field. Euclidean algorithm. Euclidean polynomial for finding GCD of polynomials. Euclidean rings. Properties of Euclidean rings. Principle ideal domain, Unique factorization domains.

Fields: Algebraic field extensions, degree of extensions, minimal polynomials, Splitting fields and normal extensions, separable field extensions, Finite fields and applications.

Text and reference books:

1. Artin M., *Algebra*, 2nd Edition, Pearson education, 2011.
2. Fraleigh J., *A First Course in Abstract Algebra*, 7th Edition, Pearson Education, 2003.
3. Beachy J. A. and Blair W. D., *Abstract Algebra*, 2nd Edition, Waveland Press, 2006.
4. Beachy, J. A., *Abstract Algebra* II, Cambridge University Press, 1999.
5. Dummit D. S. and Foote R. M., *Abstract Algebra,* 3rd Edition, John Wiley & Sons, NY, 2017.
6. Jacobson N., *Basic Algebra-I & II*, 2nd Edition, Dover Publication, 1989.
7. Gallion J. A., *Contemporary Abstract Algebra*, 7th Edition, Brooks/Cole Cengage Learning, 2010.
8. Herstein I. N., *Abstract Algebra,* 3rd Edition, John Wiley & Sons, 1996.
9. Sharma R. K., Shah S. K. and Shankar A. G., *Algebra I: A Basic course in Abstract Algebra*, Pearson Education, 2011.

MAT-822 Topology 3L+1T Credits: 4

Topological Spaces: open sets, closed sets, neighbourhoods, bases, sub bases, limit points, closures, interiors, continuous functions, homeomorphisms. Examples of topological spaces: subspace topology, product topology, metric topology, order topology.

Quotient Topology: Construction of cylinder, cone, Moebius band, torus, etc. Connectedness and Compactness: Connected spaces, Connected subspaces of the real line, Components and local connectedness, Compact spaces, Heine-Borel Theorem, Local -compactness.

Separation Axioms: Hausdorff spaces, Regularity, Complete Regularity, Normality, Urysohn Lemma, Tychonoff embedding and Urysohn Metrization Theorem, Tietze Extension Theorem. Tychnoff Theorem, One point Compactification. Complete metric spaces and function spaces, Characterization of compact metric spaces, equicontinuity, Ascoli-Arzela Theorem, Baire Category Theorem.

Applications: space filling curve, nowhere differentiable continuous function. Optional Topics: Topological Groups and orbit spaces, Paracompactness and partition of unity, Stone-Cech Compactification, Nets and filters.

Text and reference books:

1. Armstrong M. A., *Basic Topology*, Springer (India), 2004.
2. Joshi K. D., *Introduction to General Topology*, New Age International, 2000.
3. Kelley J. L., *General Topology*, Van Nostrand, 1955.
4. Munkres J. R., *Topology*, 2nd Edition, Pearson Education (India), 2001.
5. Simmons G. F., *Introduction to Topology and Modern Analysis*, McGraw-Hill, 1963.

MAT-823 Partial Differential Equations 3L+1T Credits: 4

Formulation and classification of Linear and Quasi- Linear Partial Differential Equation of the First Order, Lagrange's Method for Linear Partial Differential Equation of the First Order, Pfaffian Equation, Cauchy Problems, Complete Integrals of Non Linear Equations of First Order, Four Standard Forms, Charpit's Method, Monge's Method.

Solutions of linear PDE with constant coefficients using differential operators, reducible and irreducible non homogeneous linear PDE, Homogeneous linear PDE with constant coefficients.

Classification of second order linear PDE and Reduction to canonical forms, Laplace, Wave and Diffusion Equations in various coordinate systems and their solutions under different Initial and boundary conditions.

Green's Functions and Properties. Existence Theorem by Perron's Method. Heat Equation, Maximum Principle. Uniqueness of Solutions via Energy Method.

Text and reference books:

1. Sankara Rao K., *Introduction to Partial Differential Equations*, PHI learning Pvt. Ltd, 2011.
2. Prasad P. and Ravindran R., *Partial Differential Equations*, New Age International, 2011.
3. Amaranath T., *An Elementary Course in Partial Differential Equations*, Narosa, 2003.
4. Sneddon I. N., *Elements of Partial Differential Equation,* Dover Publications, 2006.
5. Sharma J. N. and Singh K., *Partial Differential Equations for engineers and scientists*, 2nd Edition, Narosa, New Delhi, 2009.

MAT-824 Complex Analysis 3L+1T Credits: 4

Complex Functions, Limits, Continuity and differentiability of functions of a complex variable, analytic functions, harmonic conjugates, the Cauchy-Riemann equations. Complex integration, Proofs of Cauchy's integral theorem, Cauchy's Integral formula, Morera's theorem, derivatives of analytic functions, Contour Integration, Liouville's theorem, maximum modulus principle, argument principle, Rouche's theorem. Power Series, Taylor's theorem, zeros of analytic functions, classification of singularities, poles, meromorphic functions, Laurent's series. Residue theorem and its applications. Contour Integration Conformal and bilinear mappings. Analytic continuation.

Text and reference books:

1. Churchill R. V., Brown J. W., *Complex Variables & Applications*, Tata McGraw Hill Eduction, 2009.
2. Conway John B., *Functions of One Complex Variable*, Narosa Distributors Pvt. Ltd., 1973.
3. Titchmarsh E.C., *Theory of Functions*, Oxford University Press, 2 edition, 1976.
4. Narayan Shanti, *Theory of Functions of a Complex Variable*, S. Chand Publishers, 2005.
5. Ahlfors L., *Complex Analysis*, McGraw Hill, 3 edition, 1979.
6. Ponnusamy S., *Foundations of Complex Analysis*, Alpha Science Intl Ltd; 2 edition , 2006.

MAT-825 Multivariable Calculus 3L+1T Credits: 4

Euclidean Spaces: Review of vectors in $\mathbb{R}^n$ and basic notions such as addition and scalar multiplication, dot product, length (norm), and distance. Cross product of vectors in $\mathbb{R}^3$. Scalar triple product. Polar coordinates in $\mathbb{R}^2$. Cylindrical and spherical coordinates in $\mathbb{R}^3$. Real-valued functions of several variables. Graph of a function. Level sets (level curves, level surfaces, etc.).Vector valued functions of several variables. Component functions. Vector fields.

Limits and Continuity: Sequences in $\mathbb{R}^n$ and their limits. Neighbourhoods in $\mathbb{R}^n$ Limits and continuity of real-valued functions of several variables. Sequential characterization. Limits and continuity of vector valued functions of several variables.

Differentiation: Partial derivatives, basic properties, Increment Theorem. Differentiability of a real-valued function of several variables, the concept of (total) derivative. Basic properties. Gradient and directional derivatives. Examples. Chain Rule. Euler's Theorem. Higher order partial derivatives. Mixed Derivative Theorem. Mean Value Theorem and Taylor's Theorem for functions of several variables.

Local maxima/minima and saddle points. Discriminant test. Absolute maxima and minima of real-valued functions defined on closed and bounded subsets of $\mathbb{R}^n$.

Constrained maxima and minima of real-valued functions of several variables. Lagrange Multiplier Theorem (Statement only). Examples.

Differentiation of vector-valued functions of several variables. Jacobians, Chain Rule.

Implicit function theorem, Inverse function theorem.

Multiple Integrals: Definition of double (resp: triple) integral of a function defined and bounded on a rectangle (resp: box). Geometric interpretation as area and volume. Basic properties of double and triple integrals. Iterated integrals, Fubini's Theorem.

Integrability and the integral over arbitrary bounded domains. Change of variables formula (Statement only). Polar, cylindrical and spherical coordinates, and integration using these coordinates. Differentiation under the integral sign.

Line Integrals: Paths (parametrized curves) in $\mathbb{R}^n$ Smooth and piecewise smooth paths. Closed paths. Equivalence and orientation preserving equivalence of paths. Definition of the line integral of a vector field over a piecewise smooth path. Basic properties of line integrals including linearity, path-additivity and behaviour under a change of parameters. Examples. Line integrals of the gradient vector field (Second Fundamental Theorem of Calculus for Line Integrals). First Fundamental Theorem of Calculus for Line Integrals.

Green's Theorem (proof only in the case of rectangular domains). Applications to evaluation of line integrals. Necessary and sufficient conditions for a vector field (continuous on open connected sets) to be conservative.

Surface Integrals: Parametrized surfaces. Smoothly equivalent parameterizations. Area of such surfaces. Definition of surface integrals of scalar-valued functions as well as of vector fields defined on a surface. Curl and divergence of a vector field.

Stoke's Theorem (proof assuming the general form of Green's Theorem). Examples.

Gauss' Divergence Theorem (proof only in the case of cubical domains). Examples.

Texts and reference books:

1. Apostol, T., *Calculus*, Vol. 2, Second Ed., John Wiley, New York, 1969.
2. Apostol, T., *Mathematical Analysis*, Second Ed., Narosa, New Delhi, 1974.
3. Courant, R. and John, F., *Introduction to Calculus and Analysis*, Vol. 2, Springer-Verlag, New York, 1989.
4. Fleming, W., *Functions of Several Variables*, Second Ed., Springer-Verlag, New York, 1977.
5. Ghorpade, S. R. and Limaye, B. V., *A Course in Multivariable Calculus and Analysis*, Springer, New York, 2010.
6. Kaplan, W., *Advanced Calculus*, *Addison-Wesley*, Reading Mass., 1952.
7. Marsden, J. E. and Tromba, A. J., *Vector Calculus*, Fourth Ed., W. H. Freeman and Co., New York, 1996.
8. Protter, M. H. and Morrey, Jr C. B., *Intermediate Calculus*, Second Ed., Springer-Verlag, New York, 1996.
9. Widder, D. V., *Advanced Calculus*, Second Ed., Dover Pub., New York, 1989.

MAT-831 Numerical Analysis 3L+1T Credits : 4

Errors: Floating-point approximation of a number, Loss of significance and error propagation, Stability in numerical computation.

Linear Systems: Gaussian elimination with pivoting strategy, Gauss Jordan method, LU factorization, QR decomposition, Residual corrector method, Solution by iteration (Jacobi and Gauss-Seidal with convergence analysis), Nonlinear Equations: Bisection method, Regula-falsi method, Newton-Raphson method. Fixed-point iteration method, Secant method, Newton's method, Rate of convergences, Solution of a system of nonlinear equations.

Interpolation and finite differences: Forward, backward and central differences, relations between the operators, Newton's forward and backward differences interpolation formulae, Stirling, Bessel and Gauss formulae for central difference, numerical differentiation, Lagrange, Hermite and Newton's divided difference interpolation formulae for unequal interval. Error of the interpolating polynomials.

Numerical Integration: Gaussian quadrature formula ,Trapezoidal, Simpson's one-third , Simpson's three- eighth and Weddle's rule .

Differential Equations: Taylor's series method, Picard's method, Euler's and modified Euler's methods, Runge-Kutta fourth order method, Multi-step methods, Predictor-Corrector methods . Finite difference method for ordinary and Partial differential equations.

Text and reference books:

1. Atkinson K. E., *An Introduction to Numerical Analysis*, 2nd Edition, Wiley-India, 1989.
2. Conte S. D. and Boor C. , *Elementary Numerical Analysis* - An Algorithmic Approach, 3rd Edition, McGraw-Hill, 1981.
3. Burden R. L. and Faires J. D., *Numerical Analysis*, 9th Edition, Cengage learning, 2011.
4. Jain M. K., Iyengar S.R.K. and Jain R.K., *Numerical Methods for Scientific and Engineering Computation*, Wiley Eastern Limited, 2012.
5. Sastry S. S., *Introductory Methods of Numerical Analysis*, Prentice Hall of India, 2012.
6. Sharma J. N., *Numerical methods for Engineers and Scientists*, 2nd edition Narosa Publishing House New Delhi, 2008.
7. Smith G. D., *Numerical Solutions to Partial Differential Equations*, Brunel Univ. Clarendon Press, 1985.

MAT-832 Measure Theory 3L+1T Credits: 4

Riemann integrals and basic properties, Insufficiency of Riemann integrals and the need of more general integrals, Measurable spaces and Measurable sets, Measurable functions, Measures, Borel measure, Outer Measures and Generation of Measures, Lebesgue measure, Lebesgue Integration, Basic Integration Theorems, Comparison of Lebesgue and Riemann Integrals, Lp spaces, Various Models of Convergence of Measurable Functions, Signed Measure, Hahn and Jordan Decomposition Theorems, The Radon-Nikodym Theorem, Regular Borel measure, Riesz representation theorem, Product Measures, Tonelli's and Fubini's Theorem.

Text and reference books:

1 Bartle R.G., *The Elements of Integration and Lebesgue Measures*, Wiley Publication, 1966.
2 Halmos P. R., *Measure Theory*, Springer-Verlag, New York, 1974.
3 Royden H. L., *Real Analysis*, 3rd Ed., Prentice Hall of India, 1988.
4 Rudin W., *Real and Complex Analysis*, 3e, TMH, 1987.

MAT-833 Statistics & Probability Theory 3L+1T Credits: 4

Sample space, outcomes and events, Probability, conditional probability.
Random variables, expected value, moment generating function, specific discrete and continuous distributions, e.g. Binomial, Poisson, Geometric, Pascal, Hypergeometric, Uniform, Exponential, Weibull, Beta, Gamma, Erlang, Normal and student's 't' distributions. χ-square and F distributions.
Law of large numbers, IIDRV and central limit theorem, sampling distributions, point and interval estimation, testing of hypothesis, large and small samples χ-Square test as a test of goodness of fit.

Text and reference books:

1. Ross S. M., *A first course in Probability*, Pearson, 2006.
2. Johnson R. A., *Probability & Statistics for Engineers*, PHI Learning, 2011.
3. FELLER W., *An Introduction to Probability theory and its Application*, Wiley, 2008.
4. Hogg R.V. and Craig A.T., *Introduction to Mathematical Statistics*, 5th Ed., Prentice-Hall, Inc., Englewood Cliffs, N.J., 1995.
5. Billingsley P., *Probability and measure*, Wiley publications, 4 edition, 2012.
6. Mood A.M., Graybill F.A. and Boes D.C., *Introduction to the Theory of Statistics*, 3rd Ed. McGraw Hill, Inc., New York, 1974.
7. DeGroot, Morris H., and Mark J. Schervish, *Probability and Statistics*. 3rd ed. Boston, MA: Addison-Wesley, 2002. ISBN: 0201524880.
8. Freund W.J., *Mathematical Statistics*, 5th Ed., Prentice-Hall, Inc., Englewood Cliffs, N.J., 1994.
9. Hoel P.G., *Mathematical Statistics*, 5th Ed., John Wiley & Sons, Inc., NewYork, 1984.

MAT-841 Functional analysis 3L+1T Credits : 4

Normed linear spaces, continuity of a linear mapping. Banach spaces, Linear Transformations and functionals and Normed bounded linear transformation, dual spaces, Hahn – Banach extension theorem. Hilbert Spaces. Orthonormal sets, Bessel's Inequality, Parseval's relation, Riesz Representation theorem.

Adjoint operators in Hilbert Spaces, Self adjoint operators, positive operators, Projection operators and orthogonal projections in Hilbert spaces, contraction mapping theorem, fixed point theorems and their applications, Best approximations in Hilbert Spaces. Gateaux and Frechet derivatives. Open mapping theorem, closed graph theorem, uniform boundedness theorem

Text and reference books:

1. Kreyszig, E., *Introductory functional analysis with applications*, Wiley publications, 1989.
2. Limaye, B. V., *Functional Analysis*, Wiley Publication, 1996.
3. Brown, A. L. and Page, A., *Functional Analysis*, Van Nostrand Reinhold, 1970.
4. Limaye, B., V., *Linear functional analysis for scientists and engineers*, Springer, 2016.

MAT-842 Integral Transforms 3L+1T Credits: 4

Laplace Transforms: Definition, Transform of some elementary functions, rules of manipulation of Laplace Transform, Transform of Derivatives, relation involving Integrals, the error function, Transform of Bessel functions, Periodic functions, convolution of two functions, Inverse Laplace Transform of simple function, Tauberian Theorems, Solution of Differential Equations- Initial value problems for linear equations with constant coefficients, two-point boundary value problem for a linear equation with constant coefficients, linear differential equation with variable coefficients, simultaneous differential equations with constant coefficients, Solution of diffusion and wave equation in one dimension and Laplace equation in two dimensions.

Fourier Series and Fourier Transforms: Orthogonal set of functions, Fourier series, Fourier sine and cosine series, Half range expansions, Fourier integral Theorem, Fourier Transform, Fourier Cosine Transform, Fourier Sine Transform, Transforms of Derivatives, Fourier transforms of simple Functions, Fourier transforms of Rational Functions, Convolution Integral, Parseval's Theorem for Cosine and Sine Transforms, Inversion Theorem, Solution of Partial Differential Equations by means of Fourier Transforms. first order and second order Laplace and Diffusion equations.

Hankel Transforms: Elementary properties, Inversion theorem, transform of derivatives of functions, transform of elementary functions, Parseval relation, relation between Fourier and Hankel transform, use of Hankel Transform in the solution of Partial differential equations, Dual integral equations and mixed boundary value problems.

Mellin transforms: Definition and properties of Mellin transform, shifting and scaling properties, Mellin transforms of derivatives and integrals, Applications of Mellin transform.

Text and reference books:

1. Sneddon I.N., *The use of Integral Transforms*, McGraw Hill; Second Printing edition, 1972.
2. Sneddon I. N., *Fourier Transforms* , Dover Publications, 2010 .
3. Debnath L., *Integral Transforms and their applications*, Chapman and Hall/CRC; 2 edition, 2006.
4. Erdelyei et al., *Tables of integral transforms*, Vol. I and II, Mcgraw-hill book company, INC, 1954.

MAT-911 Number Theory 3L+1T Credits: 4

Congruences: basic definitions and properties, complete and reduced residue systems, theorems of Fermat, Euler & Wilson, application to RSA cryptosystem. Linear congruences and Chinese remainder theorem, quadratic congruences, and Quadratic Reciprocity law.

Arithmetical functions: examples, with some properties and their rate of growth.

Diophantine Approximation: Continued fractions and their connection with Diophantine approximations, applications to Pell's equations.

Diophantine Equations: Linear equations, Binary quadratic forms, Solutions of some quadratic and higher degree diophantine equations.

Partitions: Partitions of a number, Some basic properties and results.

Text and reference books:

1. Burton D., *Elementary Number Theory*, McGraw Hill Edu. 2006.
2. Niven I., Zuckerman H. S., Montgomery H. L., *An introduction to the theory of numbers*, 5e, Wiley, 1991.
3. Baker A., A concise introduction to the theory of numbers, Cambridge Univ. Press, 1984.
4. Hardy G. H. and Wright E. M., An introduction to the theory of numbers, 4^{th} Editions, Oxford, Univ. Press, 1960.

MAT-912 Applied Stochastic Processes 3L+1T Credits : 4

Definition and classification of general stochastic processes, Examples. Markov chains, Transition Probability Matrices, classification of states, Recurrence, examples. Basic Limit theorems of markov chains, Renewal Equation (Discrete case), Absorption probabilities. Random walk and queueing examples. Continuous time Markov chains, Pure Birth Processes, Poisson Processes, Birth and Death Processes, Differential Equation of Birth and Death Processes, Examples. Renewal processes, Renewal equations and Elementary Renewal theorem. Brownian motion, Continuity of paths and the Maximum variables, Variations and Extensions.

Text and reference books:

1. Bhat U.N., Miller G.N., *Elements of Applied Stochastic Processes*, 3rd Ed., Wiley, New York, 2002.
2. Kulkarni V.G.,*Modeling and Analysis of Stochastic Systems*, 2nd Ed., Chapman and Hall,1996.
3. Medhi J. ,*Stochastic Models in Queueing Theory*, Academic Press, Amsterdam,2003.
4. Nelson R., *Probability, Stochastic Processes and Queuing Theory*- The Mathematics of Computer Performance Modelling ,Springer-Verlag, New York,1995.
5. Ross S. M. , *Stochastic Processes*, 2nd Ed., Wiley, New York,1996.

MAT-913 Advanced Matrix Theory 3L+1T Credits: 4

Characteristic roots and characteristic vectors of matrices: Characteristic roots and characteristic vectors, Nature of the characteristic roots of special types of matrices, relation between algebraic and geometric multiplicities of characteristic roots, mutual relation between characteristic vectors corresponding to different characteristic roots.

Quadratic forms and congruence of Matrices: Quadratic forms, Quadratic forms as a product of matrices, Matrices as representative of linear transformation, the set of quadratic forms over F, congruence of quadratic forms and matrices. Congruence transformation of symmetric matrix. Elementary congruent transformations, congruent reduction of a symmetric matrix, congruence of skew symmetric matrices. Sylvester law of inertia.

Quadratic forms in the real field: Reduction in the real field, classification of real quadratic forms in n-variables, definite, semi definite and indefinite real quadratic forms. Quadratic characteristics properties of definite, semi definite forms, gram matrices, case of complex field, reduction in the complex field.

Hermitian matrices and forms: Hermitian matrices and forms, linear transformation of Hermitian form, conjunctive transformation of a matrix, conjunctive reduction of a Hermitian matrix, types of Hermitian forms.

Text and reference books:

1. Barnett S., *Matrix Methods for Engineers and Scientists*,McGraw-Hill,London, 1979.
2. Howard Eves, *Elementary Matrix Theory*, Dover Publication, 1980.
3. Narayan Shanti and Mittal P.K., *Text book on Matrix Theory*, S.Chand Publication, 1953.
4. Rao A. R., Bhimashanakrsen P., *Linear algebra*, Hindustan Book Agency,2nd Ed., 2000.
5. Lang S., *Algebra,,*third edition, 2005.

MAT-914 Special Functions 3L+1T Credits: 4

The Gamma and Beta Functions: Eulers' integral for Γ(z), the beta function, factorial function, Legendre's duplication formula, Gauss's multiplication theorem, summation formula due to Euler, behaviour of log Γ(z) for large |z |, relation between functions of Γ(z) and, Γ(1-z).
The Hypergeometric function: An integral representation. Its differential equation and solution, F(a,b,c;1) as a function of the parameters, evaluation of F(a,b,c;1), contiguous function relations, the hypergeometric differential equation, logarithmic solutions of the hypergeometric equation, F(a,b,c;z) as a function of its parameters, Elementary series manipulations, simple transformations, quadratic transformations, theorem due to Kummer, additional properties.
The Confluent Hypergeometric function: Basic properties of ${}_1F_1$, Kummer's first formula. Kummer's second formula. Ramanujan's product theorems.
Generalized Hypergeometric Series: The function pFq, the exponential and binomial functions, differential equation, contiguous function relations, integral representation pFq, with unit argument, Saalshutz' theorem, Whipple's theorem, Watson theorem, Dixon's theorem, Contour integrals of Barnes' type.

Text and reference books:

1. Ranvillie E. D., *Special Functions* , Macmillan, 1960.
2. Andrews L.C., *Special Functions of Mathematics for Engineers*, SPIE Press, 1992.
3. Szego G. , *Orthogonal Polynomials*, American mathematical society, 1939.
4. Slater L.J., *Generalized Hypergeometric Functions*, Cambridge University Press; Reissue edition, 2008.
5. Artin M. L., *Gamma functions*, Holt, Rinehart and Winston, 1931.

MAT-915 Introduction to Graph Theory 3L-1T Credits:4

Definition and basic concepts, Trees, characterizations, counting of minimum spanning tree, graph and matrices, Paths and distance in graphs, center and median of a graph, activity digraph and critical path, Eulerian graphs, Definition and characterization,
Hamiltonian graphs, Necessary and sufficient conditions, Planar Graphs: properties, dual, genus of a graph. Peterson graph.
Graph coloring, vertex coloring, chromatic polynomials, edge coloring, planar graph coloring, Matching and factorizations, maximum matching in bipartite graphs, maximum matching in general graphs, Hall's marriage theorem, factorization, Networks, The Max-flow min-cut theorem, connectivity and edge connectivity, Menger's theorem.

Text and reference books:

1. West D. B., *Introduction to Graph Theory*, Second Edition, Pearson, 2001.
2. Wilson R. J., *Introduction to Graph Theory*, Fourth Edition, Prentice Hall, 1996.
3. Bondy J. A. and Murty U. S. R., *Graph Theory,* Springer, 2008.

MAT-916 Fractional Calculus and Applications 3L+1T Credits: 4

Riemann Liouville fractional operator: Fractional Integrals of some functions namely binomial, exponential, the hyperbolic and trigonometric functions, Bessel's functions, Hyper-geometric function and the Fox's H-function. Dirichlet's Formula, Derivatives of the Fractional Integral and the Fractional Integral of Derivatives. Laplace Transform of the Fractional integral, Leibniz's Formula for Fractional Integrals. Derivatives, Leibniz's Formula of Fractional Derivatives.

Weyl fractional operator: Definition of Weyl fractional integral, Weyl fractional derivatives, A Leibniz formula for Weyl fractional integral and simple applications.

Fractional Differential Equations: Introduction, Laplace Transform, Linearly Independent Solutions, Solutions of the Homogeneous Equations, Solution of the Non-homogeneous Fractional Differential Equations, Reduction of Fractional Differential Equations to ordinary differential equations. Semi Differential equations.

Text and reference books:

1. Oldham, K.B. and Spanier, J., *The Fractional Calculus: Theory and Applications of Differentiation and Integration to Arbitrary Order*, Dover Publications Inc, 2006.
2. Miller, K.S. and Ross, B., *An Introduction to the Fractional Calculus and Fractional Differential Equations*, Wiley-Blackwell, 1993.
3. Samko, S.G., Kilbas, A.A., Marichev O.I., *Fractional Integrals and Derivatives*, Gordon and Breach Science publishers, 1987.
4. Podlubny, I., *Fractional differential equations*, Academic Press, 1999.
5. Kilbas, A.A., Srivastava, H.M., Trujillo, J. J., *Theory and applications of fractional differential equations*, Elsevier, 2006.

MAT-917 Computational Fluid Dynamics 3L+1T Credits: 4

Basic Fluid Dynamics, Numerical Solution of some Fluid Dynamical problems, Local similar solution of boundary layer equations, Transonic Relaxation methods, Small perturbation equations, Transonic small Perturbation equations, Line relaxation Techniques, Time dependent methods, Finite element method.

Text and reference books:

1. Bose T. K., *Numerical Fluid Dynamics*, Narosa Publishing House, 1997.
2. Anderson J. D., *Computational Fluid Dynamics*: *The Basics with Applications*, McGraw Hill, NY, 2009.

MAT-918 Queueing Theory and Applications 3L+1T Credits: 4

Review of probability, random variables, distributions, generating functions.

Poisson, Markov, renewal and semi-Markov processes; Characteristics of queueing systems, Markovian and non-Markovian queueing systems, embedded Markov chain applications to M/G/1, G/M/1 and related queueing systems.

Networks of queues, open and closed queueing networks; Queues with vacations, priority queues, queues with modulated arrival process, discrete time queues, introduction to matrix-geometric methods, applications in manufacturing, computer and communication networks.

Text and reference books:

1. Gross D. and Harris C., *Introduction to Queueing Theory*, 3rd Edition, Wiley, 1998.
2. Kleinrock L., *Queueing Systems*, Vol. 1: Theory, John Wiley, 1975.
3. Medhi J., *Stochastic Models in Queueing Theory*, 2nd Edition, Academic Press, 2003.
4. Buzacott J.A. and Shanthikumar J.G., *Stochastic Models of Manufacturing Systems*, Prentice Hall, 1992.
5. Cooper R. B., *Introduction to Queueing Theory*, 2nd Edition, North-Holland, 1981.
6. Kleinrock L., *Queueing Systems*, Vol. 2: Computer Applications, John Wiley, 1976.
7. Nelson R., *Probability, Stochastic Processes, and Queueing Theory*: The Mathematics of Computer Performance Modelling, Springer, 1995.

MAT-919 Optimization Algorithms for Networks 3L+1T Credits: 4

Introduction to graphs and networks: Introduction, concepts and definitions, linear programming.

Tree algorithms: Spanning tree algorithms.

Path algorithms: Shortest path algorithm, all shortest path algorithms, other shortest path algorithms.

Postman problem: Postman problem for undirected graphs, directed graphs and mixed graphs.

Travelling salesman problem: Salesman problem, existence of Hamiltonian circuits, lower bound and solution techniques.

Text and reference books:

1. Minieka Edward, *Optimization Algorithms for Networks and Graphs*,2nd Ed., 1992.

MAT-920 Analytic function theory 3L+1T Credits: 4

Analytic functions, Entire and meromorphic functions, Harmonic functions, Univalent functions. Maximum modulus theorem, Schwarz lemma, Schwarz function, Weierestrass factorization theorem, Mittag-Leffler theorem, Picards theorems, subordination.

Families of analytic functions: Convex, Starlike, Spirallike, Geometric properties of functions, Conformal mapping on simply connected domains, Mapping properties of special functions, Riemann mapping theorem, Schwarz-Christoffel transformations, Potential function, Laplace equation and solution.

Text and Reference Books:

1. Graham, I., Kohr, G., *Geometric Function Theory in One and Higher Dimensions*, Marcel Dekker Inc., New York, 2003.
2. Nehari, Z., *Conformal Mapping*, Dover publications, NewYork, 1952.
3. Serge Lang, *Complex Analysis*, Springer Verlag, NewYork, 4th ed. 1999.
4. Duren, P.L., *Univalent Functions*, Springer Verlag, NewYork, 1935.
5. Hille, E., *Analytic Function Theory* (Vol. II), 2nd Ed., Chelsea Publications, 1987.
6. Conway, J.B., *Functions of One Complex Variable*, Springer Verlag, NewYork, 2nd Ed., 1978.
7. Steven, G. Krantz, *Complex variables*, Chapman & Hall/CRC, Indian Reprint 2012.
8. Ahlfors, L. V., *Complex Analysis,* McGraw-Hill, 1966.
9. Rudin, W., *Principles of Mathematical Analysis,* McGraw-Hill, 1976.

MAT-921 Mathematical Modelling 3L+1T Credits: 4

What is a model? What is Mathematical modelling? Role of mathematics inproblem solving; Transformation from real world problem to real worldmodel and then to Mathematical Model; some illustrations of real worldproblems; Mathematical formulation, Dimensional Analysis, Scaling, Validation, Simulation, Some case studies with analysis (such as exponential growth and decay models, population models, Traffic flowmodels, Optimization models) Projects.

Text and reference books:

1. Murthy D. N. P., Page N. W., Rodin E. Y., *Mathematical Modelling* , Pergamon Press, 1990.
2. Dyne Clive L., *Principles of Mathematical Modelling*, Elsevier Publication, 2004.
3. Illner R., Bohun C Sean, McCollum S. and Roode T van, *Mathematical Modelling* –A case study approach, AMS publication, 2005
4. Kapur J. N., *Mathematical Modelling*, Wiley, 1988.

MAT-922 Operations Research 3L+1T Credits: 4

Introduction to Linear Programming Problem: Statement of Linear Programming Problem, Transportation problem, Assignment Problem.

Dynamic Programming: Introduction, Solution of Linear Programming Problem using Dynamic Programming.

Integer programming: Gomory's algorithm for all integer programming problem, branch and bound technique.

Non-linear programming: Unconstrained optimization via iterative methods: Direct search methods (Univariate method), Gradient methods (steepest descent (Cauchy's) method).
Constrained optimization: Lagrange multipliers, Kuhn Tucker conditions.

Quadratic programming: Wolfe's and Beale's method.

Network Analysis: Project planning and control with PERT-CPM

Text and reference books:

1. Rao S.S., *Engineering Optimization Theory & Practice*, John Wiley and Sons, 2009.
2. Sharma S.D., *Operations Research*, Kedar Nath Publ.,2008.
3. Sharma J.K., *Operations Research Problems and Solutions*, Macmillan Publishers India Ltd., 2008.
4. Winston, *Operations Research*, Duxbury Press,1987.
5. Taha Hamdy A., *Operations Research,* Macmillan, 1982.
6. Mangasarian O.L., *Non-linear Programming*, SIAM, 1987.
7. Hadley G., *Linear Programming*, Addison-Wesley Pub.Co., 1962.
8. Gross & Moris, *Fundamental of Queuing theory*, 4th Ed., Wiley, 2008.
9. Srinath L.S., *PERT and CPM Principles and Applications*, East-West Press Private Limited, 1971.

MAT-923 Fluid Mechanics 3L+1T Credits: 4

Basic concepts: Fluid, Continuum Hypothesis, Viscosity, Rate of strain quadric, Stress at a point, Stress Quadric, Relation between Stress and rate of strain Components (Stokes Law of Friction), Thermal Conductivity.

Fundamental equation of the flow of viscous fluid: Equation of state, equation of continuity – conservation of mass, Equation of motion (Navier-Stokes' equations)- conservation of momentum, Equation of energy – conservation of energy.

Dimensional analysis:-Dynamical Similarity (Reynolds Law), Inspection Analysis, Dimensional Analysis, Buckingham π-Theorem. Physical Importance of Non-Dimensional Parameters.

Exact solution of the Navier – Stokes' equations: Steady incompressible flow with constant fluid properties, Steady incompressible flow with variable viscosity, Unsteady incompressible flow with constant fluid properties, Steady compressible flow, steady incompressible flow with fluid suction/injection of the boundaries.

Text and reference books:

1. Pai S. I., *Viscous Flow Theory- Laminar flow*, Vol.1, D. Van Nostrand Co., NY, 1956.
2. Schlichting H., *Boundary-Layer Theory*, 7th Edition, McGraw-Hill, 1979.
3. Bansal J. L., *Viscous Flow Theory*, Jaipur Publishing House, 2008.

MAT-924 Integral Equations 3L+1T Credits: 4

Definition and classification, conversion of initial and boundary value problems to an integral equation, Eigen-Values and Eigen functions. Solutions of homogeneous and general Fredholm integral equations of second kind with separable kernels.

Solution of Fredholm and Volterra integral equations of second kind by methods of successive substitutions and successive approximations, Resolvent kernel and its results.

Integral equations with symmetric kernels: Complex Hilbert space, Orthogonal system of functions, fundamental properties of eigen values and eigen functions for symmetric kernels, expansion in eigen-functions and bilinear forms, Hilbert-Schmidt theorem. Solution of Fredholm integral equations of second kind by using Hilbert-Schmidt theorem. Fredholm theorems. Solution of Volterra integral equations with convolution type kernels by Laplace transform.

Text and reference books:

1. Lovitte, W. V., *Linear Integral Equations*, Dover Publications; Reissue edition, 2005.
2. Kanwal, R. P., *Linear Integral Equations*, Birkhäuser; 2nd edition, 1996.
3 Mikhlin, S.G., *Linear Integral Equations*, Routledge, 1961.

MAT925 Information Theory and Coding 3L -1T 4 credits

Mathematical foundation of information theory in communication system: Measures of information- self information, Shannon's entropy, joint and conditional entropies, mutual information and their properties.

Discrete memory less channels: classification of channels, calculation of channel capacity. Source coding, and channels coding. Unique decipherable codes, condition of instantaneous codes, average codeword length, Kraft inequality. Shannon's noiseless coding theorem. Construction of codes: Shannon fano, Shannon binary and Huffman codes. Higher extension codes. Decoding scheme- the ideal observer decision scheme.

Error correcting codes: minimum distance principle. Relation between distance and error correcting properties of codes, the Hamming bound. Construction of linear block codes, parity check coding and syndrome decoding.

Text and reference books:

1. Gallager, R. G., *Information theory and Reliable Communication,* John Wiley & Sons,Inc., New York, 1968.
2. Robert Ash, *Information Theory, Dover Publication,* New York, 1965.
3. Reza, F. M., *An Introduction to Information Theory,* McGraw Hill, New York, 1961.
4. Peterson, W. W. and Weldon, E. J., *Error correcting codes,* MIT, 1961.
5. Mceliece, S. J., *The theory of Information and Coding*; Student Edition (Encyclopedia of Mathematics and its Applications), Cambridge University Press, 1977.

MAT-926 Calculus of variations and Tensor Analysis 3L+1T Credits: 4

Calculus of variations: Basic concepts of calculus of variations, Variation and its properties, Euler's equation, Fundamental lemma of calculus of variation, Functionals dependent on higher order derivatives and on several independent variables, Variational problem in parametric form, applications Variational problem with fixed boundaries, Variational problem with moving boundaries, Sufficient condition for an extremum. Isoparametric problem.

Tensor Analysis : Notation and Definitions of Contravariant and covariant tensors of first and second order. Invariants. Contravariant, covariant and mixed tensors. The Kronecker delta. Algebra of tensors Symmetric and skew-symmetric tensors. Addition and scalar multiplication. Contraction and Quotient law for tensor. Reciprocal Tensor. Definition and properties of first and second kind of Christoffel's symbols, covariant differentiation of tensor, Ricci's theorem , Riemann- Christoffel 's tensor and its properties, Covariant curvature tensor .

Text and reference books:

1. Raisinghania M. D., *Advanced Differential Equation*, S. Chand & company, 2016.
2. Bali R., *Tensor Analysis*, Navkar Publications, 2012.
3. Elsgolc L.D., *Calculus of Variations*, Pergamon Press Ltd., 1962.
4. Gupta S., *Calculus of Vartiation with Applications*, Prentice Hall of India, 1999.
5. Bansal J.L., *Tensor Analysis*, Jaipur Publishing house, 2012.

MAT-927 Fractional Differential equation 3L+1T 4 Credits

Linear Fractional Differential Equations: Fractional Differential Equation of a General Form. Existence and Uniqueness Theorem as a Method of Solution. Dependence of a Solution on Initial Conditions.

The Laplace Transform Method. Standard Fractional Differential Equations. Sequential Fractional Differential Equations.

Fractional Green's Function: Definition and Some Properties. One-Term Equation. Two-Term Equation. Three-Term Equation. Four-Term Equation. General Case: n-term Equation.

Other Methods for the Solution of Fractional-order Equations: Power Series Method. Babenko's Symbolic Calculus Method. Method of Orthogonal Polynomials. The Mellin Transform Method.

Numerical Evaluation of Fractional Derivatives: Approximation of Fractional Derivatives. The "Short-Memory" Principle. Calculation of Heat Load Intensity Change in Blast Furnace Walls. Order of Approximation. Computation of Coefficients. Higher-order Approximations.

Numerical Solution of Fractional Differential Equations: Initial Conditions: Which Problem to Solve? Numerical Solution. Examples of Numerical Solutions. The "Short-Memory" Principle in Initial Value Problems for Fractional Differential Equations. Matrix approach to discrete fractional calculus. Numerical solution of nonlinear problems.

Applications. Fractional order systems and controllers.

Text and reference books:

1 Podlubny. I., *Fractional differential equations*, Academic Press, 1999.
2 Kilbas. A.A.,Srivastava, H.M., Trujillo, J.J., *Theory and applications of fractional differential equations*, Elsevier, 2006.

MAT-928 Lie Groups and Lie Algebras 3L+1T Credits: 4

Introduction, Examples: Rotations of the plane, Quaternions and space rotations, SU(2) and SO(3), The Cartan-Dieudonné Theorem, Quaternions and rotations in R4, SU(2)xSU(2) and SO(4). Matrix Lie groups: definitions and examples. The symplectic, orthogonal and unitary groups, connectedness, compactness. Maximal tori. centres and discrete subgroups The exponential map, Lie algebras The matrix exponential, tangent spaces, the Lie algebra of a Lie group. Complexification, the matrix logarithm, the exponential map, One parameter subgroups, the functor from Lie groups to Lie algebras The adjoint mapping, normal subgroups and Lie algebras The Campbell-Baker-Hausdorff Theorem, simple connectivity, simply connected Lie groups and their characterization by Lie algebras, covering groups.

Text and reference books:

1. Stillwell, J., *Naive Lie Theory*, Springer, 2008.
2. Kirillov, Jr., *Introduction to Lie Groups and Lie Algebras*, Cambridge University Press, 2008.
3. Cartor, R. W., Ian G. MacDonald, Graeme B. Segal, *Lectures on Lie Groups and Lie Algebras* (London Mathematical Society Student Texts) 1st Edition, 32, 1995.

MAT-929 Differential Geometry 3L+1T Credits: 4

Graphs and level sets of functions on Euclidean spaces, vector fields, integral curves of vector fields, tangent spaces.

Surfaces in Euclidean spaces, vector fields on surfaces, orientation, Gauss map. Geodesics, parallel transport, Weingarten map.

Curvature of plane curves, arc length and line integrals, Curvature of surfaces. Parametrized surfaces, local equivalence of surfaces.

Gauss-Bonnet Theorem, Poincare-Hopf Index Theorem.

Text and reference books:

1. DoCarmo, M., *Differential Geometry of Curves and Surfaces*, Prentice Hall, 1976.
2. O'Neill, B., *Elementary Differential Geometry*, Academic Press, 1966.
3. Stoker, J.J., *Differential Geometry*, Wiley-Interscience, 1969.
4. Thorpe, J.A., *Elementary Topics in Differential Geometry*, Springer (India), 2004.

MAT-930 Algebraic Geometry 3L+1T Credits: 4

Rings of polynomials and their quotients, local rings, modules, free modules, exact sequences. Affine algebraic sets, The Hilbert basis theorem. Hilbert's Nullstellansatz. Affine varieties: Coordinate rings, polynomial maps, coordinate changes, rational functions. Local Properties of plane curves: Multiple points, tangent lines, multiplicities and local rings, intersection number. Projective varieties: projective algebraic sets, projective plane curves, linear systems of curves, Bezout's theorem, Max Noether's fundamental theorem and its applications. Variety, Morphisms and Rational maps: The Zariski topology, varieties and their morphism, dimension of varieties, rational maps. Resolution of singularities: Blowing up a point in affine and projective planes, quadratic transformations and nonsingular models of curves.

Text and reference books:

1. Musili C., *Algebraic Geometry for Beginners*, Hindustan Book Agency, 2001.
2. Harris Joe, *Algebraic Geometry A First Course*, Springer -Verlag, 1992.
3. Abhyankar S. S., *Algebraic Geometry for Scientists and Engineers*, American Mathematical Society, 1990.
4. Fulton W., *Algebraic Curves*, Benjamin, 1969.
5. Reid M., *Undergraduate Algebraic Geometry*, Cambridge University Press, Cambridge, 1990.
6. Shafarevich I.R., *Basic Algebraic Geometry*, Springer-Verlag, Berlin, 1974.
7. Walker R.J., *Algebraic Curves*, Springer- Verlag, Berlin, 1950.

MAT-931 Finite Element Method 3L+1T Credits: 4

Introduction of finite element method, Weighted residual methods: Galerkin's, Least squares and Collocation methods. Shape functions, Normalised coordinates.

Variational methods: Functional and its variation, Rayleigh-Ritz method, Equivalence of Rayleigh-Ritz and Galerkin methods in one and two dimensions.

Finite element method: Applications to ordinary differential equations, Node-wise assembly, Higher order elements, Element of rectangular shape, Elliptic, Parabolic and Hyperbolic Equations

Text and reference books:

1. Reddy J. N., *An Introduction to the Finite Element Method*, 3rd Edition, McGraw Hill, 2005.
2. Cook R. D., Malkus D. S., Plesha M. E. and Witt R. J., *Concepts and Applications of Finite Element Analysis*, 4th Edition, John Wiley, 2002.

MAT-932 Fourier Analysis 3L+1T Credits: 4

Basic Properties of Fourier Series: Uniqueness of Fourier Series, Convolutions, Cesaro and Abel Summability, Fejer's theorem, Poisson Kernel and Dirichlet problem in the unit disc. Mean square Convergence, Example of Continuous functions with divergent Fourier series. Distributions and Fourier Transforms: Calculus of Distributions, Schwartz class of rapidly decreasing functions, Fourier transforms of rapidly decreasing functions, Riemann Lebesgue lemma, Fourier Inversion Theorem, Fourier transforms of Gaussians.

Tempered Distributions: Fourier transforms of tempered distributions, Convolutions, Applications to PDEs (Laplace, Heat and Wave Equations), Schrodinger-Equation and Uncertainty principle.

Paley-Wienner Theorems, Poisson Summ-ation Formula: Radial Fourier transforms and Bessel's functions. Hermite functions.

Texts and reference books:

1. Strichartz, R. S., *A Guide to Distributions and Fourier Transforms*, CRC Press, 1994.
2. Stein, E. M., and Shakarchi, R., *Fourier Analysis: An Introduction*, Princeton University Press, 2003.
3. Richards and Youn, H., *Theory of Distributions: A Nontechnical Introduction*, Cambridge University Press, 1990.

MAT-933 Commutative Algebra 3L+1T Credits: 4

Revision of Rings and Ideals: Prime and maximal ideals. Chinese remainder theorem, Nilradical, Jacobson radical, operations on ideals, extension and contraction.

Basics of Modules: Module, submodule, quotient module, sums and products, Nakayama's lemma; Homomorphism, kernel, cokernel, direct sum, direct product, universal properties, free module, exact sequences, tensor product of modules and its exactness property, Localization of Rings and modules.

Chain conditions: Noetherian rings, Hilbert basis theorem, Primary decomposition of ideals in Noetherian rings. Artinian rings and modules.

Integral Extensions: Integral dependence, going-up and going down theorems, Noether's normalization lemma, Hilbert Nullstellensatz.

Text and reference books:

1 Atiyah M. F. and MacDonald I. G., *Introduction to commutative algebra*, Addison-Wesley series in Mathematics, 1969.
2 Eisenbud D., *Commutative Algebra* (with a view toward algebraic geometry), Graduate Texts in Mathematics 150, Springer-Verlag, 2003.
3 Matsumura H., *Commutative ring theory*, Cambridge Studies in Advanced Mathematics No. 8, Cambridge University Press, 1980.

MAT-934 Field Theory and Galois Theory 3L+1T Credits: 4

Field Theory: Review of basics of rings, integral domains and fields, Characteristic and prime subfields.

Field extensions, Finite, algebraic, and finitely generated field extensions, Classical ruler and compass constructions,

Splitting fields and normal extensions, algebraic closures. Finite fields. Quadratic and cyclotomic fields. Separable and inseparable extensions.

Norm, trace and discriminant.

Galois Theory: Galois extensions, Galois groups, Fundamental Theorem of Galois Theory, Composite extensions, Examples (including cyclotomic extensions and extensions of finite fields).

Solvability by radicals, Galois' Theorem on solvability.

Text and reference books:

1. Artin M., *Algebra*, Prentice Hall of India, 1994.
2. Dummit D. S. and Foote R. M., *Abstract Algebra*, 2nd Ed., John Wiley, 2002.
3. Gallian J. A., *Contemporary Abstract Algebra*, 4th Ed., Narosa, 1999.
4. Jacobson N., *Basic Algebra* I, 2nd Ed., W.H. Freeman, 1985.
5. Lang S., *Algebra*, 3rd Ed., Springer, New York, 2002.
6. Hungerford T. W., Algebra, Springer, 2003.

MAT-935 Algebraic Number Theory 3L+1T Credits: 4

Algebraic number fields, cyclotomic fields, quadratic and cubic fields, integral extensions, conjugate elements, norms and traces. The discriminant. Noetherian rings and Dedekind domains. Finiteness of the class group. Dirichlet's unit theorem and its applications.

Text and reference books:

1. Mollin R. A., *Algebraic Number Theory*, CBC Press, 2011.
2. Ireland K. and Rosen M., *A Classical Introduction to Modern Number Theory*, 2nd Edition, Springer-Verlag, Berlin, 1990.
3. Lang S., *Algebraic Number Theory,* Addison- Wesley, 1970.
4. Marcus D. A., *Number Fields*, Springer-Verlag, 1977.

MAT-936 Orthogonal Polynomials 3L+1T Credits: 4

Orthogonal polynomials: simple set of polynomials, Orthogonality, zero of orthogonal polynomials, expansion of polynomials, the three term recurrence relation, Christoffel-Darboux formula, Bessel's inequality.

Legendre polynomial : Introduction, solution of Legendre's Equation, Generating functions, Orthogonality, Recurrence relations, Differential equation, Rodrigue's formula, orthogonality, expansion of x^n ; Trigonometric series for $P_n(x)$, Laplace first integral, some bounds on $P_n(x)$, Christoffel's summation formula .

Jacobi polynomial: Introduction, solution of Jacobi Equation Explicit forms, Generating functions, Jacobi's first and second question, Recurrence relations, differential Recurrence relations, Rodrigue's formula, Orthogonality.

Laguerre polynomial: Introduction, solution of Laguerre Equation, Laguerre polynomial of order n, Generating functions, Recurrence relations, first few Laguerre polynomial, relation between Laguerre polynomial and their derivatives, Orthogonality, Generalized Laguerre polynomial.

Hermite polynomial: Introduction, solution of Hermite Equation, Hermite polynomial of order n, Generating functions, Recurrence relations, Rodrigue's formula, Orthogonality, expansion of x^n

Chebyshev polynomials: Introduction, Orthogonality, Recurrence relations, Generating functions, first and second kinds

Text and reference books:

1. Raisinghania M. D., *Advanced Differential Equations*, S. Chand & company, 2016.
2. Rainville E. D., *Special Functions*, Macmillan Co, 1960.
1. Andrews G. E., R. Askey, and Ranjan Roy, *Special Functions*, Cambridge University Press, 2004.
2. Andrews L. C., *Special Functions of Mathematics for Engineers*, McGraw Hill Book Co, 1998.
3. Wang Z. X. and Guo D. R., *Special Functions*, World Scientific Publication, 1989.
4. Srivastava H.M. and Manocha H.L., *A Treatise on Generating Functions*, Ellis Hortwood Ltd. 1984.
5. Szego G., *Orthogonal Polynomial*, American Mathematical society, 1939.
6. Bateman H., *Higher Transcendental Function, Volume 1,2,3*, McGraw-hill book Company, Inc. 1953.

MAT-937 Viscous Fluid Dynamics 3L+1T Credits: 4

Fundamental equations of' the flow of viscous fluids: Equation of state, equation of continuity- conservation of mass, Equation of motion (Navier- Stokes equations)- conservation of momentum, Equation of energy -conservation of energy, Dimensional analysis.

Exact solution of the Navier- stokes equations: Steady incompressible flow with constant fluid properties, Steady incompressible flow with variable viscosity, Unsteady incompressible flow with constant fluid properties, Steady compressible flow, Steady incompressible flow with fluid suction/injection on the boundaries.

Theory of very slow motion: Stokes equations, Stokes flow, Oseen equations, Oseen flow, Lubrication theory.

Text and reference books:

1. Pai S. I., *Viscous Flow Theory- Laminar flow*, Vol.1, D. Van Nostrand Co., NY, 1956.
2. Schlichting H., *Boundary-Layer Theory*, 7th Edition, McGraw-Hill, 1979.

MAT-938 Measure Theoretic Probability 3L+1T Credits: 4

Algebra of sets, σ-algebra, examples, Borel σ-algebra. Definition of measure, set functions, finite and countable additivity. Finite and infinite measures, probability measures, basic laws of probability. Measurable functions, Monotone classes, π-systems, λ-systems. Monotone Class Theorem and Dinkin's π-λ Theorem. Outer measure, Carathéodory's Extension Theorem. Construction of the Lebesgue measure on unit interval. Distribution function, inverse distribution function, the Fundamental Theorem of Probability. Lebesgue Theory of Integration. Monotone convergence theorem, Fatou's Lemma, Dominating convergence theorem, Concept of "almost surely (a.s)". Change of variable formula. Expectation of a random variable. Product measure, existence and uniqueness. Fubini's Theorem, applications. Independence. Borel-Cantelli Lemmas. Tail σ-algebra, Kolmogorov's 0-1 Law. Various modes of convergence. Weak law of large numbers, Strong law of large numbers. Characteristic functions, Moment expansion, characteristics function for Normal distribution. Inversion formula, density formula. Revision of weak convergence, definition, representation theorem. Characteristic functions and weak convergence, Lévy's Continuity Theorem. Central Limit Theorems: De Moiver-Laplace, Lindeberg and Lyapounov's central limit theorems.

Text and reference books:

1. Bartle R. G., *The elements of integration and Lebesgue Measure*, Wiley, 1966.
2. Billingsley P., *Probability and Measure*, 3e, Wiley, 1995.
3. Chung K. L., *A course in probability theory*, 3e, Academic Press, 2001.
4. Athreya S. and Sunder V. S., *Measure and Probability,* Univ. Press, 2008.
5. Parthasarathy K. R., *Introduction to Probability and Measure*, Hindustan Book Agency, 2005..

MAT-939 Numerical Methods for Partial Differential Equations 3L+2P Credits: 4

Finite differences: Grids, Finite-difference approximations to derivatives.

Linear Transport Equation: Upwind, Lax-Wendroff and Lax-Friedrich schemes, Von-Neumann stability analysis, CFL condition, Lax-Richtmyer equivalence theorem,
Modified equations, Dissipation and dispersion.

Heat Equation: Initial and boundary value problems (Dirichlet and Neumann), Explicit and implicit methods (Backward Euler and Crank-Nicolson schemes) with consistency and stability, Discrete maximum principle, ADI methods for two dimensional heat equation (including LOD algorithm).

Poisson's Equation: Finite difference scheme for initial and boundary value problems, Discrete maximum principle, Iterative methods for linear systems (Jacobi, Gauss-Seidel, SOR methods and Conjugate Gradient method), Peaceman-Rachford algorithm (ADI) for linear systems.

Wave Equation: Explicit schemes and their stability analysis, Implementation of boundary conditions.

Lab Component: Exposure to MATLAB and computational experiments based on the algorithms discussed in the course.

Text and reference books:

1. Morton K. W. and Mayers D., *Numerical Solution for Partial Differential Equations*, 2nd edition, Cambridge, 2005.
2. Smith G. D., *Numerical Solutions of Partial Differential Equations*, 3rd Edition, Calrendorn Press, 1985.
3. Strikwerda J. C., *Finite difference Schemes and Partial Differential Equations*, Wadsworth and Brooks/ Cole, 1989.
4. Thomas J. W., *Numerical Partial Differential Equations : Finite Difference Methods*, Texts in Applied Mathematics, Vol. 22, Springer Verlag, 1999.
5. Thomas J. W., *Numerical Partial Differential Equations: Conservation Laws and Elliptic Equations,* Texts in Applied Mathematics, Vol. 33, Springer Verlag, 1999.
6. Mitchell R. and Griffiths S. D. F., *The Finite Difference Methods in Partial Differential Equations,* Wiley and Sons, NY, 1980.

MAT-940 Classical Mechanics 3L+1T Credits: 4

D'Alembert's principle, General equations of motion, Motion of the centre of inertia (Motion of translation), Motion relative to the centre of inertia (Motion of rotation)

Motion about a fixed axis: Moment of effective forces about a fixed axis of rotation, Moment of momentum, Kinetic energy of a rotating body about a fixed line, Principal of angular momentum, Principle of energy and work

Lagrange's equations of motion: Degree of freedom and generalized coordinates, Lagrange's equations of motion under finite forces, Lagrangian function, Deduction of principle of conservation of energy from the Lagrange's equations

Motion in three dimensions: Euler's theorem for motion in three dimensions, system of moving axes, Euler's dynamical equations of motion under finite forces, Kinetic energy of a body rotating about a fixed point, Eulerian angles and Euler's geometrical equations, Deduction of Euler's dynamical equations from Lagrange's equations of motion,

Text and reference books:

1. Rana N. C. and Goag P. S., *Classical Mechanics*, Tata McGraw-Hill, 2015.
2. Hand L. N. and Finch J. D., *Analytical Mechanics*, Cambridge University Press, 2008.

MAT-941 Analytic Number Theory 3L+1T Credits: 4

The Wiener-Ikehara Tauberian theorem, the Prime Number Theorem. Dirichlet's theorem for primes in an Arithmetic Progression. Zero free regions for the Riemann-zeta function and other L-functions.

Euler products and the functional equations for the Riemann zeta function and Dirichlet L-functions.

Modular forms for the full modular group, Eisenstein series, cusp forms, structure of the ring of modular forms. Hecke operators and Euler product for modular forms. The L-function of a modular form, functional equations. Modular forms and the sums of four squares.

Optional topics: Discussion of L-functions of number fields and the Chebotarev Density Theorem. Phragmen-Lindelof Principle, Mellin inversion formula, Hamburger's theorem. Discussion of Modular forms for congruence subgroups. Discussion of Artin's holomorphy conjecture and higher reciprocity laws. Discussion of elliptic curves and the Shimura-Taniyama conjecture (Wiles' Theorem).

Texts and reference books:

1. Lang, S., *Algebraic Number Theory*, Addison-Wesley, 1970.
2. Serre, J.P., *A Course in Arithmetic*, Springer-Verlag, 1973.
3. Apostol, T., *Introduction to Analytic Number Theory*, Springer-Verlag, 1976.