M.Sc. MATHEMATICS

(Syllabus passed/approved by BoS meeting on 03.5.2012)

DEPARTMENT OF MATHEMATICS, FACULTY OF SCIENCE, BANARAS HINDU UNIVERSITY

Semester –I		
Course Code	**Title**	**Credits**
MTM 101	Algebra-I	4
MTM 102	Real Analysis-I	4
MTM 103	Topology	4
MTM 104	Differentiable Manifolds	4
MTM 105	Complex Analysis	4
	Total	**20**
Semester –II		
MTM 201	Algebra-II	4
MTM 202	Real Analysis-II	4
MTM 203	Riemannian Manifolds	4
MTM 204	Theory of Optimization	4
MTM 205M #	*Minor Elective*: Mathematical Methods (for students of other PG programmes) *Minor Elective* (for Mathematics students in other Departments)	2
	Total	**18**
Semester –III		
MTM 301	Fluid Dynamics	4
MTM 302	Normed Linear Spaces & Theory of Integration	4
MTM 303	Numerical Analysis	3+1P
MTM 304M #	*Minor Elective*: Mathematical Modeling (for students of other PG programmes) *Minor Elective* (for Mathematics students in other Departments)	2
	Major Electives **Any two** of following courses , each of 4 credits	
MTM 305	Theory of Automata	4
MTM 306	Fourier Analysis and Summability Theory	4
MTM 307	Gravitation	4
MTM 308	Complex Manifolds	4
MTM 309	Advanced Topology	4
MTM 310	Integral Equations	4
MTM 311	Algorithms and Data Structures	4
MTM 312	Operations Research	4
MTM 313	Mathematical Modeling	4
MTM 314	Foundations of Optimization	4
	Total	**22**
Semester –IV		
MTM 401	Functional Analysis	4
MTM 402	Partial Differential Equations	4
MTM 403	Analytic Dynamics	4
	Major Electives **Any two** of following courses , each of 4 credits	
MTM 404	Magnetohydrodynamics	
MTM 405	Numerical Solution of Partial Differential Equations	3+1P
MTM 406	Riemannian Geometry of Contact Manifolds	4
MTM 407	Wavelets Analysis	4
MTM 408	Cosmology	4
MTM 409	Category Theory	4
MTM 410	Fuzzy Sets and Applications	4
MTM 411	Financial Mathematics	4

MTM 412	Number Theory and Cryptography	4
MTM 413	Operator Theory	4
MTM 414	Bio-Mechanics	4
MTM 415	Module Theory	4
MTM 416	Advanced Graph Theory	4
MTM 417	Geometry of Submanifolds	4
MTM 418	Finsler Geometry	4
MTM 419	Generalized Convexity and Optimization	4
	Total	**20**
	Grand Total	**80**

(Note: Not all above-mentioned elective papers may be offered at the same time.)

Syllabus for M.Sc. Mathematics Course

SEMESTER I

MTM 101 Algebra-I Credits : 4

The class equation, Cauchy`s theorem, Sylow *p*-subgroups, Direct product of groups. Structure theorem for finitely generated abelian groups. Normal and subnormal series. Composition series, Jordan-Holder theorem. Solvable groups. Insolvability of S_n for $n \geq 5$.

Extension fields. Finite, algebraic, and transcendental extensions. Splitting fields. Simple and normal extensions. Perfect fields. Primitive elements. Algebraically closed fields. Automorphisms of extensions. Galois extensions.

Fundamental theorem of Galois theory. Galois group over the rationals.

Recommended Books:

1. I. N. Herstein, *Topics in Algebra*, Wiley Eastern, 1975.
2. P. B. Bhattacharya, S. K. Jain and S. R. Nagpal, *Basic Abstract Algebra* (2nd Edition), Cambridge University Press, Indian Edition 1977.
3. Ramji Lal, *Algebra,* Vols.1 & 2, Shail Publications, Allahabad 2001.
4. Vivek Sahai and Vikas Bist, *Algebra*, Narosa Publishing House 1999.
5. D. S. Malik, J. N. Mordeson, and M. K. Sen, *Fundamentals of Abstract Algebra*, McGraw-Hill International Edition, 1997.

MTM 102 Real Analysis-I Credits : 4

Definition and existence of Riemann-Stieltjes integral, Conditions for R-S integrability. Properties of the R-S integral, R-S integrability of functions of a function.

Series of arbitrary terms. Convergence, divergence and oscillation, Abel's and Dirichilet's tests. Multiplication of series. Rearrangements of terms of a series, Riemann's theorem.

Sequences and series of functions, pointwise and uniform convergence, Cauchy's criterion for uniform convergence. Weierstrass M-test, Abel's and Dirichlet's tests for uniform convergence, uniform convergence and continuity, uniform convergence and Riemann-Stieltjies integration, uniform convergence and differentiation. Weierstrass approximation theorem. Power series. Uniqueness theorem for power series, Abel's and Tauber's theorems.

Recommended Books:

1. Walter Rudin, *Principle of Mathematical Analysis* (3rd edition) McGraw-Hill Kgakusha, 1976, International Student Edition.
2. K. Knopp, *Theory and Application of Infinite Series*.
3. T. M. Apostol, *Mathematical Analysis*, Narosa Publishing House, New Delhi, 1985.

MTM 103 Topology Credits : 4

Definition and examples of topological spaces. Closed sets. Closure. Dense sets. neighborhoods, interior, exterior, and boundary. Accumulation points and derived sets. Bases and sub-bases. Subspaces and relative topology.

Alternative methods of defining a topology in terms of Kuratowski closure operator and neighborhood systems.

Continuous functions and homeomorphism. First and second countable space. Lindelöf spaces. Separable spaces.

The separation axioms T_0, T_1, T_2, $T_{3½}$, T_4; their characterizations and basic properties. Urysohn's lemma. Tietze extension theorem.

Compactness. Basic properties of compactness. Compactness and finite intersection property. Sequential, countable, and B-W compactness. Local compactness. One-point compactification.

Connected spaces and their basic properties. Connectedness of the real line. Components. Locally connected spaces.

Tychonoff product topology in terms of standard sub-base and its characterizations.Product topology and separation axioms, connected-ness, and compactness (incl. the Tychonoff's theorem), product spaces.

Nets and filters, their convergence, and interrelation. Hausdorffness and compactness in terms of net/filter convergence.

Recommended Books:

1. J. L. Kelley, *General Topology*, Van Nostrand, 1995.
2. K. D. Joshi, *Introduction to General Topology*, Wiley Eastern, 1983.
3. James R. Munkres, *Topology,* 2nd Edition, Pearson International, 2000.
4. J. Dugundji, *Topology*, Prentice-Hall of India, 1966.
5. George F. Simmons, *Introduction to Topology and Modern Analysis*, McGraw-Hill, 1963.
6. N. Bourbaki, *General Topology,* Part I, Addison-Wesley, 1966.
7. S. Willard, *General Topology,* Addison-Wesley, 1970.
8. S.W. Davis *Topology*, Tata McGraw Hill, 2006

MTM 104 Differentiable Manifolds Credits : 4

Differentiable manifolds - Definitions and examples. Differentiable maps. Jacobian matrix. Tangent spaces. Vector fields. Integral curves. Submanifolds. Distributions and integrability. 1-parameter group of transformations. Tensors and forms. The Koszul connection. Covariant, Lie and Exterior derivatives. Geodesics and curvature. Lie Groups and Lie Algebra. Fibre bundles.

Recommended Books:

1. R. L. Bishop and R. J. Crittenden, Geometry of Manifolds, Academic Press, 1964.
2. S.S. Chern, W.H. Chen and K.S. Lam, Lectures on Differential Geometry, World Scientific, 2000.
3. N. J. Hicks, Notes on Differential Geometry, Von Nostrand, 1965.
4. J.M. Lee, Introduction to Smooth Manifolds, Springer, 2006.
5. Y. Matsushima, Differentiable Manifolds, Dekker, 1972.
6. M. Spivak, A Comprehensive Introduction to Differential Geometry Vol 1 3ed., Publish or Perish, 1999.
7. F. Warner, Foundations of Differentiable Manifolds and Lie Groups, Springer, 1983.

MTM 105 Complex Analysis Credits : 4

Integration and differentiation of power series, Absolute and uniform convergence of power series.
Linear transformations, the transformation $w = 1/z$, Möbius transformations and its geometric properties, Conformal mappings. Schwarz' theorem, Riemann mapping theorem and its applications.
Branch point, branch cut, branches of a multi-valued function, analyticity of the branches of $\mathrm{Log}\, z$, z^a.
Singularities and their classification, Weierstrass-Casorati's theorem.
Residue calculus: Zeros, poles and meromorphic functions. Cauchy residue theorem, Argument principle, Rouche's theorem. Jordan's lemma, evaluation of proper and improper integrals, integration along a branch cut, Analytic continuation, Schwarz reflection principle, Monodromy theorem.

Recommended Books:

1. E. C. Titchmarsh, *The Theory of Functions*, Oxford University Press.
2. J. B. Conway, *Functions of One Complex Variable*, Narosa Publishing House, 1980
3. E. T. Copson, *Complex Variables*, Oxford University Press.
4. L. V. Ahlfors, *Complex Analysis*, McGraw-Hill, 1977.
5. D. Sarason, *Complex Function Theory*, Hindustan Book Agency, Delhi, 1994.
6. S.Ponnusamy, Foundation of complex analysis, Narosa publication, 2003.

SEMESTER - II

MTM 201 Algebra–II Credits : 4

Modules, submodules, Quotient Modules, Homomorphism, linear combination, direct sums, Product of modules, External sum of family of modules, Homomorphism decomposition theorem, Isomorphism theorems. Cyclic modules, simple modules and semi-simple modules and rings Schur's lemma. Free modules. Noetherian and Artinian modules and rings. Hilbert basis theorem .
Solution of polynomial equations by radicals. Insolvability of the general equation of degree ≥ 5 by radicals. Finite fields.
Canonical forms: Similarity of linear transformations. Invariant subspaces. Reduction to triangular forms. Nilpotent transformations. Index of nilpotency. Invariants of a nilpotent transformation. The primary decomposition theorem. Jordan blocks and Jordan form.

Recommended Books:

1. I. N. Herstein, *Topics in Algebra*, Wiley Eastern, 1975.
2. P. B. Bhattacharya, S. K. Jain and S. R. Nagpaul, *Basic Abstract Algebra* (2nd Edition), Cambridge University Press, 1997.
3. K. Hoffman and R. Kunze, *Linear Algebra*, 2nd Edition, Prentice Hall of India, 1971.
4. D. S. Malik, J. N. Mordeson, and M. K. Sen, *Fundamentals of Abstract Algebra,* McGraw-Hill International Edition, 1997.
5. Vivek Sahai and Vikas Bist, *Algebra*, Narosa Publishing House, 1999.
6. Ramji Lal, *Fundamentals in Abstract Algebra*, Chakra Prakashan, Allahabad, 1985.
7. J.S. Golan, Modules & the Structures of Rings, Marcl Dekkar. Inc.

MTM 202 Real Analysis-II Credits : 4

Functions of several variables. Derivative of functions in an open subset of $\Re^n$ into $\Re^m$ as a linear transformation. Chain rule. Partial derivatives. Taylor's theorem. Inverse function theorem. Implicit function theorem. Jacobians.

Measures and outer measures. Measure induced by an outer measure, Extension of a measure. Uniqueness of Extension, Completion of a measure. Lebesgue outer measure. Measurable sets. Non-Leesgue measurable sets. Regularity. Measurable functions. Borel and Lebesgue measurability.

Integration of non-negative functions. The general integral. Convergence theorems. Riemann and Lebesgue integrals.

Recommended Books:

1. Walter Rudin, *Principle of Mathematical Analysis* (3rd edition) McGraw-Hill Kogakusha, International Student Edition, 1976.
2. H. L., Royden, *Real Analysis*, 4th Edition, Macmillan, 1993.
3. P. R. Halmos, *Measure Theory*, Van Nostrand, 1950.
4. G. de Barra, *Measure Theory and Integration*, Wiley Eastern, 1981.
5. E. Hewitt and K. Stromberg, *Real and Abstract Analysis*, Springer, 1969.
6. P. K. Jain and V. P. Gupta, *Lebesgue Measure and Integration*, New Age International, New Delhi, 2000.
7. R. G. Bartle, *The Elements of Integration*, John Wiley, 1966.

MTM 203 Riemannian Manifolds Credits : 4

Riemannian Metrics. Riemannian connection. Fundamental Theorem of Riemannian Geometry. Geodesics. Curvature - Riemann curvature, Sectional curvature, Ricci curvature, scalar curvature. Jacobi Fields. Complete manifolds, Hopf-Rinow Theorem, The Theorem of Hadamard. Real space forms, Theorem of Cartan on the determination of the metric by means of the curvature. Fundamental equations for Riemannian submanifolds.

Recommended Books:

1. S.S. Chern, W.H. Chen and K.S. Lam, Lectures on Differential Geometry, World Scientific, 2000.
2. MP do Carmo, Riemannian Geometry, Birkhauser, 1992.
3. N. J. Hicks, Notes on Differential Geometry, Von Nostrand, 1965.
4. P. Petersen, Riemannian Geometry, Springer 2006.
5. J. Jost, Riemannian Geometry and Geometric Analysis (6ed. Springer, 2011)

MTM 204 Theory of Optimization Credits : 4

Unconstrained Optimization: Introduction, Gradient methods, Conjugate Direction Methods, Newton's Method, Quasi Newton Method.

Linear Programming: Simplex Method, Duality and Non- simplex Methods.

Non- Linear Constrained Optimization: Introduction, Lagrange's multipliers, Kuhn-Tucker conditions, Convex Optimization.

Algorithms for Constrained Optimization: Projected Gradient Methods, Penalty Methods.

Multiobjective Programming.

Recommended Books:

1. Edwin K. P. P. Chong, Stanislaw H. Zak; An Introduction to Optimization, Third Edition, Johan Welly & Sons Inc 2003.

2. David G. Luenberger and Yinyu Ye; Linear and Nonlinear Programming, Third Edition, Springer, International Series in Operations Research and Management Science, 2008.
3. Andrzej Ruszczynski; Nonlinear Optimization, Princeton University Press, 2006.

MTM 205M Mathematical Methods Credits : 2

Laplace Transform.
Fourier Series.
Matrix Coputations.
Complex Integration.

Recommended Books:

1. G. B. Thomas, R.L.Finney, M.D.Weir, Calculus and Analytic Geometry, Pearson Education Ltd, 2003.
2. Erwin Kreyszig, Advanced Engineering Mathematics, John Wiley & Sons, 1999.

SEMESTER -III

MTM 301 Fluid Dynamics Credits : 4

Equation of continuity, Boundary surfaces, path lines and streamlines, Irrotational and rotational motions, Vortex lines, Euler's Equation of motion, Bernoulli's theorem, Impulsive actions, Motion in two-dimensions, Conjugate functions, Source, sink, doublets and their images, conformal mapping.

Stress components in real fluid, Equilibrium equation in terms of stress components, Transformation of stress components, Principal stresses, Nature of strains, Transformation of rates of strain, Relationship between stress and rate of strain, Navier-Stokes equation of motion.

Buckingham $\prod$-theorem, Flow between parallel flat plates, Couette and plane Poiseuille flows, Flow through a pipe, Hagen Poiseuille flow, flow between two co-axially cylinders and two concentric rotating cylinders, Unsteady motion of a flat plate

Recommended Books:

1. W. H. Besant and A. S. Ramsey, *A Treatise on Hydrodynamics*, CBS Publishers and Distributors, Delhi, 1988.
2. S. W. Yuan, *Foundations of Fluid Dynamics*, Prentice-Hall of India, 1988.
3. F. Charlton, *A Text Book of Fluid Dynamics*, CBC, 1985.

MTM 302 Normed Linear Spaces and Theory of Integration Credits : 4

Normed linear spaces and Banach spaces. The L^P-space. Convex functions. Jensen's inequality. Holder and Minkowski inequalities. Completeness of L^P. Convergence in measure, Almost uniform convergence.

Signed measure. Hahn and Jordan decomposition theorems. Absolutely continuous and singular measures. Radon Nikodyn theorem. Labesgue decomposition. Riesz representation theorem. Extension theorem (carathedory). Lebesgue-Stieltjes integral.

Product measures. Fubini's theorem. Baire sets. Baire measure. Continuous functions with compact support. Regularity of measures on locally compact spaces. Integration of continuous functions with compact support. Reisz-Markoff theorem.

Recommended Books:

1. H. L. Royden, *Real Analysis*, Macmillan, 4th Edition, 1993.
2. P. R. Halmos, *Measure Theory*, Van Nostrand, 1950.
3. S. K. Berberian, *Measure and Integration*, Wiley Eastern, 1981.
4. A. E. Taylor, *Introduction to Functional Analysis*, John Wiley, 1958.
5. G. de Barra, *Measure Theory and Integration*, Wiley Eastern, 1981.
6. R. G. Bartle, The Elements of Integration, John Wiley, 1966.
7. Inder K. Rana, *An Introduction to Measure and Integration*, Narosa Publishing House, 1997.

MTM 303 Numerical Analysis Credits : 4

Integral equations: Fredholm and Volterra equations of first and second types. Conversions of initial and boundary value problems into integral equations, numerical solutions of integral equations using Newton-Cotes, Lagrange`s linear interpolation and Chebyshev polynomial.
Matrix Computations: System of linear equations, Conditioning of Matrices, Matrix inversion method, Matrix factorization, Tridiagonal systems.
Numerical solutions of system of simultaneous first order differential equations and second order initial value problems (IVP) by Euler and Runge-Kutta (IV order) explicit methods.
Numerical solutions of second order boundary value problems (BVP) of first, second and third types by shooting method and finite difference methods.
Finite Element method: Introduction, Methods of approximation: Rayleigh-Ritz Method, Gelarkin Method and its application for solution of BVP.

Recommended Books:

1. M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, New Age Publications, 2003.
2. M. K. Jain, *Numerical Solution of Differential Equations*, 2nd edition, Wiley-Eastern.
3. S. S. Sastry, *Introductory Methods of Numerical Analysis*,
4. D.V. Griffiths and I.M. Smith, *Numerical Methods for Engineers*, Oxford University Press, 1993.
5. C. F. Gerald and P. O. Wheatley, *Applied Numerical Analysis*, Addison- Wesley, 1998.
6. A. S. Gupta, *Text Book on Calculas of Variation*, Prentice-Hall of India, 2002.
7. Naveen Kumar, *An Elementary Course on Variational Problems in Calculus*, Narosa Publishing House, New Delhi, 2004.

MTM 304M Mathematical Modeling Credits : 2

Simple situations requiring mathematical modeling, techniques of mathematical modeling, Classifications, Characteristics and limitations of mathematical models, Some simple illustrations.
Mathematical modeling through differential equations, linear growth and decay models, Non linear growth and decay models, Mathematical modeling in dynamics through ordinary differential equations of first order.
Mathematical models through difference equations, some simple models, Basic theory of linear difference equations with constant coefficients, Mathematical modeling through difference equations in economic and finance, Mathematical modeling through difference equations in population dynamic.
Mathematical modeling through linear programming, Linear programming models in Transportation and assignment.

***Recommended Books*:**

1. J. N. Kapur, *Mathematical Modeling*, Wiley Eastern.
2. D. N. Burghes, *Mathematical Modeling in the Social Management and Life Science*, Ellie Herwood and John Wiley.
3. F. Charlton, *Ordinary Differential and Difference Equations,* Van Nostrand.

MAJOR ELECTIVES

(**Any two** of the following courses each having 4 Credits)

MTM 305 Theory of Automata Credits : 4

Finite automata; deterministic and non-deterministic. Acceptance of language by finite automata. Equivalence and minimization of finite automata. Moore and Mealy machines. Regular expressions. Grammars and Languages, Derivations, Language generated by a grammar. Regular Language and regular grammars. Pumping Lemma, Kleene's theorem.
The Chomsky hierarchy, Context-free and context-sensitive grammars and languages.

Turing Machines: Basic definitions. Turing machines as language acceptors. Universal Turing machines. The halting problem.

Recommended Books:

1. D. Kelly, *Automata and Formal Languages: An Introduction*, Prentice-Hall, 1995.
2. J. E. Hopcroft, R. Motwani, and J. D. Ullman, *Introduction to Automata, Languages, and Computation* (2nd edition), Pearson Edition, 2001.
3. P. Linz, *An Introduction to Formal Languages and Automata*, 3rd Edition,

MTM 306 Fourier Analysis and Summability Theory Credits : 4

Convergence problem, Dirichlet's integral, Riemann-Lebesgue Theorem, Convergence tests, Dini's, Jordan's, de la Vallee-Poussin's tests and their inter-relations. Summation of series by arithmetic means, summability of Fourier' series, Fejer's theorem, Weierstrass's approximation theorem, Almost everywhere summability, The Fejér-Lebesgue theorem, A continuous fuction with a divergent Fourier series, Order of partial sums, Integration of Fourier series, Convergent trigonometric series need not be a Fourier series, Parseval's theorem.

Functions of the class L^2: Bessel's inequality, Parseval's theorem for continuous functions, The Riesz-Fischer theorem, Properties of Fourier coefficients, Uniqueness of trigonometric series, Cantor's lemma, Riemann's first and second theorems.

Special methods of summation: Nörlund means, Regularity and Consistency of Nörlund means, Inclusion, Equivalence, Euler's means, Abelian means, Riesz's typical means.

Arithmetic means: Hölder's means, simples theorems concerning Hölder summability, Cesàro means, means of non-integral orders, simple theorems concerning Cesàro summability , Cesàro and Abel summability, Cesàro means as Nörlund means, Tauberian theorems for Cesàro summability.

Recommended Books:

1. E.C. Titchmarsh: A Theory of Functions, Oxford University Press, 1939 .
2. A Zygmund: Trigonometric series Vol. I, , The University Press, Cambridge, 1959,
3. G. H. Hardy : Divergent series, The Clarendon Press , Oxford, 1949 .

MTM 307 Gravitation Credits : 4

Newtonian theory : Attraction and potential of rod, disc, spherical shell and sphere. Surface integral of normal attractions-Gauss theorem, Laplace and Poission equations. Work done by self attracting systems. Distribution for given potentials. Equipotential surfaces.

Einstein's Theory : Principles of equivalence and general covariance, Geodesic postulate. Newtonian approximation of general relativistic equations of motion. Heuristic derivation of Einstein's field equations, Newtonian approximation of Einstein's field equations. Schwarzschild external solution. Planetary orbit. The three crucial tests. Energy momentum tensor of a perfect fluid. Schwarzschild internal solution.

Recommended Books:

1. S. L. Loney, *An Elementary Treatise on Statics*, Kalyani Publishers, New Delhi, 1979.
2. A. S. Ramsey, *Newtonian Attraction,* Cambridge University Press, 1964.
3. A. S. Eddington, *The Mathematical Theory of Relativity,* Cambridge University Press, 1954.
4. R. Adler, M. Bazin and M. Schiffer, *Introduction to General Relativity*, McGraw-Hill, 1965.
5. S. R. Roy and Raj Bali, *Theory of Relativity*, Jaipur Publishing House, 1987.
6. J. V. Narlikar, *General Relativity and Cosmology*, Macmillan, 1978.

MTM 308 Complex Manifolds Credits : 4

COMPLEX STRUCTURES ON VECTOR SPACES: Complexification of a Real Vector Space, Complex Structure, The Relation between Complexification and Complex Structure, Conjugate Complex Structure, Complexification of the Dual Space, Expressions in Terms of Bases, Orientations.

COMPLEX MANIFOLDS: Complex Structures, Necessary Conditions for a Complex Structure to Exist, Examples of Complex Manifolds.

VECTORS AND TENSORS ON A COMPLEX MANIFOLD: The Tangent Space and the Cotangent Space, The Complexified Tangent Space, Complex Structure on the Tangent Space, Complex Structure on the Cotangent Space, Relation Between the Canonical Complex Structure and the Manifold Complex Structure,

Vectors and Tensors, Real Tensors, Vectors and One-Forms of Type (1,0) and Type (0,1), Complex Tensors and Complex Manifolds, Tensor Fields.

ALMOST COMPLEX MANIFOLDS: Almost Complex Structure, Conditions for Existence of an Almost Complex Structure, Almost Complex Structure on a Complex Manifold, The Nijenhuis Tensor, Vanishing of the Nijenhuis Tensor as Necessary and Sufficient Condition for Integrability.

HERMITIAN AND KAHLERIAN MANIFOLDS: Hermitian Structures on Vector Spaces, Hermitian Manifolds, Kaehlerian Manifolds, Differential Geometry on Hermitian and Kaehlerian Manifolds, Curvature on Kaehlerian Manifolds, Complex space froms.

Recommended Books:

1. S.S. Chern, W.H. Chen and K.S. Lam, Lectures on Differential Geometry, World Scientific, 2000.
2. E.J. Flaherty, Hermitian and Kahlerian Geometry in Relativity, LNP 46, Springer, 1976.
3. Y. Matsushima, Differentiable Manifolds, Dekker, 1972.

MTM 309 Advanced Topology Credits : 4

The Stone-Cech compactification. Paracompact spaces, their properties and characterizations. Metrizable spaces and Metrization theorems. Uniform spaces, Weak uniformity, Uniformizability. Completion of uniform spaces.

Function spaces. Point-wise and uniform convergence.The compact open Topology. The Stone-Weierstrass theorem.

Recommended Books:

1 S. Willard, General Topology, Addison Wesley, 1970.

2 S.W.Davis, Topology, Tata McGraw Hill, 2006

MTM 310 Integral Equations Credits : 4

Classification. Modeling of problems as integral equations. Conversion of initial and boundary value problem into integral equations. Conversion of integral equations into differential equations. Volterra integral equations and their numerical solutions. Greens function for Fredholm Integral equations. Fredholm integral equations: Degenerate kernels, symmetric kernels. Fredholm Integral equation of second kind. Numerical Solution of Fredholm Integral equations.

Existence of the solutions: Basic fixed point theorems.

Integral equations and transformations: Fourier, Laplace and Hilbert transformation.

Recommended Books:

1. Abdul J. Jerry, Introduction to Integral Equations with applications, Marcel Dekkar Inc. NY.
2. L.G.Chambers, Integral Equations: A short Course, Int. Text Book Company Ltd. 1976,
3. R. P. Kanwal, *Linear Integral Equations*.
4. Harry Hochsdedt, *Integral Equations*.
5. Murry R. Spiegal, *Laplace Transform* (SCHAUM Outline Series), McGraw-Hill.

MTM 311 Algorithms and Data Structures Credits : 4

Fundamentals of C Programming, Structures, Pointers. Introduction to the concepts of an abstract data structure and its implementation.

Mathematical Basis: Asymptotic notations, Summations, Recursion formulas.

Basic Data Structures: Stacks, queues, lists, trees, priority queues, tables.

Searching Methods: Binary search Tree.

Sorting: General Background, Insertion sorts, Merge sorts and Heap sort.

Recommended Books:

1. Y.Langsam, M.J. Augenstein, A.M. Tanenbaum, Data Structures using C and C++ , PHI, New Delhi, 2002.
2. T.H. Cormen, C.E. Leiserson, R.C. Rivest, Algorithms, PHI New Delhi, 2001.
3. B.W. Kernighan, D.M. Ritchie, The C Porgramming Language, 2nd Ed., Prentice Hall, 1989.

MTM 312 Operations Research Credits : 4

Game Theory: Two person zero sum games, Games with mixed strategies.

Basic Concept of Multi Objective and Multi Level Optimization.
Integer Programming, Mixed Integer Programming. Linear Fractional Programming. Goal Programming. Sensitivity Analysis and System Reliability.
Geometric Programming: Constrained and Unconstrained Minimization Problems.
Dynamic Programming: Deterministic and Probabilistic dynamic programming.
Stochastic Programming: Stochastic Linear and Stochastic Non linear Programming.
Netwok Schedulig by PERT/CPM.

Recommended Books:

1. F. S. Hiller and G. J. Leiberman, *Introduction to Operations Research* (6th Edition), McGraw-Hill International Edition, 1995.
2. G. Hadley, *Nonlinear and Dynamic Programming*, Addison Wesley.
3. H. A. Taha, *Operations Research –An Introduction*, Macmillan.
4. Kanti Swarup, P. K. Gupta and Man Mohan, *Operations Research*, Sultan Chand & Sons, New Delhi.
5. S. S. Rao, *Optimization Theory and Applications*, Wiley Eastern.
6. N. S. Kambo, *Mathematical Programming Techniques*, Affiliated East-West Press Pvt. Ltd., New Delhi.

MTM 313 Mathematical Modelling Credits : 4

Introduction to Mathematical Modeling: modeling process, Elementary mathematical models; Role of mathematics in problem solving. Single species population model: The exponential model and the Logistic model, Harvesting model and its critical value.
Modeling with Ordinary Differential Equations: Overview of basic concepts in ODE and stability of solutions: steady state and their local and global stability; Some applications in Epidemiology and ecology.
Modeling with Difference Equations: Overview of basic concepts concerning matrices, Eigen-values and Eigenvectors; Fixed points, stability and iterative processes; Applications to population growth.

Recommended Books:

1. J.N. Kapur, Mathematical Modelling, New Age Intern. Pub..
2. J.N. Kapur, Mathematical Models in Biology and Medicine, East-West Press.
3. Fred Brauer and Carlos Castillo-Chavez, Mathematical Models in Population Biology and Epidemiology, Springer.
4. Frank R. Giordano, William Price Fox, Maurice D. Weir, A First Course in Mathematical Modelling, 4th Ed., Charlie Van Wagner.
5. Walter J. Meyer, Concept of Mathematical Modelling, McGraw-Hill.

MTM 314 Foundations of Optimization Credits: 4

Structure of Convex Sets and Functions: Algebraic Interior and Algebraic Closure of Convex Sets, Minkowski Gauge Function, Relative Algebraic Interior and Algebraic Closure of Convex Sets, Facial Structure of Convex Sets, Continuity of Convex Functions
Convex Polyhedra: Convex Polyhedral Sets and Cones, Convex Polyhedra, Tucker's Complementarity Theorem
Nonlinear Programming: Derivation of Fritz John Conditions using Penalty Functions, Constraint Qualifications, Applications of Nonlinear Programming, Duality Theory in Nonlinear Programming, Examples of Dual Problems, Generalized Convexity in Nonlinear Programming
Semi-infinite Programming: Fritz John Conditions for Semi-infinite Programming, Jung's Inequality, Duality in Semi-infinte programming, Generalized Convexity in Semi-infinite programming, Applications of Semi-infinite Programming.

Recommended Books:

1. O. Guler, Foundations of Optimization, Springer Science+Business Media, 2010.
2. M. Avriel, W. E. Diewert, S. Schaible and I. Zang, Generalized Concavity, SIAM Classics in Applied Mathematics, Philadelphia, 2010.
3. A. Cambini and L. Martein, Generalized Convexity and Optimization, Lecture Notes in Economics and Mathematical Systems Vol. 616, Springer-Verlag Berlin Heidelberg, 2009.
4. Anulekha Dhara and J. Dutta, Optimality Conditions in Convex Optimization: A Finite Dimensional View, CRC Press, 2012
5. S. K. Mishra and G. Giorgi, Invexity and Optimization, Nonconvex Optimization and Its Applications Vol. 88, Springer-verlag berlin Heidelberg, 2008.

SEMESTER - IV

MTM 401 Functional Analysis Credits : 4

Bounded linear transformations. B(X,Y) as a normed linear space. Open mapping and closed graph theorems.

Uniform boundedness principle and its consequences. Hahn-Banach theorem and its application. Dual spaces with examples. Separability. Reflexive spaces. Weak convergence. Compact operators.

Inner product spaces, Hilbert spaces. Orthonormal sets. Bessel's inequality. Complete orthonormal sets and Parseval's identity. Structure of Hilbert spaces. Projection theorem. Riesz representation theorem. Riesz-Fischer theorem. Adjoint of an operator on a Hilbert space. Reflexivity of Hilbert spaces. Self-adjoint operators. Positive, projection, normal, and unitary operators.

Recommended Books:

1. G. F. Simmons, *Introduction to Topology and Modern Analysis*, McGraw-Hill, 1963.
2. G. Bachman and L. Narici, *Functional Analysis*, Academic Press, 1966.
3. A. E. Taylor, *Introduction to Functional Analysis*, John Wiley, 1958.
4. B. V. Limaye, *Functional Analysis*, Wiley Eastern.
5. N. Dunford and J. T. Schwartz, *Linear Operators*, Part-I, Interscience, 1958.
6. R. E. Edwards, *Functional Analysis*, Holt Rinehart and Winston, 1965.
7. C. Goffman and G. Pedrick, *First Course in Functional Analysis*, Prentice- Hall of India, 1987.
8. K. K. Jha, *Functional Analysis and Its Applications*, Students' Friend, 1986

MTM 402 Partial Differential Equations Credits : 4

Classisification, Characteristic equation. Some important linear PDE. Fundamental solution of Laplace's Equation. Mean value formulae, Harmonic functions and properties, Representation formula. Green's function, Green representation formula. Poisson representation formula, Solution of Dirichlet problem on the ball. Sub Hormonic functions. The maximum principle. Energy methods.

Fundamental solutions of Heat Equation, Mean value formulae, properties of solutions, Initial BVP for heat equation.

Wave Equation. Mean value Method, Solution of Wave equation with initial values, Energy methods.

Recommended Books:

1. L. C. Evans, *Partial Differential Equations*, Graduate Studies in Mathematics, Vol. 19, AMS, 1999.
2. Jurgen Jost, Partial Differential Equations: Graduate Text in Mathematics, Springer Verlag Heidelberg, 1998.
3. Robert C Mcowen, Partial Differential Equations: Methods and Applications, Pearson Education Inc. 2003.
4. Fritz John, *Partial Differential Equations*, Springer-Verlag, 1986.
5. I.N. Sneddon, *Elements of Partial Differential Equations*, McGraw-Hill, 1988.

MTM 403 Analytic Dynamics Credits : 4

Rotation of a vector in two and three dimensional fixed frame of references. Kinetic energy and angular momentum of rigid body rotating about its fixed point.

Euler dynamic and geometrical equations of motion.

Generalized coordinates, momentum and force components. Lagrange equations of motion under finite forces, cyclic coordinates and conservation of energy.

Lagrangian approach to some known problems-motions of simple, double, spherical and cycloidal pendulums, motion of a particle in polar system, motion of a particle in a rotating plane, motion of a particle inside a paraboloid, motion of an insect crawling on a rod rotating about its one end, motion of masses hung by light strings passing over pulleys, motion of a sphere on the top of a fixed sphere and Euler dynamic equations.

Lagrange equations for constrained motion under finite forces. Lagrange equations of motion under impulses, motion of parallelogram about its centre and some of its particular cases.

Small oscillations for longitudinal and transverse vibrations.

Equations of motion in Hamiltonian approach and its applications on known problems as given above. Conservation of energy. Legendre dual transformations.

Hamilton principle and principle of least action. Hamilton-Jacobi equation of motion, Hamilton-Jacobi theorem and its verification on the motions of a projectile under gravity in two dimensions and motion of a particle describing a central orbit.

Phase space, canonical transformations, conditions of canonicality, cyclic relations, generating functions, invariance of elementary phase space, canonical transformations form a group and Liouville theorem.

Poisson brackets, Poisson first and second theorems, Poisson. Jacobi identity and invariance of Poisson bracket.

Recommended Books:

1. A. S. Ramsay, *Dynamic* –Part II.
2. N. C. Rana and P.S. Joag, *Classical Mechanics*, Tata McGraw-Hill, 1991.
3. H. Goldstein, *Classical Mechanics*, Narosa Publishing House, New Delhi, 1990.
4. J. L. Synge and B. A. Griffith, *Principles of Mechanics*, McGraw-Hill, 1991.
5. L. N. Hand and J. D. Finch, *Analytical Mechanics*, Cambridge University Press, 1998.
6. Naveen Kumar, *Generalized Motion of Rigid Body*, Narosa Publishing House, New Delhi, 2004.

MAJOR ELECTIVES

(**Any two** of the following courses, each having 4 credits)

MTM-404 Magnetohydrodynamics Credits : 4

Basic concepts of Magnetohydrodynamics, Maxwell's equations, Frame of reference, Lorentz force, Electromagnetic body force, Fundamental equations of MHD, Ohm's law for a moving conductor, Hall current, Conduction current, Kinematic aspect of MHD, Magnetic Reynolds number, MHD waves: alfven's waves, MHD waves in compressible fluid, MHD approximations, Electromagnetic boundary conditions, One dimensional MHD flow, Hartmann flow, MHD Couette flow, MHD Stoke's flow, MHD Rayleigh's flow, Hartmann-Stoke's boundary layer, Alfven's boundary layer, Two dimensional MHD flow (a) Aligned flow (b) Stagnation point flow, MHD flows in a rotating medium, Effects of Hall current on MHD flows in a rotating channel, MHD heat transfer.

Recommended Books:

1. T. G. Cowling, Magnetohydrodynamics, Interscience Publishers New York, 1957.
2. J.A. Shercliff, A Text Book of Magnetohydrodynamics, Pergamon Press, Oxford, 1965.
3. S. I. Pai, Magnetohydrodynamics and Plasma Dynamics, Springer Verlag, New York, 1962.
4. K. R. Cramer and S. I. Pai, Magnetofluid Dynamics for Engineers and Applied Physicists, McGraw Hill, New York, 1973.

MTM 405 Numerical Solutions of Partial Differential Equations Credits : 4 (3+1)

Numerical solutions of parabolic PDE in one space: two and three levels explicit and implicit difference schemes. Convergence and stability analysis.

Numerical solution of parabolic PDE of second order in two space dimension: implicit methods, alternating direction implicit (ADI) methods. Non linear initial BVP.

Difference schemes for parabolic PDE in spherical and cylindrical coordinate systems in one dimension.

Numerical solution of hyperbolic PDE in one and two space dimension: explicit and implicit schemes. ADI methods. Difference schemes for first order equations.

Numerical solutions of elliptic equations, approximations of Laplace and biharmonic operators. Solutions of Dirichlet, Neuman and mixed type problems.

Finite element method: Linear, triangular elements and rectangular elements.

Recommended Books:

1. M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Computational Methods for Partial Differential Equations*, Wiley Eastern, 1994.
2. M. K. Jain, *Numerical Solution of Differential Equations*, 2nd edition, Wiley Eastern.
3. S. S. Sastry, *Introductory Methods of Numerical Analysis*, , Prentice-Hall of India, 2002.
4. D. V. Griffiths and I. M. Smith, *Numerical Methods of Engineers*, Oxford University Press, 1993.
5. C. F. General and P. O. Wheatley *Applied Numerical Analysis*, Addison- Wesley, 1998.

MTM 406 Riemannian Geometry of Contact Manifolds Credits : 4

(Note: The pre-requisite for this course is MTM 308)

Contact manifolds. Almost contact manifolds. K-contact, Sasakian and cosymplectic manifolds. Some other classes of almost contact metric manifolds. Sasakian space form and cosymplectic space form. Curvature of contact manifolds. Submanifolds of Kaehler and Sasakian manifolds. Tangent Bundles and Tangent Sphere Bundles.

Recommended Books:

1. D. Blair, Blair Contact Manifolds in Riemannian geometry, LNM, Springer 509, 1976.
2. D. Blair, Riemannian geometry of Contact and Symplectic Manifolds, Birkhauser, 2010.

MTM 407 Wavelet Analysis Credits : 4

Fourier Analysis: Fourier and inverse Fourier transforms, Convolution and delta function, Fourier transform of Square integrable functions. Fourier series, Poisson's Summation formula.

Wavelet Transforms and Time Frequency Analysis: The Gabor Transform. Short-time Fourier transforms and the uncertainity principle. The integral wavelet transforms Dyadic wavelets and inversions. Frames. Wavelet Series.

Scaling Functions and Wavelets: Multi resolution analysis, scaling functions with finite two scale relations. Direct sum decomposition of $L^2(R)$. Linear phase filtering, Compactly supported wavelets, Wavelets and their duals, Orthogonal Wavelets and Wavelet packets, Example of orthogonal Wavelets. Identification of orthogonal two-scale symbols, Construction of Compactly supported orthogonal wavelets, Orthogonal wavelet packets, orthogonal decomposition of wavelet series.

Recommended Books:

1. C.K.Chui, A First Course in Wavelets, Academic press NY 1996.
2. I. Daubechies, Ten Lectures in Wavelets, Society for Industrial and Applied Maths, 1992.

MTM 408 Cosmology Credits : 4

(Note: The pre-requisite for this course is MTM 306 Gravitation)

An overview of the large scale structure of the universe. Einstein's modified field equations with the cosmological term.

Static cosmological models of the Einstein and de-Sitler; their derivation, geometrical and physical properties and comparison with the actual universe.

Hubble's law, non-static cosmological models, cosmological principles and Weyl's postulate.

Derivation of the Robertson-Walker metric and its geometrical properties. Hubble and deceleration parameters. Red shift in the Robertson-Walker geometry.

Einstein's equations for the Robertson-Walker metric, fundamental dynamical equations of the standard big-bang cosmology-Friedman Robertson-Walker models. Initial singularity-the bang, density and pressure in the present universe. Critical density- the open, closed and flat universes. Age of the universe. The radiation and matter dominated era of the universe. The red shift versus distance relation. Event and particle horizons.

Prequisite: Gravitation.

Recommended Books:

1. R. C. Tolman, *Relativity, Thermodynamics and Cosmology,* Clarendon Press, Oxford, 1934.
2. S. Weinberg, *Gravitation and Cosmology*, John Wiley, 1972.
3. J. V. Narlikar, *Introduction to Cosmology*, Cambridge University Press, 1998.
4. J. N. Islam, *An Introduction to Mathematical Cosmology*, Cambridge University Press, 1999.
5. J. A. Peacock, *Cosmological Physics*, Cambridge University Press, 1999

MTM 409 Category Theory Credits : 4

Categories, Functors and natural transformations. Monics, Epis and zeors. Construction on Categories, Duality. Contravariance and opposites. Products of categories, Functor Categories, Comma Categories, Universals and Limits. Universal arrows. The Yoneda lemma. Coproducts and Colimits. Products and Limits. Adjoints. Examples of Adjoints. Reflective Subcatgories. Equivalence of categories. Adjoints for preorders, cartesion closed categories. Limits, Creation of Limits, Limits by Products and Equailizer. Freyd's Adjoint Functor Theorem. Special Adjoint Functor Theorem. Adjoints in Topology. Monads and Algebras. Monads in a Category, Algebra for a Monad. The comparison with algebras. Words and free semi groups, Free Algebras for Monads. Beck's Theorem. Algebras are T-algebras. Compact Hausdorff Spaces.

Recommended Books:

1 S. MacLane, Categories for the Working Mathematician, Springer 1971.
2 M.A. Arbib and E. G. Manes, Arrows, Structures and Functors- The Categorical Imperative, Academic Press, 1975.
3 H. Herrlich and G.E. Strecker, Category Theory, Allyn & Bacon, 1973.
4 J. Adamek, H. Herrlich & G. E. Streeker, Abstract and Concrete Categories, John Wiley 1992.

MTM 410 Fuzzy Sets and Applications Credits: 4

Basic Concepts of Fuzzy Sets: Motivation, Fuzzy sets and their representations, Membership functions and their designing, Types of Fuzzy sets, Operations on fuzzy sets, Convex fuzzy sets. Alpha-level cuts, Zadeh's extension principle, Geometric interpretation of fuzzy sets.

Fuzzy Relations: Fuzzy relations, Projections and cylindrical extensions, Fuzzy equivalence relations, Fuzzy compatibility relations, Fuzzy ordering relations, Composition of fuzzy relations.

Fuzzy Arithmetic: Fuzzy numbers. Arithmetic operations on fuzzy numbers.

Fuzzy Logic: Fuzzy propositions, Fuzzy quantifiers, Linguistic variables, Fuzzy inference,

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

Probability of a fuzzy event. Baye's theorem for fuzzy events. Probabilistic interpretation of fuzzy sets.

Fuzzy mapping rules and fuzzy implication rules. Fuzzy rule-based models for function approximation. Types of fuzzy rule-based models (the Mamdani, TSK, and standard additive models). Fuzzy Implications and Approximate Reasoning:

Decision making in Fuzzy environment: Fuzzy Decisions, Fuzzy Linear programming, Fuzzy Multi criteria analysis, Multi-objective decision making.

Fuzzy databases and queries: Introduction, Fuzzy relational databases, Fuzzy queries in crisp databases.

Recommended Books:

1. J. Yen and R. Langari: *Fuzzy Logic: Intelligence, Control, and Information,* Pearson Education*, 2003.*
2. G. J. Klir and B. Yuan: *Fuzzy Sets and Fuzzy Logic: Theory and Applications,* Prentice-Hall of India, *1997.*
3. H.J. Zimmermann, *Fuzzy Set theory and its Applications*, Kluwer Academic Publ, 2001.

MTM 411 Financial Mathematics Credits : 4

Some Basic Definitions and Terminology. Basic option theory: single and multi-period binomial pricing models. Cox-Ross-Rubinstein (CCR) model, Black Scholes formula for potion pricing as a limit of CCR model.

Brownian ad Geometric Brownian Motion. Theory of Martingales. Stochastic Calculus, Stochastic differential Equations, Ito's formula to solve SDE's. Feymann Kac theorem. Application of stochastic calculus in option pricing. Black Scholes partial differential equations and Black Scholes formula.

Mean Variance portfolio theory: Markowitz model for Portfolio optimization and Capital Asset Pricing Model (CAPM).

Interest rates and interest rate derivatives: Binomial lattice model, Vasicek, Hull and White and Cox-Ingersoll-Ross (CIR) Model for bond pricing.

Recommended Books:

1 D.G. Luembergar, Investment Science, Oxford University press, 1999.
2 S.Ross, An Introduction to Mathematical Finance, Cambridge University press, 1999.
3 J.C.Parikh, Stochastic Process and Financial Markets, Narosa Publishing House, New Delhi, 2003.
4 S. Roman, An Introduction the Mathematics of Finance, Springer, 2000.

MTM 412 Number Theory and Cryptography Credits: 4

Number Theory: Introduction, Time estimates for doing arithmetic. Divisibilty and Euclidean algorithm. Congruencies. Some applications to factoring. Finite Fields and quadratic residues: Finite Fields, Quadratic Residues and Reciprocity.

Cryptography: Some simple crypto Systems. Enciphering matrices. Public Key: The Idea of Public key Cryptography. RSA. Discrete log. Knapsack. Zero-knowledge protocols and Oblivious Transfer. Pseudo Primes, Rho Method, fermat factorization and Factor bases.

Recommended Books:

1. Neal Koblitz, A Course in Number Theory and cryptography: A Graduate Text, Springer (Second Ed).

MTM 413 Operator Theory Credits: 4

Spectral Theory of Linear Operators in Normed Spaces, Spectral Theory in Finite Dimensional Normed Spaces, Basic Concepts, Spectral properties of Bounded Linear Operators, Further Properties of Resolvant and Spectrum, Use of Complex Analysis in Spectral Theory. Banach Algebras, Further properties of Banach Algebra. Gelfard- Naimark theorem. Non-commutative C*-algebras and Gelfand-Naimark-Segal construction.

Recommended Books:

1 E. Kreysyig, Introductory Functional Analysis with Applications, John Wiley and Sons.
2 John B. Conway, A Course in Operator Theory, Springer.
3 G.Bachman, L. Narici, Functional analysis, Academic Press, N.Y.
4 G. F. Simmons, An Introduction to Topology and Modern Analysis, Tata McGrawHill.

MTM 414 Bio Mechanics Credits: 4

External Flow: Fluid Dynamic forces acting on moving bodies. Flying and swimming. Blood flow in Heart, Lung, arteries and veins. Micro and Macro Circulation. Respiratory gas flow. The Laws of Thermo dynamics. Molecular diffusion. Mechanism in Membrances and Multiphasic structure.

Mass transport in Capillaries, Tissues, Interistitial spaces. Lymphatics, Indicator dilution method and Peristlsis.

Recommended Books:

1 Y.C.Fung, Bio Mechanics, Springer Verlag, NY 1990.
2 S.I. Rubinow, Introduction to Mathematical Biology, John Wiley, 1975.
3 Riccilardi, Biomathematics and Related Computational Problems, Kluwer Publ. 1988.
4 J. Keener, J. Sneyol, Mathematical Physiology, Springer, 2001
5 J.N.Kapoor, Mathematical Models in Biology and Medicine, EWP New Delhi, 1992.

MTM 415 Module Theory Credits: 4

Modules. Linear mapping. Transpose of a module, Homomorphism. Bimodules, Bilinear maps. Tensor product of modules. Exact and split-exact sequences. Small and essential submodules and their properties. Free modules, Projective modules, projective covers. Injective modules and injective envelopes. Finiteness conditions on modules, composition series, Jordan theorem, Hölder theorem.

Recommended Books:

1 F.W.Anderson and K. R. Fuller, Rings and Categories of Modules. Springer, Verlag.
2 J. Lambek, Lectures on Rings and Modules, Blaisdell Publ. Co.
3 J.S. Golan, Modules and Structures of Rings, Marcel Dekkar Inc.

MTM 416 Advanced Graph Theory Credits: 4

Trees: Spanning trees and enumeration. Matching: Matching and Maximum Matching, Hall's Matching condition, Minimax Theorems. Independent Sets and Covers. Dominating Sets.

Connectivity: Connectivities of graphs, Cut-sets, Edge Connectivity and Vertex Connectivity. Menger's Theorem.

Network Flow problem, maximum network flows, flow augmenting paths, Ford-Fulkerson Theorem.

Coloring of graphs: Chromatic number and chromatic polynomial of graphs, Brook's Theorem. Four Color Theorem.

Planarity: Planar Graphs, Testing of Planarity, Kuratowski Theorem for Planar graphs, Random Graphs.

Recommended Books:

1 D.B.West, Graph Theory , Pearson Publ. 2002.
2 F.Harary, Graph Theory. Narosa Publishing House, New Delhi
3 R. Diestel, Graph Theory, Springer, 2000.

MTM 417 Geometry of Submanifolds Credits: 4

Review of Riemannian manifolds. Induced connection and second fundamental forms. Equations of Gauss Codazzi and Ricci. Totally umbilical submanifolds. Scalar curvature curvature of submanifolds. Connection

of van der Waerden-Bortolotti. Minimal submanifolds. Ricci curvature and scalar curvature for pseudo umbilical submanifolds. The Gauss map. Basic inequalities for Riemannian submanifolds.

Recommended Books:

1. A. Bejancu, Geometry of CR-Submanifolds, Birkhauser, 1986.
2. B-Y Chen, Geometry of Submanifolds, Marcel Dekker, 1972.
3. B-Y Chen, Geometry of Submanifolds and its applications, Tokyo, 1981.
4. B-Y Chen, Geometry of slant Submanifolds, KU Leuven, 1990.
5. B-Y Chen, Riemannian Submanifolds, in HANDBOOK OF DIFFERENTIAL GEOEMTRY, North Holland, 2000.

MTM 418 Finsler Geometry Credits: 4

Minkowski norm, Finsler metric, Length Structure and Volume Form, Randers metric, Chern connection, Flag Curvature, Finsler metric of constant flag curvature, Finsler metric of scalar flag curvature, Projective Finsler metric, Projective flat Finsler metrics, Parallel vector Fields, Parallel translation, Landsberg metric, Berwald metric, Riemann curvature, S-Curvature, Isotropic S-curvature, Exponential map, First and second variation, Jacobi field.

Recommended Books:

1.D. Bao, S.S. Chern and Z. Shen, An Introduction to Riemannian-Finsler Geometry, GTM, Springer, 2000.

2.S.S.Chern and Z.Shen, Riemannian Finsler Geometry, World Scientific, 2004.

3.Z.Shen, Lectures on Finsler Geometry, Lectures on Finsler Geometry, World Scientific, 2001.

4.Z. Shen, Differential Geometry of spray and Finsler Space, Kluwer Academic publications, 2001.

MTM 419 Generalized Convexity and Optimization

Credits: 4

Convex Functions: Convex sets and topological properties of convex sets; Convex functions; Convexity and homogeneity, minima of convex functions.

Non-differentiable Generalized Convex Functions: Quasiconvexity, strict quasiconvexity, semistrict quasiconvexity, generalized convexity of some homogeneous functions; The Cobb-Douglas function, the constant Elasticity function, the Leontief production function, a generalized Cobb-Douglas function; Pre-invex functions and its properties.

Differentiable Generalized Convex Functions: Pseudoconvex functions, differentiable quasiconvex functions, pseudolinear functions, invex functions, pseudoinvex functions, quasiinvex functions, their properties and relationship.

Optimality and Generalized Convexity: Generalized convexity and constraint qualifications, KKT necessary and sufficient optimality conditions and generalized convexity, Wolfe type dual for nonlinear optimization problem, Mond-Weir type dual, for nonlinear optimization problem, weak , strong and converse duality, theorems under generalized convexity assumptions; The expenditure minimization problem, the utility minimization problem, the profit minimization problem, and the cost minimization problem.

Generalized Convexity and Generalized Monotonicity: Concept of generalized monotonicity, differentiable generalized monotone maps, relationship between generalized monotonicity and generalized convexity.

Generalized Convex Functions and Fractional Programming: Nonlinear Fractional programming problems, optimality conditions and duality theory for nonlinear fractional programming problems and generalized convexity, non-differentiable fractional programming problems; Multiobjective fractional programming problems.

Applications in Machine Learning: Binary pattern classification problems, optimal separation for linearly separable data sets; Hard margin classifier, soft margin classifier, nonlinear support vector machine.

Applications in Financial Mathematics: Two asset portfolio optimization; Multi asset portfolio optimization; Capital asset pricing model.

Recommended Books:

1. Alberto Cambini and Laura Martein, Generalized Convexity and Optimization, Lecture Notes in Economics and Mathematical Systems Vol. 616, Springer-Verlag Berlin Heidelberg, 2009.
2. S. K. Mishra and G. Giorgi, Invexity and Optimization, Nonconvex Optimization and Its Applications Vol. 88, Springer-Verlag Berlin Heidelberg, 2008.

3. S. K. Mishra, S. Y. Wang and K. K. Lai, Generalized Convexity and Vector Optimization, Nonconvex Optimization and Its Applications Vol. 90, Springer-Verlag Berlin Heidelberg, 2009.
4. S. Chandra, Jayadeva and A. Mehra, Numerical Optimization with Applications, Narosa, 2009.
5. B. D. Craven, Fractional Programming, Berlin; Helderman Verlag, 1988.