आईएफटीएम विश्वविद्यालय, मुरादाबाद, उत्तर प्रदेश

IFTM University, Moradabad, Uttar Pradesh

NAAC ACCREDITED

SCHOOL OF SCIENCES
DEPARTMENT OF MATHEMATICS

MASTER OF SCIENCE (MATHEMATICS)

TWO YEAR PROGRAMME

[W. E. F. ACADEMIC SESSION: 2020 - 21]

IFTM UNIVERSITY
N.H.-24, Lodhipur Rajput, Delhi Road, Moradabad, Uttar Pradesh-244001
www.iftmuniversity.ac.in

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SCHOOL OF SCIENCES
DEPARTMENT OF MATHEMATICS

Study & Evaluation Scheme of Master of Science (Mathematics) [Session 2020-21]

Programme:	***Master of Science (Mathematics)***
Course Level:	***PG Degree***
Duration:	***Two Year (Four Semester) Full Time***
Medium of Instruction:	***English***
Minimum Required Attendance:	***75%***
Maximum Credits:	***80***

Programme Outcomes (POs):

Students completing this programme will be able to:

- Equip the student with skills to analyze problems, formulate a hypothesis, evaluate and validate results, and draw reasonable conclusions thereof.
- Prepare students for pursuing research or careers in industry in mathematical sciences and allied fields.
- Understanding of the fundamental axioms in mathematics and capability of developing ideas based on them.
- Provide advanced knowledge on topics in pure mathematics, empowering the students to pursue higher degrees at reputed academic institutions.
- Create awareness to become an enlightened citizen with commitment to deliver one's responsibilities within the scope of bestowed rights and privileges.
- Nurture problem solving skills, thinking, creativity through assignments, project work.
- Good understanding of number theory which can be used in modern online cryptographic technologies.
- Assist students in preparing (personal guidance, books) for competitive exams e.g. NET, GATE, etc.

M.Sc. Mathematics, Degree Programme

Effective from Session 2020-21

S. N.	Semester 1.	Course code	Theory Course (Name Of The Paper)	Periods			EVALUATION SCHEME (Marks)				Course Total (Marks)	Credits
							Mid Semester Exam			End Semester Exam		
				L	T	P	MS 1+2	AS +AT	Total			
THEORY												
1.		MATH – 101	Abstract Algebra	4	1	0	10+ 10	5+5	30	70	100	4
2.		MATH– 102	Real Analysis	4	1	0	10+ 10	5+5	30	70	100	4
3.		MATH – 103	Number Theory	4	1	0	10+ 10	5+5	30	70	100	4
4.		MATH – 104	Ordinary Differential Equations	4	1	0	10+ 10	5+5	30	70	100	4
5.		MATH – 105	Computer Fundamental and Programming in C	4	1	0	10+ 10	5+5	30	70	100	4
			TOTAL	20	5	0	x	x	X	x	500	20

S. N.	semester 2.	Course Code	Theory Course (Name Of The Paper)	Periods			EVALUATION SCHEME				Course Total (Marks)	Credits
							Mid semester Exam			End semester Exam		
				L	T	P	MS 1+2	AS +AT	Total			
THEORY												
1.		MATH – 201	Topology	4	1	0	10+ 10	5+5	30	70	100	4
2.		MATH – 202	Classical Mechanics	4	1	0	10+ 10	5+5	30	70	100	4
3.		MATH – 203	Discrete Mathematics	4	1	0	10+ 10	5+5	30	70	100	4
4.		MATH– 204	Linear Algebra	4	1	0	10+ 10	5+5	30	70	100	4
5.		MATH – 205	Complex Analysis	4	1	0	10+ 10	5+5	30	70	100	4
			TOTAL	20	5	0	x	x	X	x	500	20

S. N.	semester 3.	Course Code	Theory Course (Name Of The Paper)	Periods			EVALUATION SCHEME				Course Total (Marks)	Credits
							Mid semester Exam			End semester Exam		
				L	T	P	MS 1+2	AS +AT	Total			
THEORY												
1.		MATH – 301	Functional Analysis	4	1	0	10+ 10	5+5	30	70	100	4
2.		MATH – 302	Fluid Dynamics	4	1	0	10+ 10	5+5	30	70	100	4
3.		MATH – 303	Numerical Analysis	4	1	0	10+ 10	5+5	30	70	100	4

4.		MATH – 304	Partial Differential Equations	4	1	0	10+ 10	5+5	30	70	100	4
5.		MATH – 305	Integral Equations and Integral Transforms	4	1	0	10+ 10	5+5	30	70	100	4
			TOTAL	20	5	0	x	x	X	x	500	20
S. N.	**semester 4.**	**Course Code**	**Theory Course (Name Of The Paper)**	**Periods**			**EVALUATION SCHEME**				**Course Total (Marks)**	**Credits**
							Mid semester Exam			**End semester Exam**		
				L	**T**	**P**	**MS 1+2**	**AS +AT**	**Total**			
THEORY												
1.		MATH- 401	Operations Research	4	1	0	10+ 10	5+5	30	70	100	4
2.		MATH - 402	Mathematical Statistics	4	1	0	10+ 10	5+5	30	70	100	4
3.		MATH – 403	Ring Theory	4	1	0	10+ 10	5+5	30	70	100	4
3.		**(Choose any one of the following after consulting to the Department)** MATH – 404(A): Plasma Dynamic MATH – 404(B):Difference Equations MATH – 404(C): Mathematical Methods MATH – 404(D):Theory of Relativity MATH– 404(E):Fuzzy Sets and their Applications MATH – 404(F):Differential Geometry of Manifolds		4	1	0	10+ 10	5+5	30	70	100	4
4.		MATH – 405 (Project & Viva- Voce)	Project / Dissertation in any one of the above Subjects	4	-	0	-	-	30	70	100	4
			TOTAL	20	4	0	x	x	X	x	500	20

Lecture load for one section (60 students) in theory and two sections (30 students each) in practical

IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (I Semester)

MATH-101: ABSTRACT ALGEBRA

Objective: - The main aims of this course abstract algebra areto provide a first approach to the subject of algebra, which is one of the basic pillars of modern and applied mathematics. The focus of the subject will be the study of certain structures called groups, rings, fields,field extensions, idealsand some related structures.

UNIT – 1 **(10 Sessions)**

Algebraic structure, Semi-Group, Groups, Abelian group, Order of a finite group, Permutations, Cyclic permutations, Order of element of a group, Isomorphism of groups, Subgroup, Cosets, Lagrange's theorem, Cayley's theorem, Cyclic groups.

UNIT – 2 **(10 Sessions)**

Normal subgroups, Conjugate elements, Normalizer of an element of a group, Centre of a group, Quotient group, Homomorphism of groups, Kernel of a homomorphism, automorphism of a group, Inner automorphism, Solvable groups, *p* - Sylow subgroup, Sylow's theorem.

UNIT – 3 **(10 Sessions)**

Ring, Commutative ring, Integral domains, Field, Division ring, Isomorphism of rings, Subrings, Subfields, Characteristics of a ring, The field of quotients, Ideals, Principal ideal ring, Prime fields.

UNIT – 4 **(08 Sessions)**

Quotient rings, Homomorphism of rings, Kernel of a ring homomorphism, Maximal ideal, Prime ideals, Unique factorization theorem.

UNIT – 5 **(10 Sessions)**

Field extensions, Finite field extension, Roots of a polynomial, Remainder theorem, Factor theorem, Elements of Galois Theory, Fundamental theorem of Galois Theory.

Course Outcomes:

Students completing this course will be able to:

- Demonstrate insight into abstract algebra with focus on axiomatic theories.
- Apply algebraic ways of thinking.
- Demonstrate knowledge and understanding of fundamental concepts including groups, subgroups, normal subgroups, homeomorphisms and isomorphism.
- Demonstrate knowledge and understanding of rings, fields and their properties.
- Understand and prove fundamental results and solve algebraic problems using appropriate techniques.

Suggested Readings:

1. A. R. Vasishtha : Modern Algebra, Krishna Prakashan Media (P) Ltd Meerut, India.
2. Joseph A. Gallian : Contemporary Abstract Algebra, (Fourth Edition), Narosa, 1999.
3. Goyal &Gupta: Advanced course in Modern Algebra, Pragati Prakashan, Meerut.
4. P. B. Bhattacharya, S. K. Jain & S. R. Nagpaul : Basic Abstract Algebra (Second Edition), Cambridge University Press(Indian Edition 1995).
5. John B. Fraleigh: A First Course in Abstract Algebra, Pearson Education India..
6. I. N. Herstein:Topics in Algebra,2nd Edition , John Wiley & Sons. Copyright.

Website Sources:

- www.pdfdrive.com
- www.dmi.gov.in
- www.yourarticlelibrary.com
- onlinecourses.nptel.ac.in
- en.wikipedia.org

Note: Latest editions of all the suggested readings must be used.

IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (I Semester)

MATH-102: REAL ANALYSIS

Objective: - The main aims of this course real analysis are to provide students with the special knowledge which necessary for basic concepts in real analysis.It strives more precisely to enable students to learn basic concepts about functions of bounded variation grasp basic concepts about the uniform convergence of sequences and series of functions, total variation and learn about Riemann integrals.

UNIT-1 **(10 Sessions)**

Elements of set theory, Finite, Countable and uncountable sets, Least upper bound property, The field of real numbers, Archimedean property, Density of rational numbers, Existence of n^{th} root of positive real numbers, Exponential and logarithm, The extended real number system.

UNIT-2 **(10 Sessions)**

Numerical sequences and their convergence, Bounded sequences, Cauchy sequences, Construction of real numbers using Cauchy sequences, Limit supremum and limit infimum.

UNIT-3 **(08 Sessions)**

Power series, Summation by parts, Absolute convergence, Addition and multiplication of series, Rearrangements (statement only), Uniform convergence of series and sequences of functions, Bolzano Weierstrass Approximation Theorem.

UNIT-4 **(10 Sessions)**

Limits of functions, Continuous functions, Uniform continuity, Absolute continuity ,Connected sets, Connected subsets of real numbers, Continuity and connectedness, Intermediate value theorem, Discontinuities and their classifications, Monotonic functions, Infinite limits and limits at infinity.

UNIT-5 **(10 Sessions)**

Differentiation of real-valued functions and its elementary properties, Mean value theorem, Taylor's theorem, Differentiation of vector-valued functions, Elementary properties of Riemann integral, Integration of vector-valued functions, Fundamental Theorem of integral calculus.

Course Outcomes:

Students completing this course will be able to:

- Describe the basic differences between the rational and the real numbers.
- Understand and perform simple proofs.
- Answer question concerning uniform convergence of concrete numerical sequences and series.
- Give the definition of concepts related to metric spaces, such as continuity, compactness, completeness and connectedness.
- Give the essence of the proof of Stone-Weierstrass theorem, the contraction theorem as well as the existence of convergent subsequences using equicontinuity.

Suggested Readings:

1. T. Apostol: Mathematical Analysis (5th edition), Addison-Wesley Pub.
2. R. G. Bartle and D. R. Sherbert : Introduction to Real Analysis (3rd edition), John Wiley &Sons, Inc.
3. G.C.Chadda & K.P.Gupta: Real Analysis, Students Friends & Company, Agra.
4. Pawan K. Jain & Shiv K. Kaushik: Real Analysis, S.Chand& Company Ltd, New Delhi.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (I Semester)

MATH-103: NUMBER THEORY

Objective: - The main aims of this course are to providean introduction of basic course in number theory for the interest of students in mathematics and teaching of mathematics. The course begins with the basic notions of integers and sequences, divisibility, and Mathematical Induction. It also covers standard topics such as prime numbers, the fundamental theorem of arithmetic and Euclidean algorithm, the Diophantine equations, Congruence equations, Euler's phi-function, Cryptography, Data encryption, Digital signatures and their applications.

UNIT 1 **(10 Sessions)**

Divisibility in Z, Fundamental theorem of arithmetic, Primes, Congruence, Fermat's theorem, Euler's theorem and Wilson's theorem, Fermat's quotients and their elementary consequences, Solutions of congruence's, Chinese Remainder theorem.

UNIT 2 **(10 Sessions)**

Euler's phi-function, Power residues, Primitive roots and their existence, Quadratic residues, Legendre symbol, Gauss lemma about legendre symbol, Quadratic reciprocity law, Proofs of various formulations Jacobi symbol.

UNIT 3 **(10Sessions)**

Greatest integer function, Arithmetic functions, Multiplicative arithmetic functions, M*ö*bius inversion formula, Convolution of arithmetic functions, Group properties of arithmetic functions, Recurrence functions, Fibonacci numbers and their elementary properties, Properties of Pythagorean triples.

UNIT 4 **(08Sessions)**

Solution of sum of two, Four and five squares of integers, Difference of two squares, Perfect numbers, Polygonal numbers, Partition generating function, Uniqueness, representation of rational and irrational numbers as simple continued fractions.

UNIT 5 **(10 Sessions)**

Introduction to Cryptography: Stream ciphers, Pseudo-random number generators, Block ciphers and modes of operations, Data encryption standard, Private key encryption, Public key encryption, RSA cryptosystem, Rabin's public key cryptosystem, Digital signatures, RSA digital signature scheme, Key distribution, Two-party and Multi-party protocols.

Course Outcomes:

Studentscompleting this course will be able to:

- Analyses hypotheses and conclusions of mathematical statements.
- Apply different methods of proof to verify mathematical assertions, including proof by induction, by contrapositive and by contradiction.
- Solve systems of Diophantine equations using the Chinese Remainder Theorem & the Euclidean algorithm
- Understand the basics of modular arithmetic.
- State and prove Fermat's little Theorem & its generalization using Euler's function & use them to implement the RSA cipher &discrete log cipher.

Suggested Readings:

1. I. Niven, H. Zuckerman and H. L. Montgomery: An Introduction to the Theory of Numbers (6th edition) , John Wiley and sons, Inc., New York, 2003.
2. D. M. Burton: Elementary Number Theory (4th edition) –Universal Book Stall,New Delhi,2002.
3. S.B.Malik: Basic Number Theory (Second Revised Edition), Visas Publishing House (Pvt.) Ltd. New Delhi
4. Dr.G.S.Sandhu :Number Theory –I, First world Publication,

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (I Semester)

MATH-104: ORDINARY DIFFERENTIAL EQUATIONS

Objective: - The main aims of this course ordinary differential equations are to provide an introduction of ordinary differential equations. Solving first-order differential equations, existence and uniqueness theorems, second-order linear equations, power series solutions and higher-order linear equations, systems of equations, non-linear equations, Sturm Liouville theory, and applications. An introduction to numerical solutions and applications of differential equations in physics, engineering, biology, and economics are presented. This course covers more material at greater depth than the standard undergraduate-level ODE course.

UNIT-1 **(10 Sessions)**

Existence and Uniqueness theorem, Linearly dependent and independent solutions, The Wronskian, Theorems for Wronskian, Necessary and sufficient conditions for the Wronskian, The Wronskian for n functions, Solution of Exact differential equation of order n, Solution of differential equations of special forms.

UNIT-2 **(10 Sessions)**

Existence and Uniqueness of solution of initial value problem for first order ODEs, Singular solution of first order ODEs, System of first order ODEs, General theory of homogeneous and non – homogeneous linear ODEs .

UNIT-3 **(08Sessions)**

Solutions of ODEs of Second order with variable coefficient when C.F. is known, Normal form, Change of independent variable, Variation of parameter by Initial and boundary conditions.

UNIT-4 **(10 Sessions)**

Bessel's Differential equation and its solution, Recurrence relations for Bessel's function, Generating function for Bessel's function, Orthogonality of Bessel's function, Problems on Bessel's function, Legendre differential equation and its solution, Generating function for Legendre Polynomial , Trigonometric series for $P_n(x)$, Laplace first and second Integral for $P_n(x)$, Orthogonal property for $P_n(x)$, Recurrence relations, Rodrigue formula.

UNIT-5 **(10 Sessions)**

Picard's Method, Existence and uniqueness of Picard's solutions, Sturm – Liouville boundary value problem, Green's function.

Course Outcomes:

Students completing this course will be able to:

- Explain the concept of differential equation, Classifies the differential equations with respect to their order and linearity.
- Explains the meaning of solution of a differential equation.
- Expresses the existence-uniqueness theorem of differential equations.
- Solve first-order ordinary differential equations.
- Solves exact differential equations.
- Converts separable and homogeneous equations to exact differential equations by integrating factors.

Suggested Readings:

1. J.N.Sharma &Dr. R.K. Gupta: Differential Equations, Krishna Publication.
2. M.D. Rai Singhania: Advanced Differential Equations, S. Chand & Company Ltd, New Delhi.
3. Shepley.L.Ross : Differential Equations, Wiley India (Pvt.) Ltd.
4. RamKrishnaGhosh & Maity :An Introduction to Differential Equations,Sarthak Publication

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (I Semester)

MATH- 105: COMPUTER FUNDAMENTAL AND PROGRAMMING IN C

Objective: - The main aims of this course Computer Fundamental and Programming in C are to provide an introduction of Computer fundamental, an understanding of basic concepts of computer science and engineering, fundamentals of hardware, software and programming, mathematical software. This course also provides an understanding of cyber laws and computer security.

UNIT-1 **(10 Sessions)**

Computer Fundamental: Introduction of computer, Classification of computers, Applications of computers, Generations of computer, Basic organization of a computer, Software and its types, Hardware, Input devices, Output devices.

UNIT-2 **(08 Sessions)**

Computer memory, Memory hierarchy, Registers, Cache memory, Primary memory, Secondary memory, Logic gates.

Operating System: Definition of operating system, Function of operating system, Types of operating system.

UNIT-3 **(10 Sessions)**

Programming Using C: Variables, Constant, Operators, Basic data types, Type casting, Type conversion, Functions, Decision control statements, Looping statements, Arrays and String.

UNIT-4 **(10 Sessions)**

Internet: Introduction of internet and Internet services (E-mail, File transfer protocol, Online shopping etc), Searching information through a search engines, World wide web.

UNIT-5 **(10 Sessions)**

Networks: Computer networks, Types of networks, Network topology, Data transmission mode.

Course Outcomes:

Students completing this course will be able to:

- Implement the algorithms and draw flowcharts for solving Mathematical and Engineering problems. Demonstrate an understanding of computer programming language concepts.
- Develop C programs on linux platform. Ability to design and develop Computer programs, analyzes, and interprets the concept of pointers, declarations, initialization, operations on pointers and their usage.
- Define data types and use them in simple data processing applications also he/she must be able to use the concept of array of structures. Student must be able to define union and enumeration user defined data types.
- Develop confidence for self-education and ability for life-long learning needed for Computer language.

Suggested Readings:

1. 1.Pradeep K. Sinha and Priti Sinha: Computer Fundamentals, BPB Publications, (4th Edition).
2. V. Raja Raman: Fundamentals of Computers, PHI Learning, (5th Edition).
3. Yashavant P. Kanetkar: Let us C, Infinity Science Press, (8th Edition).
4. E. Balagurusamy: Fundamentals of Computers, McGraw-Hill Inc.,US.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (II Semester)

MATH-201: TOPOLOGY

Objective: - The main aims of this course are to introduce Topological spaces, Open Sets, closed sets, and Subspaces, Basis, Product Topology and Subbasis, Metrics, Metric spaces, Hausdorff Space, Sequences in Topological Spaces, Metrizability Problem and Examples of Metrizable Spaces, Continuity, Homeomorphisms, Compactness, Limit Point Compactness and Sequentially Compact Spaces and Some of their properties.

UNIT-1 **(10 Sessions)**

Metric Space: Metric, Metric space, Open sets, Interior, Exterior, and Frontier points, Closed sets, Continuity and Homomorphism in metric space.

UNIT-2 **(10 Sessions)**

Topological Spaces: Topological space, Open and closed sets and Limit points, Metric topology, Subspace, Continuous functions, Homomorphism of topological space, Basis for a topology, Product space and Quotient space.

UNIT-3 **(10 Sessions)**

Connectedness: Connected spaces, connected subspaces of real line, Components and Local connectedness, totally disconnected spaces.

UNIT-4 **(08 Sessions)**

Compactness: Compact spaces, Compact subspaces of real line, Limit point compactness, Local compactness.

UNIT-5 **(10 Sessions)**

Countability and Separation Axioms: Countability axioms, the separation axioms, Normal spaces, Regular spaces, Completely regular spaces, Urysohn's lemma, Urysohn metrization theorem(without proof), Tietze extension theorem.

Course Outcomes:

Students completing this course will be able to:

- Know how the topology on a space is determined by the collection of open sets, by the collection of closed sets, or by a basis of neighborhoods at each point, and you know what it means for a function to be continuous.
- Know the definition and basic properties of connected spaces, path connected spaces, compact spaces, and locally compact spaces.
- Know what it means for a metric space to be complete, and you can characterize compact metric spaces.
- Know about the Urysohn lemma and the Tietze extension theorem, and you can characterize metrizable spaces.
- Construction of the fundamental group of a topological space and applications to covering spaces and homotopy theory.

Suggested Readings:

1. J.L.Kelley: *General Topology,* Springer Verlag, New York 1991.
2. B. D. Gupta: Topology, Kadarnath Ramnath Publication.
3. J. R Munkres: Topology, a first course, Prentice-Hall of India Ltd., New Delhi, 2000.
4. K. D. Joshi, An introduction to general topology, 2nd edition, Wiley Eastern Ltd., New Delhi,2002.
5. J. N. Sharma J. P. Chauhan : Topology, Krishna Prakashan Media.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (II Semester)

MATH – 202: CLASSICAL MECHANICS

Objective: - The main aims of this courseare to demonstrate the knowledge of functional and extremum path and the application in solving some fundamental problems, demonstrate the knowledge and understanding of the fundamental concepts in the dynamics of system of particles and Lagrangian and Hamiltonian formulation of mechanics and to represent the equations of motion for complicated mechanical systems using the Lagrangian and Hamiltonian formulation.

UNIT – 1 **(10 Sessions)**
Definitions, Moment of Inertia, Product of inertia, Moment of Inertia of rectangle, Hollow sphere, Solid sphere, Circular wire, Archual wire, Cone, Moment of Inertia of heterogeneous bodies.

UNIT – 2 **(10 Sessions)**
Principle axes,Moment of Inertia about principle axes at any point, Motion about fixed axes.

UNIT – 3 **(08 Sessions)**
Generalized coordinate, Holonomic & non-holonomic system, D'Alembert's principle, Lagrange's equations.

UNIT – 4 **(10 Sessions)**
Hamilton's principle, Lagrange's equations from Hamilton's principle, Extension of Hamilton's principle to non-conservative and non-holonomic systems, Conservation theorems and symmetry properties.

UNIT – 5 **(10 Sessions)**
Eulerian angles, Euler's theorem on the motion of a rigid body, Infinitesimal rotations, Rate of a vector, Coriolis force, Euler's equation of motion, force free motion of a rigid body, Heavy symmetrical top with one point fixed.

Course Outcomes:
Students completing this course will be able to:

- Define and understand basic mechanical concepts related to discrete and continuous mechanical systems.
- Describe and understand the vibrations of discrete and continuous mechanical systems.
- Describe and understand planar and spatial motion of a rigid body.
- Describe and understand the motion of a mechanical system using Lagrange-Hamilton formalism.

Suggested Readings:

1. C.R. Mondal : Classical Mechanics, Prentice-Hall of India,2001 .
2. T. W. B. Kibble:Classical Mechanics, Longman, Londan,1985 .
3. L.D. Landau and E. M. Lipshitz: Mechanics, pergamon press, oxford, 1976 .
4. Morin David: Introduction to Classical Mechanics with Problems and Solutions, Cambridge.

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- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (II Semester)

MATH-203: DISCRETE MATHEMATICS

Objective: -The main aims of this course areto prepare students to develop mathematical foundations to understand and create mathematical arguments require in learning many mathematics and computer sciences courses. To motivate students how to solve practical problems using discrete mathematics. Also, in this course basic concepts of Graph theory such as Trees, Eulerian Graphs, Matching, Vertex colourings.

UNIT – 1 **(10 Sessions)**

Propositional Calculus: Propositions, Compound propositions, Basic logical operations, Tautologies and Contradictions, Logical equivalence, Algebra of propositions, Conditional and Biconditional statements, Normal forms, Arguments and Quantifiers.

UNIT – 2 **(10 Sessions)**

Graph Theory: Graph, Finite and Infinite graphs, Multigraph, Trivial graph, Simple graph, Psuedograph, Degree of a vertex, Null graph, Subgraph, Connected and Disconnected graphs, Directed graph, Paths, cycles, Isomorphic graph, Homomorphic graph, Complete graph, Regular graph, Bipartite graph, Complete bipartite graph, Operations of graphs, Shortest path problems.

UNIT – 3 **(08 Sessions)**

Planar graph, Region of a graph, Euler's formula, Graph coloring, Chromatic number, Matching,Matrix representation of undirected graph and directed graph,Adjacency matrix, Incidence matrix, Path matrix and Circuit matrix.

UNIT – 4 **(10 Sessions)**

Trees: Tree, Forest, Rooted tree, Properties of trees, Binary tree, Level, Height, Balanced tree, Spanning Trees, Path length of tree, Minimal Spanning Tree, Kruskal's algorithm, Prim's algorithm, Cut Sets, Fundamentals Cut-set, Edge connectivity and vertex connectivity.

UNIT – 5 **(10 Sessions)**

Combinatorics: Basic counting principles, Permutation, Combination, Pigeonhole principle, Inclusion-Exclusion principle, and discrete numeric function, Generating function, Recurrence relations.

Course Outcomes:

Students completing this course will be able to:

- Write an argument using logical notation and determine if the argument is or is not valid.
- Demonstrate the ability to write and evaluate a proof or outline the basic structure of and give examples of each proof technique described.
- Understand the basic principles of sets and operations in sets.
- Apply counting principles to determine probabilities.
- Demonstrate an understanding of relations and functions and be able to determine their properties.
- Demonstrate different traversal methods for trees and graphs.

Suggested Readings:

1. J.P. Tremblay and R.P. Manohar: Discrete Mathematics with Applications to Computer Science, Tata McGraw-Hill Publishing Company Limited, New Delhi, 1989.
2. Seymour Lipschutz and Marc Lars Lipson: Discrete Mathematics, Tata McGraw-Hill publishing company Limited, New Delhi.
3. N. Deo : Graph Theory with application to Engineering and Computer Science, PHI.
4. Swapan Kumar Sarkar: A text book of discrete mathematics, S. Chand & Company Pvt. Ltd. New Delhi.
5. M. K. Gupta : Discrete Mathematics, Krishna Prakashan Media P. Ltd.-Meerut.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (II Semester)

MATH – 204: LINEAR ALGEBRA

Objective: - The main aims of this course are to enables the students to understand the basic ideas of vector algebra, linear dependent and independent set, basis, the fundamental properties of eigenvalue, eigenvectors of a linear transformation Various types of real quadratic forms and their applications to familiar with the notion of inner product space and orthogonal vectors.

UNIT-I **(10 Sessions)**

Vector spaces, Linear independence,linear transformations, Matrix representation of a linear transformation, Isomorphism between the algebra of linear transformations and that of matrices.

UNIT-II **(10 Sessions)**

Similarity of matrices and linear transformations, Trace of matrices and linear transformations, Characteristic roots and characteristic vectors, Characteristic polynomials, Relation between Characteristic polynomial and Minimal polynomial, Cayley-Hamilton theorem, Diagonalizability.

UNIT-3 **(10 Sessions)**

Linear transformations and their algebra, Range and null space, Rank and nullity, Rank-nulity theorem, Matrix representation of linear transformations, Change of basis.

UNIT-4 **(08 Sessions)**

Linear functions, Dual space, Bi-dual space, Natural isomorphism, Annihilators, Bilinear and quadratic forms.

UNIT-5 **(10 Sessions)**

Inner product spaces, Cauchy-Schwarz's inequality, Bessel's inequality and orthogonality, Hermitian, Unitary and normal transformations and their diagonalizations.

Course Outcomes:

Students completing this course will be able to:

- Define basic terms and concepts of matrices, vectors and complex numbers.
- Use of various forms of complex numbers to solve numerical problems.
- Apply the matrix calculus in solving a system of linear algebraic equations
- Calculate the area of planar shapes (triangle, parallelogram) and the volume of parallelepiped using vector algebra.

Suggested Readings:

1. I. N. Herstein : Topics in Algebra (4th edition) –Wiley Eastern Limited, New Delhi, 2003.
2. G. E. Shilov : Linear Algebra -Prentice Hall, 1998.
3. P. R. Halmos, Van Nostrand Inc: Finite Dimensional Vector Spaces –1965.
4. D. T. Finkbeiner, D.B. Taraporevala: Introduction to Matrices and Linear Transformations (3rd edition), Bombay, 1990.
5. S. Kumaresan: Linear Algebra,A Geometric Approach –, Prentice-Hall of India Pvt.

Website Sources:

- www.pdfdrive.com
- www.dmi.gov.in
- www.yourarticlelibrary.com
- onlinecourses.nptel.ac.in
- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – I Year (II Semester)

MATH-205: COMPLEX ANALYSIS

Objective: - The main aims of this courseare toenables the students to understand the strength of being analytic for a complex variable function and different properties associated with analytic functions, the integration of complex variable functions and different techniques to evaluate complex integrals the series of complex variable functions, criteria for their convergence and divergence, the singularities of complex variable functions and methods to compute residues, mapping of complex variable functions and its different types.

UNIT-1 **(10 Sessions)**

Powers and roots Regions in complex plane, Functions, Mapping, Limits, Continuity, Differentiability, Analytic Functions, C-R equations, Theorems on analytic functions, Harmonic functions, Milne's Thomson method.

UNIT-2 **(10 Sessions)**

Elementary Complex Functions like Exponential, Logarithmic, Complex exponent, Trigonometric, Inverse trigonometric and hyperbolic functions, Cauchy's fundamental theorem for n^{th} derivative, simply and multiply connected Domains, Cauchy's integral theorem, Cauchy's integral formula, Liouville's Theorem.

UNIT-3 **(10 Sessions)**

Convergence of sequence and series, Taylor's series, Laurent's series, Uniform convergence of power series, Continuity of sums of power series,Integration and differentiation of power series, Multiplication and division of power series.

UNIT-4 **(10 Sessions)**

Residues, Cauchy's residue Theorem, Residues at poles, Zeros of analytic functions, Zeros and poles, Behaviour of near Isolated Singular Points, Applications of Residues in Evaluation of improper integrals, Jordan's lemma, Indented paths, Integration along a branch cut.

UNIT-5 **(08 Sessions)**

Conformal mapping, Mapping by Elementary Functions, Bilinear transformations, Mappings by the transformations 1/z, Mappings of upper half plane.

Course Outcomes:

Students completing this course will be able to:

- Determine whether a sequence of analytic functions converges uniformly on compact sets
- Express some functions as infinite series or products.
- Demonstrate capacity for mathematical reasoning through analyzing, proving and explaining concepts from complex analysis.
- Apply problem-solving using complex analysis techniques applied to diverse situations in physics, engineering and other mathematical contexts.

Suggested Readings:

1. V.Ruel: Churchill / James Ward Brow:Complex Variables and Applications, TMH Publication.
2. T.Pati: Function of Complex Variable, Pothisala Pvt.Ltd, Allahabad.
3. S. Ponnusamy: Foundation of complex Analysis, Narosa Publishing House, India 2005.
4. L.V. Ahlfors: Complex Analysis, 2nd Edition. McGraw-Hill International Student Edition, 1990.
5. R.R.Kumar: Complex Analysis, Pearson Education, 2015.
6. R.Churchill and J.W. Brown, Complex Variables and Applications, 6th Edition. New- York, McGraw-Hill, 1996.

Website Sources:

- www.pdfdrive.com
- www.dmi.gov.in
- www.yourarticlelibrary.com
- onlinecourses.nptel.ac.in
- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (III Semester)

MATH-301: FUNCTIONAL ANALYSIS

Objective: - The main aims of this course are to cover the basics of functional analysis. The theory includes linear operators on Hilbert spaces, banach spaces, and locally convex spaces. It also includes an introduction to spectral theory and fixed point theorems, and applications of these on non-linear operators. Function spaces and base expansions of different kinds are also discussed.

UNIT-1 **(10 Sessions)**

Normed linear spaces, Quotient space of normed linear spaces definition and examples, Holder's inequality, Continuous linear transformations between normed linear spaces, Minkowski's inequality,Banach spaces, L*p* spaces, Convergence and completeness.

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UNIT-2 **(08 Sessions)**

Riesz-Fischer theorem, Bounded linear function on Lp spaces, Riesz representation theorem, Hahn-Banach theorem and its consequences.

UNIT-3 **(10 Sessions)**

Embedding of a normed linear space in its second conjugate space, Strong and weak convergence, Open mapping theorem, Closed graph theorem, Uniform boundedness theorem,
Conjugate of an operator.

UNIT-4 **(10 Sessions)**

Hilbert's space, Examples and simple properties, Orthogonal complements, Orthonormal set, Bessel's inequalities, Complete orthonormal sets, Gram-Schmidt orthogonalization process, Self adjoint operators.

UNIT-5 **(10 Sessions)**

Normal and unitary operators, Projection theorem, Spectrum of an operator, Spectral theorem for a normal operator on a finite dimensional Hilbert space.

Course Outcomes:

Students completing this course will be able to:

- Learn and recognize the fundamental properties of normed spaces and of the transformations between them.
- Define and thoroughly explain Banach and Hilbert spaces and self-adjoint operators.
- Independently decide if a linear space is a Banach space.
- Identify and independently use contractions of Banach spaces via Brouwers and Schauders fixed point theorems.
- Be acquainted with the statement of the Hahn-Banach theorem and its corollaries.
- Understand the notions of dot product and Hilbert space.
- Apply the spectral theorem to the resolution of integral equations.

Suggested Readings:

1. W. Rudin: Functional Analysis, Tata McGraw hill Book Company, 1974.
2. B. V. Limaye: Functional Analysis, Willy Eastern Ltd., 1991.
3. C.Goffman and G. Pedrick: First course in Functional Analysis, Prentice-Hall of India Pvt. Ltd, New Delhi.
4. Erwin Kreyszig: Introduction to functional Analysis with Application, John wiley & Son Inc.,New York.
5. S. Ponnusamy : Foundations of Functional Analysis, Narosa publication.

Website Sources:

- www.pdfdrive.com
- www.dmi.gov.in
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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (III Semester)

MATH-302: FLUID DYNAMICS

Objective: -The main aims of this course are to introduce fundamental aspects of fluid dynamics for its fluid flow behaviour. Students will learn to develop steady state mechanical energy balance equation for fluid flow systems, estimate pressure drop in fluid flow systems and determine performance characteristics of fluid machinery.

UNIT-1 **(10 Sessions)**

Kinematics of fluids:Lagrange's and Euler's Method, Stream lines, Equation of continuity, Boundary surface equation of motions of non-viscous fluids , Euler's equation of motion (Vector form), Bernoulli's pressure equation, Equation for impulsive motion (vector form).

UNIT-2 **(10 Sessions)**

Motion in two dimensions: Stream function, Complex potential of the motion, Sources and sinks in two dimensions, Doublets, Images.

UNIT-3 **(08 Sessions)**

General theory of irrotational motion: Flow and circulations, Permanence of irrotational motion, Kelvien's circulation theorem , Minimum Energy theorem , Kutta –Joukowski theorem, Kinetic Energy of infinite liquid, Motion of cylinders, Motion of a circular cylinder, Liquid Streaming passed a fixed circular cylinder.

UNIT-4 **(10 Sessions)**

Irrotational Motion in three Dimensions: Motion of a sphere, Sphere through a liquid at rest atInfinity,Liquid streaming passed a fixed sphere, Equation of a sphere, Stokes stream function.

UNIT-5 **(10 Sessions)**

Stress components in a real fluid, Relation between rectangular components of stress connection between stresses and gradients of velocity, Navier – Stoke's equations of motions plane Poiseuille and Couette flows between two parallel plates.

Course Outcomes:

Students completing this course will be able to:

- Apply knowledge of mathematics, science and engineering to arrive solutions.
- Identify, formulate and analyze engineering problems through technical literature.
- Design a component, a process and a system to meet desired needs considering economic, environmental, social, ethical, health and safety, manufacturability and sustainability.
- Conduct experiment, analyze and interpret data to arrive valid conclusions.
- Use the techniques, skills, and modern engineering tools for modeling and prediction of problems by understanding the limitations.

Suggested Readings:

1. G.K. Bachlor: An introduction to Fluid Mechanics, foundation book.
2. H. Schnichting: Boundary layer theory Mc. Graw Hill, book company.
3. R.K.Rathy: An Introduction to Fluid Dynamics, Oxford &IBH publishing company.
4. W.H. Besaint and A.S. Ramsey: A Treatise on Hydromechanics, part II, CBS publication.
5. A.J.Chorin and A. Marsden: A Mathematical introduction to Fluid Dynamics, Springer-Veriag New York
6. M. D. Rai Singhania: Fluid Dynamics, S. Chand Publication, New Delhi.
7. M.Ray: Fluid Dynamics, Ram Prasad and Sons, Agra.

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- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (III Semester)

MATH-303: NUMERICAL ANALYSIS

Objective: -The main aims of this course are to introduce a broad range of numerical methods for solving mathematical problems that arise in Science and Engineering. The goal is to provide a basic understanding of the derivation, analysis, and use of these numerical methods, along with a rudimentary understanding of finite precision arithmetic and the conditioning with stability of the various problems and methods. This will help to choose, develop and apply the appropriate numerical techniques for your problem, interpret the results, and assess accuracy.

UNIT - 1 **(10 Sessions)**

Interpolation with Equal Intervals: Introduction, Newton's-Gregory forward and Newton's-Gregorybackward interpolation formulae, Central differences, Gauss's forward and Gauss's backward interpolation formulae, Stirling's formula, Bessel's formula and Laplace-Everett formula.

UNIT - 2 **(08 Sessions)**

Interpolation with Unequal Intervals: Introduction, Divided differences, Divided difference table, Newton's divided difference formula, Lagrange's interpolation formula, Lagrange's inverse formula, Hermite interpolation formula.

Numerical Differentiation: Introduction, Derivatives of Newton's forward and Newton's backward interpolation formulae, Derivative of Stirling's formula, Maxima and minima.

UNIT - 3 **(10 Sessions)**

Numerical Integration: Introduction, General quadrature formula, Trapezoidal rule, Simpson's one-third rule, Simpson's three-eighth rule, Boole's, Weddle's rule and applications.

Numerical Solution of Ordinary Differential Equations: Introduction, Picard's method, Taylor's series method, Euler's method, Modified Euler's method, Runge–Kutta's methods and Predictor-Corrector methods.

UNIT - 4 **(10 Sessions)**

Solution of Simultaneous Algebraic Equations: Introduction, Gauss's elimination method and with pivoting, Gauss-Jordan Method, Jacobi's iteration method and Gauss- Seidal iteration method and III-Conditioned system of linear equations.

UNIT - 5 **(10 Sessions)**

Solution of Algebraic and Transcendental Equations: Introduction, Bisection method, Regula - falsi method, Iteration method, Newton - Raphson method, Graeffe's root squaring method and rate of convergence of Newton - Raphson method .

Course Outcomes:

Students completing this course will be able to:

- Derive numerical methods for various mathematical operations and tasks such as interpolation, Differentiation, linear and nonlinear equations.
- Derive numerical methods to find out solution of algebraic equations using different methods under different conditions, and numerical solution of system of algebraic equations
- Apply various interpolation methods with finite difference concepts.
- Work out numerical differentiation and integration whenever and wherever routine methods are not applicable.
- Derive numerical methods for solving ordinary differential equations with certain initial and boundary conditions.

Suggested Readings:

1. V. Rajaraman: Computer Oriented Numerical Methods, PHI.
2. Gupta & Malik: Numerical Analysis, Krishna Publication, Meerut.
3. B. S.Grewal: Numerical methods in Engineering and Science, Khanna Publishers, Delhi.
4. Pradip Niyogi: Numerical Analysis and Algorithms, TMH.
5. R. K. Jain, Iyenger: Numerical Analysis, New age publication, Delhi.

Website Sources:

- www.pdfdrive.com
- www.dmi.gov.in
- www.yourarticlelibrary.com
- onlinecourses.nptel.ac.in
- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (III Semester)

MATH-304: PARTIAL DIFFERENTIAL EQUATIONS

Objective: -The main aims of this course are to familiarize the students with the fundamental concepts of Partial Differential Equations (PDE) which will be used as background knowledge for the understanding of specialized courses in the field of science by solving homogeneous heat, wave, Laplace's equations, characteristics of Integral Transforms, special functions and orthogonal polynomials, Sturm-Liouville and generalized fourier series, PDE's in higher dimensions and numerical methods for PDE problems.

UNIT I **(10 Sessions)**

Lagrange's equations, Charpit's method, Jacobi's method for solving a non- linear first order P.D.E in two variables, Cauchy Problem for First order P.D.Es.

UNIT II **(10 Sessions)**

PDEs of order two with variables coefficient, Monge's method, Method of Separation of variables for Laplace, Heat and Wave Equations, Solution of Boundary value Problems by Laplace Transformation.

UNIT III **(10 Sessions)**

Solution of Laplace Heat and wave equations in Cartesian, Polar, Cylindrical, Application of sine and cosine transforms and their finite fourier to solve boundary value Problems.

UNIT IV **(08 Sessions)**

Calculus of variations: Variations of a functional, Euler- Lagrange's equations, Necessary and sufficient conditions for extrema, Variational method for boundary value problem in ordinary and partial differential equations.

UNIT V **(10 Sessions)**

Numerical Solution of Partial Differential Equations:

Solution of Laplace equation: Solution of Laplace equation by Liebmann's method, Jacobi method, Solution of Poisson's equations, Solution of heat equations by Bender- Schmidt and Crank-Nicholson methods, Solution of Wave equation.

Course Outcomes:

Students completing this course will be able to:

- Classify partial differential equations and transform into canonical form
- Solve linear partial differential equations of both first and second order
- Apply partial derivative equation techniques to predict the behavior of certain phenomena.
- Apply specific methodologies, techniques and resources to conduct research and produce innovative results in the area of specialization
- Extract information from partial derivative models in order to interpret reality
- Identify real phenomena as models of partial derivative equations.

Suggested Readings:

1. N. Sharma & Dr. R.K. Gupta : Differential Equations : Krishna Prakashan Media (P) Ltd. Meerut.
2. M.D. Rai singhania : Advanced Differential Equations: Including Boundary Value Problems, Laplace Transform & Its Applications : S.Chand and company Ltd, Delhi.
3. I.N. Sneddon: Elements of Partial Differential Equation, 3rd Edition. McGraw Hill BookCompany, 1998.
4. E.T.Copson: Partial Differential Equations, 2nd Edition. Cambridge University Press, 1995.

Website Sources:

- www.pdfdrive.com
- www.dmi.gov.in
- www.yourarticlelibrary.com
- onlinecourses.nptel.ac.in
- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (III Semester)
MATH-305: INTEGRAL EQUATIONS AND INTEGRAL TRANSFORMS

Objective: -The main aims of this course are to exposing the students to learn the Laplace transforms and Fourier transforms. To equip with the methods of finding Laplace transform and Fourier Transforms of different functions. To make them familiar with the methods of solving differential equations, partial differential equations,initial value problem (IVP) and boundary value problem (BVP) using Laplace transforms and Fourier transforms.

UNIT-1 **(10 Sessions)**

Integral Equations: Definitions and classification of linear integral equation, Singular Integral Equations, Integro-differential equation, Conversion of differential equation into integral equation, Solution of volterra integral equation by The method of successive substitution and Successive Approximation methods, Volterra integral equation of first kinds and Second kinds.

UNIT-2 **(08 Sessions)**

Fredholm integral Equation: Solution of Fredholm integral equation by the method of successive substitution and successive approximations, Reciprocal function, Orthogonal kernels , Linear integral equation with degenerated kernels, Fredholm fundamental relation , Hadamard's theorem, Convergence theorem , Integral formula Solution of Homogeneous integral Equation .

UNIT-3 **(10 Sessions)**

Non-liner Integral Equations: Non-linear Fredholm Integral equations, Direct Computation, decomposition method, Nonlinear Volterra Integral Equation, Series solution, Decomposition method Existence and uniqueness of solutions using fixed-point theorems in case of Linear and nonlinear Volterra and Fredholm integral equations.

UNIT-4 **(10 Sessions)**

Fourier Transforms: Definition Properties evaluation of Fourier and inverse Fourier transforms[FT] of functions, Convolution theorem of FT, Sine and Cosine Fourier transforms, Solving differential equations and integral equations using Fourier Transform.

UNIT-5 **(10 Sessions)**

Laplace Transform :- Definition, Properties evaluation of Laplace and Inverse Laplace transforms of functions, Convolution theorem for Laplace Transforms, Solving the initial value problem using Laplace Transforms, Solving integral equation using Laplace Transforms, Solution of Volterra integral Equation using Laplace Transform, Mellin Transforms.

Course Outcomes:

Students completing this course will be able to:

- Use Fourier transforms for solving a wide range of differential and integral equations.
- Formulate and solve initial and boundary value problems for the heat and wave equations in spherical and cylindrical coordinates.
- Solve linear Volterra and Fredholm integral equations using appropriate methods.
- Understand the relationship between integral and differential equations and transform one type into another.

Suggested Readings:

1. A.J. Jerri:Introduction to Integral Equation with Applications (2nd edition), Wiley Interscience.
2. I.K.Goyal & K.P.Gupta:Integral Transforms, Pragati Prakashan, Meerut.
3. F. Smithies: Integral equations, Cambridge Univ. Press (1959).
4. M. Rahman: Integral Equations and Their Applications, WIT Press, 2007.
5. P. J. Collins: Volterra integral and differential equations, Oxford University press, Oxford, 2006.

Website Sources:

- www.pdfdrive.com
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- www.yourarticlelibrary.com
- onlinecourses.nptel.ac.in
- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH-401: OPERATIONS RESEARCH

Objective: -The main aims of this course are to help the students for solving problems in different environments that needs decisions. This module aims to introduce students to use quantitative methods and techniques for effective decisions–making; model formulation and applications that are used in solving business decision problems as well as to our daily life in science and engineering.

UNIT – 1 **(10 Sessions)**

Basics of Operations Research: Definitions of operations research, Scope of operations research, Phases of operations research, Models in operations research, Uses and limitations of operations research.

Linear Programming Problems: Definition, Formulation of LPP, Advantages of LPP, Limitations of LPP, Application areas of LPP, Graphical method for solving LPP, Simplex method, Big-M simplex method, Two-Phase simplex method.

UNIT – 2 **(10 Sessions)**

Duality in Linear Programming Problems: Definition, Formulation of dual problem, Advantages of duality, Characteristics of dual problem and Dual simplex method.

Integer Linear Programming Problems: Definition, Applications of integer programming, Types ofInteger programming problems, Gomory's all integer cutting plane method and Branch and bound method.

UNIT – 3 **(10 Sessions)**

Replacement Models: Definition, Types of failure, Replacement of items whose efficiency deteriorates with time, Replacement of equipment that deteriorates with time and Replacement items that fail completely.

Inventory Control: Definition, Types of inventory, Inventory control terminology, Economic order quantity, Inventory control models without shortages, Inventory control models with shortages, EOQ models with quantity discounts with one-price break and Two-Price break.

UNIT – 4 **(10 Sessions)**

Queuing Theory: Definition, Essential features of a queuing system, Performance measures of a queering system, Probability distributions in queuing system, Classification of queuing models and their solution, Single server queuing models I, II, III and Multi-Sever queuing models.

UNIT – 5 **(08 Sessions)**

Game Theory: Definition, Pay-off, Types of games, The maximine-minimax principle, Principles of dominance, Games without saddle points (Mixed strategies), Solution of games by Graphical method and Linear programming method.

Non-Linear Programming Problem: Definition, Lagrange multiplier method, Quadratic programming and Kuhn-Tucker conditions.

Course Outcomes:

Students completing this course will be able to:

- Formulate real-world problems as a linear programming model and describe the theoretical workings of the graphical and simplex method, demonstrate the solution process by hand and solver.
- Explain the relationship between a linear program and its dual, including strong duality and complementary slackness.
- Formulate specialized linear programming problems, namely transportation and assignment problems and describe theoretical workings of the solution methods for transportation and assignment problems.
- Demonstrate solution methods including graphs and linear programming to analyze and solve the Two-person, zero-sum games.

Suggested Readings:

1. H. A. Taha: Operations Research an introduction, Macmillan.
2. J. K. Sharma: Operations Research Theory and Applications, Macmillan India Ltd.
3. V. K. Kapoor: Operations Research, Sultan Chand and Sons, New Delhi.
4. S. D. Sharma: Operations Research, Kedarnath & Ramnath and Company.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH- 402: MATHEMATICAL STATISTICS

Objective: -The main aims of this course are to enable the students with understanding of various types of probability distributions and testing of hypothesis problems. Its aim to equip the students with standard concepts of statistical techniques and their utilization in the field of science.

UNIT-1 **(10 Sessions)**
Probability set theoretic approach, Baye's theorem, Geometric probability, Random variables: Distribution function, Joint probability distribution, Conditional distribution function.

UNIT-2 **(10 Sessions)**
Mathematical Expectation, Expectation of continuous random variable, Moment generating functions, Cumulantand characteristic functions, Weak law and Bernoulli's Laws of large numbers.

UNIT-3 **(10 Sessions)**
Distributions: Bernoulli, Binomial, Poisson and Normal distributions, Central limit theorem

UNIT-4 **(08 Sessions)**
Correlation and Regressions, Method of least square, Fitting of a straight line, Parabola and exponential curves. Derivation of Chi-square distribution, Goodness of fit, Test of significance, t-test and F-test.

UNIT-5 **(10 Sessions)**
Analysis of variance, Analysis of variance in one way and two ways classification, Theory of estimation, Principle of maximum likelihood, Properties of maximum likelihood estimators.

Course Outcomes:
Students completing this course will be able to:

- Recognize the importance and value of mathematical and statistical thinking, training, and approach to problem solving, on a diverse variety of disciplines.
- Be familiar with a variety of examples where mathematics or statistics helps accurately explain abstract or physical phenomena.
- Recognize and appreciate the connections between theory and applications.
- Be able to independently read mathematical and statistical literature of various types, including survey articles, scholarly books, and online sources.
- Be life-long learners who are able to independently expand their mathematical or statistical expertise when needed, or for interest's sake.

Suggested Readings:

1. J. Medhi : Statistical Methods , New age International (P) Ltd.
2. J.K.Ghosh : Mathematical Statistics , John Wiley & Sons , New York .
3. Hogg : Introduction of Mathematical Statistics, Pearson Education.
4. S. C. Gupta & V. K. Kapoor : Advanced Statistics, S. Chand.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH-403: RING THEORY

Objective: -The main aims of this course are to introduce basic structures of algebra as rings which is the main pillars of modern mathematics. Special kinds of rings, Subrings and ideals, homomorphism, Quotient rings, Prime and maximal ideals, polynomial rings The course gives the student a good mathematical maturity and enables to build mathematical thinking and skill.

UNIT-1 **(10 Sessions)**

Basic concepts of rings, Modules, Operations on ideals and sub-modules, Matrix rings, Polynomial rings, Direct products of rings, Fields and division rings, Idempotent and nilpotent elements in a ring.

UNIT-2 **(08 Sessions)**

Isomorphism theorems, Exact sequences, Group of homomorphisms and its properties relative to exact sequences.

UNIT-3 **(10 Sessions)**

Direct sums and direct products of modules, External and internal direct sums, Direct summands, Zorn's lemma, Every vector space has a basis, Free modules and projective modules, Torsion free and torsion modules over commutative domains, Exact sequences and projectivity.

UNIT-4 **(10 Sessions)**

Injective modules, Injectivity and divisibility over domains, Exact sequences and injectivity, Baer's theorem and its elementary applications, Simple modules, Semi simple modules (as per Bourbaki), Schur's lemma.

UNIT-5 **(10 Sessions)**

Equivalent conditions for semi simple modules, Wedderburn structure theorem (only statement), Characterization of semi simple rings via projective and injective modules.

Course Outcomes:

Students completing this course will be able to:

- Prove results involving divisibility and greatest common divisors.
- Applications of Modular Arithmetic, Solve systems of linear equations.
- Find integral solutions to specified linear Diophantine Equations.
- Apply Euler-Fermat's Theorem to prove relations involving prime numbers.
- Apply the Wilson's theorem and Polynomial addition, subtraction, division, multiplication, roots of polynomial, Transformation, translation and reflection equations.

Suggested Readings:

1. I. T. Adamson : Elementary Rings and Modules, Oliver and Boyd, Edinburgh, 1995.
2. J. J. Rotman : Notes on Homological Algebra, Van nostrand, 1990.
3. N. Jacobson : Basic Algebra II (3rd edition), Hindustan Publishing Corporation, New Delhi, 2002.
4. John B Fraleigh: A First Course in Abstract Algebra, Pearson Education India, 2003.
5. I.S. Luthar and I.B.S. Passi :Algebra (Volume 1) Groups, Narosa Publishing House.

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- www.yourarticlelibrary.com
- onlinecourses.nptel.ac.in
- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH- 404(A): PLASMA DYNAMICS

Objective: -The main aims of this course are to study of flow problems of electrically and magnetism conducting fluids, ionized gases, astrophysics, geophysics, the stability of the flow of a plasma in a magnetic field is very important for successful fusion reaction, it is useful may engineering problems.The characterization of plasmas in terms of the deviations from thermodynamic equilibrium is proposed. For this characterization to be meaningful, the measurements have to be independent of the constraints on the plasma.

UNIT-1 **(10 Sessions)**

Introduction: Particle orbit theory.

Macroscopic Equation: Fluid model of a plasma, Moment equations, Hydromagnetic equations, Criteria for applicability of a fluid description.

Hydromagnetic: Kinematics, Static problems, Hydromagnetic stability, Interchange, Instabilities, Alfven waves.

UNIT-2 **(10 Sessions)**

Hydromagnetic Flows: Hydromagnetic Navier-Stocks equation, Hartmann flows, Couette flow, Flow stability, Parallel flows, Transverse flows, Plasma propulsion, MHD generators.

Shock Waves in Cold Plasma: Hydromagnetic shock equations, Shock propagation parallel to magnetic field, Shock propagation perpendicular to magnetic field, Shock thickness, Collisionless shocks.

UNIT-3 **(10 Sessions)**

Waves in Cold Plasma: Some general wave concepts, Waves in cold plasma Alfven waves, Ion cyclotron waves, Experimental results for low frequency waves, General theory of waves in cold plasmas, CMA diagram.

Waves in Warm Plasmas: MHD waves, Longitudinal waves in warm plasmas, Ion acoustic waves, Landu damping of longitudinal plasma waves, Experimental results for waves in warm plasmas, General dispersion relation.

UNIT-4 **(08 Sessions)**

Kinetic Theory: Equation for distribution function, Near-equilibrium plasma, Vlasov equation, Landu damping, Boltzmann equation, Properties of Boltzmann equation, Fokker-Planck equation, Transport coefficients, Derivation of Landu equation.

UNIT-5 **(10 Sessions)**

Plasma Radiation: Angular distribution from an accelerated charge, Frequency spectrum of radiation from an accelerated charge, Cyclotron radiation by an electron, Bremsstrahlung from a plasma, Radiation from plasma oscillations, Scattering of radiation in plasma, Transport of radiation in a plasma, Black body radiation from a plasma,Radiation by an electron, Bremsstrahlung from a plasma, Radiation from plasma oscillations, Scattering of radiation in plasma, Transport of radiation in a plasma, Black body radiation from a plasma.

Course Outcomes:

Students completing this course will be able to:

- Understand and use the basic mathematical formalism needed for describing the dynamics of continuous media.
- Knowledge on mathematical models for plasma and will be able to distinguish the dynamics of plasmas and neutral fluid media.
- Formulating and modifying the basic dynamic fluid equations to account for the dynamics of plasma media at different levels: from MHD to kinetic scales.

Suggested Readings:

1. T. J. M. Boyd and J. J. Sanderson, Plasma Dynamics, Nelson, 1969.
2. J. A. Bittencourt, Fundamentals of Plasma Physics, Springer.
3. Vinod Krishan, Astrophysical Plasma and Fiuids, kluwer Acedemic Publishers, Dordrecht.
4. R. O. Dendy: Plasma Dynamics, Oxford University Press.

Website Sources:

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- www.dmi.gov.in
- www.yourarticlelibrary.com
- onlinecourses.nptel.ac.in
- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH – 404(B): DIFFERENCE EQUATIONS

Objective: -The main aims of this course are to understand application of sequences and series of numbers and functions, partial difference equations, Discrete boundary value problem, Application with different engineering problem, Discrete mathematical models.

UNIT-1 **(10 Sessions)**

Introduction, Difference Calculus – The Difference Operator Summation, Generating functions a approximate summation.

Linear Difference Equations – First order equations, General results for linear equation. Equations with constant coefficients Applications, Equations with variable coefficients,nonlinear equations that can be linearized and the z-transform.

UNIT-2 **(10 Sessions)**

Stabilty Theory- Initial value problems for linear systems, Stability of linear systems, Stability of nonlinear systems, Chaotic behavior.

Asymptotic methods – Introduction, Asymptotic analysis of sums, Linear equations, Nonlinear equations.

UNIT-3 **(10 Sessions)**

The self-adjoint second order linear equation – Introduction Sturmian Theory, Greens functions, Disconjugacy, The Riccati Equations and Oscillation.

The Sturm-Liouville problem- Introduction, Finite Fourier Analysis, A non-homogeneous problem.

UNIT-4 **(08 Sessions)**

Discrete Calculus of variations- Introduction, Necessary conditions, Sufficient conditions and Disconjugacy.

UNIT-5 **(10 Sessions)**

Boundary Value Problems for Nonlinear equations- Introduction, The Lipschitz case, Existence of solutions, Boundary value Problems for differential Equations, Partial differential Equations, Discretization of Partial Differential Equations, Solution of partial differential equations.

Course Outcomes:

Students completing this course will be able to:

- Apply the theory to study the qualitative theory of solutions of difference equations and partial difference equations of higher order.
- Apply the theory to study the quantitative and qualitative study of solutions of different discrete models in Engineering.
- Difference between the qualitative and quantitative behavior of solutions of the difference equations and the corresponding differential equations.
- Apply the theory to study the solution in discrete boundary value problems.

Suggested Readings:

1. M. D. Rai Singhaniya : Differential equations, S. chand Publications.
2. Difference equations : Schaum'sOutlines, TMH.
3. Fulford Glenn R. : Modelling with Differential and Difference Equations, Cambridge University Press.
4. Youssef N. Raffoul : Qualitative Theory of Volterra Difference Equations, Springer International Publishing AG.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH – 404(C): MATHEMATICAL METHODS

Objective: -The main aims of this course are to prepare the students with mathematical tools and techniques that are required in advanced courses offered in the applied mathematics and engineering programs. Apply Laplace transforms is a powerful tool to analyze and design of continuous time signals and understand relation to Fourier transform.Transforms and variation problem technique for solving differential equations and extremum problems.

UNIT-1 **(10 Sessions)**

Laplace transforms, Properties of Laplace transform, Inversion formula convolution, Application to ordinary and partial differential equations, Fourier transform, Properties of Fourier transform, Inversion formula, Convolution, Parseval's equality, Fourier transform of generalized functions, Application of transforms to heat wave and Laplace equation.

UNIT-2 **(08 Sessions)**

Formulation of integral equations, Integral equations of Fredholm and Volterra type, Solution by successive substitution and successive approximation, Integral equations with degenerate kernels.

UNIT-3 **(10 Sessions)**

Integral equations of convolution type and their solutions by Laplace transform, Fredholm's theorems, Integral equations with symmetric kernel, Eigen values and eigen functions of integral equations and their simple properties.

UNIT-4 **(10 Sessions)**

Generalized functions, Minusinkski's operational calculus of one variable (algebra of addition and convolution of functions, Ordered pairs of functions, Convolution quotients of a function with a non-zero function), Dirac delta function.

UNIT-5 **(10 Sessions)**

Eigen value problem, Ordinary differential equations of the Sturm-Liouville's type, Eigen values and Eigen functions, Expansion theorem, Extreme properties of the eigen values of linear differential operators, Formulation of the eigen value problem of a differential operator as a problem of integral equation.

Course Outcomes:

Students completing this course will be able to:

- Demonstrate to solve financial math problems.
- Demonstrate to solve exponential growth and decay problems.
- Demonstrate to solve basic problems in probability and statistics.
- Use Fourier transforms for solving a wide range of differential equations.
- Know the use of Laplace transform to solving initial and boundary values problems.

Suggested Readings:

1. I. N. Sneddon:The Use of Integral Transforms, Tata McGraw Hill, New Delhi, 1974.
2. R. R. Goldberg: Fourier Transforms, Cambridge University Press, 1970.
3. H. Widom: Lectures on integral equations, Van Nostrand, 1969.
4. L. Elsegolc: Calculus of Variation, Dover Publications, 2010.
5. R.P. Kenwal: Linear Integral Equation; Theory and Techniques, Academic Press, 1971.
6. F.B. Hildebrand: Methods of Applied Mathematics (Latest Reprint), Dover Publications.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH– 404(D): THEORY OF RELATIVITY

Objective: -The main aims of this course are to explain the behavior of objects in space and time, and it can be used to predict everything from the existence of black holes, to light bending due to gravity, to the behavior of the planet Mercury in its orbit. The implications of Einstein's most famous theory are profound.

UNIT-1 **(10 Sessions)**

The special theory of relativity: Inertial frame of reference, Postulates of the special theory of relativity, Lorentz transformations, Length contraction, Time dilation variation of mass, composition of velocities, Relativistic mechanics, World events, World regions and light cone, Minkowski space-time, Equivalence of mass and energy.

UNIT-2 **(10 Sessions)**

Energy- momentum tensors: The action principle, The electromagnetic theory, Energy-momentum tensors (general), Energy-momentum tensors (special cases), Conservation laws.

UNIT-3 **(10 Sessions)**

General Theory of Relativity: Introduction, Principle of covariance, Principle of equivalence, derivation of Einstein's equation, Newtonian approximation of Einstein's equations.

UNIT-4 **(10 Sessions)**

Solution of Einstein's equation and tests of general relativity, Schwarzschild solution, Particle and photon orbits in Schwarzschild space-time, Gravitational red shift, Planetary motion, Bending of light, Radar echo delay.

UNIT-5 **(08 Sessions)**

Brans-Dicke theory: Scalar tensor theory and higher derivative gravity, Kaluza-klein theory.

Course Outcomes:

Students completing this course will be able to:

- Explain true nature of Lorentz transformation and Doppler Effect.
- Recall the setup and significance of Michelson-Morley experiment.
- Explain relativistic momentum and Einstein field equations
- Understand time – special relations at the local and global levels of standard model.
- Calculate time dilation corrections used in GPS satellites due to special and general relativity.
- Understand the basic characteristics of black holes and gravitational waves.
- Understand the accelerated expansion of the universe in relation to Einstein's cosmological constant.

Suggested Readings:

1. S. K. Srivastava and K. P. Sinha : Aspects of Gravitational Interaction –, Nova Science Publishers Inc. Commack, New York, 1998 .
2. W. Rindler: Essential Relativity , Springer-Verlag, 1977 .
3. R. M. Wald: General Relativity , University of Chicago Press, 1984 .
4. S. P Puri:General Theory of Relativity, Pearson Publications.

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- en.wikipedia.org

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH- 404(E): FUZZY SETS AND THEIR APPLICATIONS

Objective: -The main aims of this course are to learn and understand the basic need of fuzzy sets, arithmetic operations on fuzzy sets, fuzzy relations, possibility theory, fuzzy logic, and its applications in real life. Introduce students to artificial neural networks and fuzzy theory from an engineering perspective and also develop the skills to gain a basic understanding of neural network theory.

UNIT-1 **(10 Sessions)**

Fuzzy Sets-Basic definitions, A-level sets, Convex fuzzy sets, Basic operations on fuzzy sets, Types of fuzzy sets, Cartesian products, Algebraic products, Bounded sum and difference, *T*-norms and *T*-conorms.

UNIT-2 **(10 Sessions)**

The Extension Principle- The Zadeh's extension principle, Image and inverse image of fuzzy sets, Fuzzy numbers, Elements of fuzzy arithmetic.

Fuzzy Relations and fuzzy Graphs-Fuzzy relations on fuzzy sets, Composition of fuzzy relations, Min-Max composition and its properties, Fuzzy equivalence relations, Fuzzy compatibility relations, Fuzzy relation equations, Fuzzy graphs, Similarity relation.

UNIT-3 **(10 Sessions)**

Possibility Theory- Fuzzy measures, Evidence theory, Necessity measure, Possibility measure, Possibility distribution, Possibility theory and fuzzy sets, Possibility theory versus probability theory.

Fuzzy Logic – An overview of classical logic, Multivalued logics, Fuzzy propositions, Fuzzy quantifiers, Linguistic variables and hedges, Inference from conditional fuzzy propositions, Compositional rule of inference.

UNIT-4 **(10 Sessions)**

Approximate Reasoning - An overview of fuzzy expert system, Fuzzy implications and their selection, Multiconditional approximate reasoning, Role of fuzzy relation equation.

An introduction to fuzzy control- Fuzzy controllers, Fuzzy rule base, Fuzzy inference engine, Fuzzification, Defuzzification and the various defuzzifiaction methods (the center of area, the center of maxima, and the mean of maxima methods).

UNIT-5 **(08 Sessions)**

Decision Making in Fuzzy Environment- Individual decision making, Multiperson decision making, Multicriteria decision making, Multistage decision making, Fuzzy ranking methods, Fuzzy linear programming.

Course Outcomes:

Students completing this course will be able to:

- Understand basic knowledge of fuzzy sets and fuzzy logic.
- Apply basic fuzzy inference and approximate reasoning.
- Understand principles of neural networks.
- Apply basic fuzzy system modelling methods.

Suggested Readings:

1. H. J. Zimmermann: Fuzzy set theory & its Application, , Allied Publishers Ltd.
2. Timothy J. Ross: Fuzzy Logic with Engineering Applications, , Mcgraw Hills inc, New Delhi.
3. YuanBo and J. KlirGeorge: Fuzzy Sets & Fuzzy Logic - Theory and Applications Second Edition, Pearson publication.
4. Kuncheva Ludmila I. : Fuzzy Classifier Design, Springer-Verlag Berlin and Heidelberg GmbH & Co. KG.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH- 404(F): DIFFERENTIAL GEOMETRY OF MANIFOLDS

Objective: -The main aims of this course are to make familiar with basic concepts of differential geometry of manifolds so as to deal with geometry of manifolds, curves and spaces using the methods of differential calculus and vector calculus.

UNIT-1 **(10 Sessions)**

Space curve, Arc length, Tangent and Normal, Osculating plane, Curvature, Torsion, Serret -Frenet formulae, Circular Helix, Osculating circle, Osculating sphere, Behavior of curve in the neighborhood of a point, Involute and Evolute.

UNIT-2 **(10 Sessions)**

Metric: The first and second fundamental form, Weingarton equation, Orthogonal trajectories, Mensuier theorem, Gaussian curvature, Euler's theorem, Dupin's theorem, Rodrigue's theorem, Dupin's indicatrix.

UNIT-3 **(08 Sessions)**

Envelopes, edge of regression, Ruled surface, Developable surface, Monge's theorem, Conjugate directions.

UNIT-4 **(10 Sessions)**

Hyper surfaces, Normal's Gauss formulae, Weingarten equations, Generalized Gauss and Mainardi Codazzi equations .

UNIT-5 **(10 Sessions)**

Manifolds, Sub manifolds, Riemannian manifold, Length of a curve in Riemannian manifolds, angle between two vectors in Riemannian manifold, Riemannian curvature, Contravariant and covariant almost analytic vector.

Course Outcomes:

Students completing this course will be able to:

- Manipulate with ease the basic operations on tangent vectors.
- Differential forms and tensors both in a local coordinate description and a global coordinate-free one.
- Gain knowledge of the basic theorems of de Rhamcohomology and some simple examples of their use.
- Know what a Riemannian manifold is and what geodesics are.

Suggested Readings:

1. R. S. Mishra: A course in tensor with application to Riemannian Geometry, Pothishala (Pvt.) Ltd , 1965.
2. R. S. Mishra: Structure on a differential manifolds and their applications, Chandrarna Prakashan, Allahabad, 1984.
3. B. B. Sinha:An introduction to modern Differential Geometry, Kalyani Publishers, New Delhi, 1982.
4. K. Yano and M. Kon : Structure of manifolds , world scientific Publishing Co. Pvt Ltd. 1984.

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IFTM University, Moradabad
Master of Science (Mathematics) Programme
M.Sc. (Mathematics) – II Year (IV Semester)

MATH-405: PROJECT & VIVA- VOCE

Objective: -The main aims of this course are to understand applications various subjects to study in previous semesters for the interest of students.

(40 Sessions)

Course Outcomes:

After completing all courses, Students will be able to:

- Analyses hypotheses and conclusions of mathematical statements.
- Explain the concept and Classification of different courses.
- Demonstrate knowledge and understanding of fundamental concepts of Research ability and writing skills.
- Give the essence of the proof of the different theorems studied in the previous courses.
- Work out to enhance the previous knowledge differentiation and integration whenever and wherever routine methods are not applicable.
- Formulate real-world problems as a linear programming model and describe the theoretical workings of the graphical and simplex method, demonstrate the solution process by hand and solver.
- Demonstrate solution methods including graphs and programming to analyze and solve the mathematical problems.

Suggested Readings:

1. John B. Fraleigh: A First Course in Abstract Algebra, Pearson Education India..
2. I. N. Herstein:Topics in Algebra,2nd Edition , John Wiley & Sons. Copyright.
3. T. Apostol: Mathematical Analysis (5th edition), Addison-Wesley Pub.
4. R. G. Bartle and D. R. Sherbert : Introduction to Real Analysis (3rd edition), John Wiley &Sons, Inc.
5. D. M. Burton: Elementary Number Theory (4th edition) –Universal Book Stall,New Delhi,2002.
6. Shepley.L.Ross : Differential Equations, Wiley India (Pvt.) Ltd.
7. James R. Munkres: *Topology*, 2nd Edition (Jan 7, 2000), Prentice Hall, ISBN-10:0131816292, ISBN-13: 978-0131816299.
8. Seymour Lipschutz and Marc Lars Lipson: Discrete Mathematics, Tata McGraw-Hill publishing company Limited, New Delhi.
9. S. Kumaresan: Linear Algebra,A Geometric Approach –, Prentice-Hall of India Pvt.
10. Erwin Kreyszig: Introduction to functional Analysis with Application, John wiley & Son Inc.,New York.
11. M. D. Rai Singhania: Fluid Dynamics, S. Chand Publication, New Delhi.
12. R. K. Jain, Iyenger: Numerical Analysis, New age publication, Delhi.
13. I.N. Sneddon: Elements of Partial Differential Equation, 3rd Edition. McGraw Hill BookCompany, 1998.
14. H. A. Taha: Operations Research an introduction, Macmillan.
15. V. K. Kapoor: Operations Research, Sultan Chand and Sons, New Delhi.

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- en.wikipedia.org
- mathsci.net

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