KERALA UNIVERSITY

SYLLABUS FOR M.Sc. MATHEMATICS IN AFFILIATED COLLEGES

2023 ADMISSION ONWARDS

M.Sc. MATHEMATICS COURSE STRUCTURE & MARK DISTRIBUTION

Semester	Course Code	Title of Course	Hours per semester	Instructional hrs./week		Duration ESA hrs.	Maximum Marks			
				L	P		CA	ESA	P	Total
I	MM 511	Linear Algebra	108	6	-	3 hrs	25	75	-	**100**
	MM 512	Real Analysis	108	6	-	3 hrs	25	75	-	**100**
	MM 513	Ordinary Differential Equations and Calculus of Variations	108	6	-	3 hrs	25	75	-	**100**
	MM 514	Basic Topology	126	7	-	3 hrs	25	75	-	**100**
II	MM 521	Abstract Algebra	108	6	-	3 hrs	25	75	-	**100**
	MM 522	Measure Theory	108	6	-	3 hrs	25	75	-	**100**
	MM 523	Partial Differential Equations and Integral Equations	108	6	-	3 hrs	25	75	-	**100**
	MM 524	Advanced Topology	126	7	-	3 hrs	25	75	-	**100**
III	MM 531	Complex Analysis	126	7	-	3 hrs	25	75	-	**100**
	MM 532	Functional Analysis-I	108	6	-	3 hrs	25	75	-	**100**
	MM 533	Elective-I	108	6	-	3 hrs	25	75	-	**100**
		*Numerical Analysis with Python	108	4	2	3 hrs	25	50	25	
	MM 534	Elective-II	108	6	-	3 hrs	25	75	-	**100**
IV	MM 541	Number theory and Cryptography	126	7	-	3 hrs	25	75	-	**100**
	MM 542	Functional Analysis-II	108	6	-	3 hrs	25	75	-	**100**
	MM 543	Elective-III	108	6	-	3 hrs	25	75	-	**100**
	MM 544	Elective-IV	108	6	-	3 hrs	25	75	-	**100**
	MM 545	Project Project viva						80 20		**100**
	MM 546	Comprehensive Viva								**100**
Grand Total			**1800**							**1800**

L: Lecture; **P**:Practical; **CA**:Continuous Assesment; **ESA**:End Semester Examination.

*MM 533.5 Numerical Analysis with Python has both Practical and ESA

LIST OF COURSES

SEMESTER- I

MM 511 Linear Algebra

MM 512 Real Analysis

MM 513 Ordinary Differential Equations and Calculus of Variations

MM 514 Basic Topology

SEMESTER - II

MM 521 Abstract Algebra

MM 522 Measure Theory

MM 523 Partial Differential Equation and Integral Equations

MM 524 Advanced Topology

SEMESTER - III

MM 531 Complex Analysis

MM 532 Functional Analysis - I

MM 533 ELECTIVE - I(**One among the following)**

- MM 533.1 Automata Theory
- MM 533.2 Operations Research
- MM 533.3 Algebraic Topology
- MM 533.4 Commutative Algebra
- MM 533.5 Numerical Analysis with Python

MM 534 ELECTIVE-II (**One among the following)**

- MM 534.1 Approximation Theory
- MM 534.2 Geometry of Numbers
- MM 534.3 Differential Geometry
- MM 534.4 Graph Theory
- MM 534.5 Fractal geometry

SEMESTER - IV

MM 541 Number Theory and Cryptography

MM 542 Functional Analysis - II

MM 543 ELECTIVE - III(**One among the following)**

MM 543.1 Difference Equations

MM 543.2 Theory of Wavelets

MM 543.3 Coding Theory

MM 543.4 Optimization Techniques in Operations Research

MM 543.5 Cryptography

MM 544 ELECTIVE - IV(**One among the following**)

MM 544.1 Advanced Complex Analysis

MM 544.2 Spectral Graph Theory.

MM 544.3 Mechanics

MM 544.4 Representation Theory of Finite Groups

MM 544.5 Advanced Graph Theory

Programme Specific Outcomes (PSO)

PSO 1 Interconnect concepts in various fields of Mathematics.

PSO 2 Enrich mathematical concepts and encourage research.

PSO 3 Able to convey mathematical concepts to the society.

PSO 4 AcquireKnowledge about scientific method and skills in mathematical computations.

PSO 5 Utilize the domain knowledge to face real life problems.

PSO 6 Enhancement of critical thinking skills and attitudes to become a thinker and professional.

PSO 7 Creating academic excellence in mathematics and allied subjects.

PSO 8 Explore and discover new fields in different dimensions.

SEMESTER-I **COURSE CODE: MM 511**

Name of the Course: LINEAR ALGEBRA

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand the concepts of vector spaces, subspaces, bases, dimension and their properties.

CO-2 Acquire the skill in matrix manipulation and linear modeling problems

CO-3 Relate matrices and linear transformations

CO-4 Compute eigenvalues and eigenvectors of linear transformations and use them in applications.

CO-5 Enhance the ability to reason mathematically and prepare them for research.

CO-6 Apply the knowledge to many fields in engineering, statistics and computer science

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X				X			
CO-2	X			X		X		
CO-3	X	X		X	X			
CO-4		X		X		X		X
CO-5	X						X	X
CO-6			X	X			X	X

COURSE CONTENT

Module I

Vector Spaces, Subspaces, Linear Span,Linear Independence, Basis and Dimension, Basis of Any Vector Space.

The topics to be discussed can be found in Chapter 1, Sections 1.1, 1.2, 1.3, 1.4, 1.5 and 1.6

Module II

Sums of Subspaces, Quotient Space, Linearity, Rank and Nullity, Isomorphisms .

The topics to be discussed can be found in Chapter 1, Sections 1.7, 1.8, Chapter 2, Sections 2.1, 2.2 and 2.3

Module III

Matrix Representation, Change of Basis, Space of Linear Transformations

The topics to be discussed can be found in Chapter 2, Sections 2.4, 2.5 and 2.6

Module IV

Existence of Eigenvalues, Characteristic Polynomial, Eigenspace, Generalized Eigen-vectors.

The topics to be discussed can be found in Chapter 5, Sections 5.1, 5.2, 5.3 and 5.4

Module V

Two Annihilating Polynomials, Diagonalizability, Triangularizability and Block-Diagonalization.

The topics to be discussed can be found in Chapter 5, Section 5.5 Chapter 6, Section 6.1, and 6.2.

Module VI

Schur Triangularization, Jordan Block, Jordan Normal Form

The topics to be discussed can be found in Chapter 6, Section 6.3, 6.4 and 6.5

Textbook: M. Thamban Nair Arindama Singh, *Linear Algebra*, Springer, 2018.

References

1. David C. Lay, *Linear Algebra and its Applications*, Third Edition, Per arson Education, 2016.

2. Gilbert Strang, *Linear Algebra and its Applications*, Cengage Learning (RS), forth edition, 2005.

3. Howard Anton, *Elementary Linear Algebra-Applications*, Eleventh edition, Wiley, 2014.

4. I. N. Herstein, *Topics in Algebra*, Wiley Eastern Ltd Reprint, 1991.

5. Kenneth Hoffman and Ray Kunze, *Linear Algebra*, Prentice Hall, 1981.

6. P. R. Halmos, *Finite Dimensional Vector spaces*, Narosa Pub House, New Delhi, 1980.

7. Sheldon Axler, *Linear Algebra Done Right*, Springer Nature, third edition, 2015.

8. Stephen H. Friedberg, Arnold J Insel & Lawrence E. Spence, *Linear Algebra*, Fourth Edition, 2013.

SEMESTER-I **COURSE CODE: MM 512**

Name of the Course: REAL ANALYSIS

Course Outcomes: After the completion of the course students should be able to

CO-1: Understand the concepts and results in analysis and apply these results to other branches of mathematics and real world applications.

CO-2: Demonstrate the importance of Riemann Stieltjles Integrals, Riemann condition, sufficient condition for the existence of Riemann Stieltjes integrals .

CO-3: Analyse the concepts of sequence of functions, its properties and to what extent this property is transferred to its limit functions.

CO-4: Understand and Demonstrate the concepts of multivariable differential calculus.

CO-5: Enhance the ability to apply the concepts in geometrical situation.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X					X		
CO-2		X			X	X		
CO-3	X	X		X				
CO-4	X				X			X
CO-5			X					X

COURSE CONTENT

Module I

Functions of Bounded Variation and Rectifiable Curves: Properties of monotonic functions, Functions of bounded variation, Total variation, Additive property of total variation, Total variation on [*a, x*] as a function of *x*, Function of bounded variation expressed as the difference of increasing functions, Continuous functions of bounded variation, Curves and paths, Rectifiable paths and arc-length, Additive and continuity of arc length, Equivalence of paths, Change of parameter.
[Chapter 6 of Textbook 1]

Module II

The Riemann-Stieltjles Integral: The definition of Riemann-Steiltjles integral, Linear properties,Integration by parts, Change of variable in a Riemann-Stieltjes integral, Reduction to a Riemann Integral, Step functions as integrators, Reduction of a Riemann Stieltjes integral to a finite sum, Euler's summation formula, Monotonically increasing integrators, Upper and lower integrals, Additive and linearity properties of upper and lower integrals, Riemann's condition, Comparison Theorems, Integrators of bounded variation, Sufficient conditions for the existence of Riemann-Stieltjes integrals, Differentiation under the integral sign.
[Chapter 7, Sections 7.1-7.16,7.24 of Textbook 1]

Module III

Sequences and Series of Functions: Discussion of Main Problem,Uniform Convergence, Uniform Convergence and Continuity, Uniform Convergence and Integration, Uniform Convergence and Differentiation
[Chapter 7(7.1 to 7.18) of Textbook 2. Do sufficient problems to study the uniform convergence of sequences and series]

Module IV

Functions of Several Variables: Linear Transformations, Differentiation.
[Chapter 9 (9.1 to 9.21) of the Textbook 2]

Module V

Implicit Functions : The Contraction Principle, The Inverse Function Theorem, The Implicit Function Theorem. The Rank Theorem, Determinants, Derivatives of Higher Order, Differentiation of Integrals
[Chapter 9 (9.22 to 9.29) of the Textbook 2]

Module VI

The Rank Theorem, Determinants, Derivatives of Higher Order, Differentiation of Integrals
[Chapter 9 (9.30 to 9.43) of the Textbook 2]

Textbooks

1. Tom M. Apostol, Mathematical Analysis, Second Edition, Narosa 1974

2. W.Rudin, Principles of Mathematical Analysis, Third Edition

References

1. J.A Dieudonne, Foundations of Modern Analysis, Academic Press

2. Tom M Apostol, Calculus, Volume 1, Wiley Edition.

3. Tom M Apostol, Calculus, Volume 2, Wiley Edition.

SEMESTER-I **COURSE CODE: MM 513**

Name of the Course: ORDINARY DIFFERENTIAL EQUATIONS AND CALCULUS OF VARIATIONS

Course Outcomes: After the completion of the course students should be able to

CO-1 To understand the concepts of Ordinary Differential Equations.

CO-2 Classify the problems and recognize appropriate methods to solve differential equations.

CO-3 Apply the methods of solving differential equations to real-world problems.

CO-4 Find the extremum of an integral $\int f(x, y, y')dx$, using Euler's formula.

CO-5 Solve an isoperimetric problem.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X		X			X	X	
CO-2		X	X		X			
CO-3				X		X		
CO-4				X	X	X		
CO-5				X		X	X	

COURSE CONTENT

Module I

A Review of Power Series, Series Solutions of First Order Equations, Second Order Linear Equations, Ordinary Points, Regular Singular Points, Regular Singular Points (Continued), Two Convergence Proofs.

Chapter 5 - 26, 27, 28, 29, 30 and Appendix A.

Module II

Gauss's Hypergeometric Equation, The Point at Infinity, Legendre Polynomials, Properties of Legendre Polynomials.

Chapter 5 - 31, 32; **Chapter 8** - 44, 45.

Module III

Bessel Functions. The Gamma Function, Properties of Bessel Functions, Additional Properties of Bessel Functions.

Chapter 8 - 46, 47 and Appendix C.

Module IV

Systems of First Order Equations: General Remarks on Systems, Linear Systems, Homogeneous Linear Systems with Constant Coefficients, Nonlinear Systems, Volterra's Prey-Predator Equations.

Chapter 10 - 54, 55, 56, 57.

Module V

Nonlinear Equations: Autonomous Systems, The Phase Plane and its Phenomena, Types of Critical Points, Stability, The Method of Successive Approximations, Picard's Theorem, Systems. The Second Order Linear Equation.

Chapter 11 - 58, 59; **Chapter 13** - 69, 70, 71;

Module VI

Introduction to the calculus of variation, Some Typical Problems of the Subject, Euler Differential Equation for an Extremal, Isoperimetric Problems.

Chapter 12 - 66, 67, 68.

Textbook:

Simmons G.F, *Differential Equations with Applications and Historical Notes*, Third Edition, CRC Press, 2017.

References:

1. A. Chakrabarti, *Elements of Ordinary Differential Equations and Special Functions*, New Age International, New Delhi, 2006.

2. Earl A. Coddington, *An Introduction to Ordinary Differential Equations*, Dover Publications, 1989.

3. Garrett Birkhoff and Gian-Carlo Rota, *Ordinary Differential Equations*, 4th Edn., Wiley & Sons, 1991.

4. Hildebrand F.B, *Methods of Applied Mathematics*, 2nd Edn., Prentice-Hall of India, New Delhi, 1965.

5. Isarel M. Gelfand and S. V. Fomin, *Calculus of Variations*, Dover Publications, USA, 2000.

6. William E. Boyce, Richard C. DiPrima, Douglas B. Meade, *Elementary Differential Equations and Boundary Value Problems*, 12th Edn., John Wiley & Sons, New York, 2021.

Name of the Course: BASIC TOPOLOGY

Course Outcomes: After the completion of the course students should be able to

CO-1 Understanding metrics as a generalization of distance in real and complex plane and discuss the basic concepts of metric spaces.

CO-2 Compare the concepts of open and closed sets of real line and complex plane to abstract spaces

CO-3 To develop the students ability to handle abstract ideas of mathematics and mathematical proofs

CO-4 Construction of topological spaces with desired properties.

CO-5 Improve skills in mathematical reading, writing and communication.

CO-6 Appreciate the importance of topology as a fundamental subject in mathematics, with connections to many other branches of the knowledge.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X			X	X			
CO-2	X				X			
CO-3	X	X		X			X	
CO-4	X						X	X
CO-5		X		X			X	X
CO-6			X		X		X	X

COURSE CONTENT

Module I

Metric Spaces:-Definition, Examples, Open sets, Closed sets, Interior, closure and boundary.

Sections 3.1, 3.2, 3.3

Module II

Continuous functions, Equivalence of metric spaces, Complete metric spaces, Cantor's Intersection Theorem.

Sections 3.4, 3.5, 3.7, Exercise 3.7(3)

Module III

Topological spaces:-Definition, Examples, Interior, Closure, Boundary.

Sections 4.1, 4.2

Module IV

Topological spaces:- Basis, Subbasis, Continuity, Topological Equivalence, Subspaces.

Sections 4.3, 4.4, 4.5

Module V

Connected and disconnected spaces, Theorems on connectedness, Connected subsets of the real line, Applications of connectedness, Path connected spaces.

Sections 5.1, 5.2, 5.3, 5.4, 5.5

Module VI

Compact spaces and subspaces, compactness and continuity, Properties related to compactness, One-point compactification.

Sections 6.1, 6.2, 6.3,6.4

Textbook: Fred H. Croom, "Principles of Topology", Dover Publications, 2016.

References

1. G.F. Simmons, Topology and Modern Analysis, Mc Graw-Hill, New York, 13th reprint, 2010.

2. J. Arthur Seebach, Lynn Arthur Steen, Counter Examples in Topology, Dover Publications, 1995.

3. James R. Munkres, Topology, PHI Learning Private Limited, Second Edition, 2009.

4. K. D. Joshi, Introduction to general topology, New Age International (P) Limited, First Edition, 1983.

5. Sheldon W. Davis, Topology, Tata Mc Graw-Hill Edition, 2006.

SEMESTER-II **COURSE CODE: MM 521**

Name of the Course: ABSTRACT ALGEBRA

Course Outcomes: After the completion of the course students should be able to

CO-1 Get familiarised with different algebraic structures.

CO-2 Understand the Fundamental Theorem of finitely generated abelian groups and list abelian groups of finite orders.

CO-3 Apply Sylow's Theorems to classify simple groups.

CO-4 Discuss different field extensions and examine the existence of zeros of irreducible polynomials over extension fields.

CO-5 Solve polynomial equations by radicals along with the understanding of ruler and compass constructions.

CO-6 Establish the connection between the concept of field extensions and Galois Theory.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X				X			
CO-2	X			X			X	
CO-3		X			X		X	
CO-4		X					X	X
CO-5		X	X	X				
CO-6					X			X

COURSE CONTENT

Module I

External direct product of groups - Definition and examples, Properties, Representing groups of units modulo *n* as an external direct product. Normal subgroups and Factor groups, Application of factor groups, Internal direct products.

The topics to be discussed can be found in Chapter 8 and 9 of the text.

Module II

Definition and examples of homomorphisms, Properties of homomorphisms, The first isomorphism theore. Fundamental theorem of abelian groups, Isomorphism classes, Proof of the fundamental theorem.

The topics to be discussed can be found in Chapter 10 and 11 of the text.

Module III

Sylow theorems, Conjugacy classes, Class Equation, Sylow theorems and Applications. Simple groups, Examples, Non simplicity tests.

The topics to be discussed can be found in Chapter 24 and 25 of the text. Theorems 25.1, 25.2 and 25.3 and corollary 1(Index Theorem), corollary 2 (embedding Theorem) may be discussed without proof.

Module IV

Extension fields, Fundamental Theorem of Field Theory, Splitting fields, Zeros of irreducible polynomial, Perfect field. Algebraic extensions, Characterization of extensions, Finite extensions, Properties of algebraic extensions.

The topics to be discussed can be found in Chapter 20 and 21 of the text.

Module V

Finite fields, Classification of finite fields, Structure of finite fields, Subfields of a finite field. Historical discussion of Geometric Constructions, Constructible Numbers, Angle - Trisectors and Circle - Squarers.

The topics to be discussed can be found in Chapter 22 and 23 of the text

Module VI

Fundamental theorem of Galois Theory(without proof), Solvability of polynomials by radicals, Insolvability of Quintic. Cyclotomic polynomials, The Constructible regular n-gons

The topics to be discussed can be found in Chapter 32 and 33 of the text.

Textbook: J A Gallian, *Contemporary Abstract Algebra*, Ninth Edition, Cengage Learning, United States of America, 2015.

References

1. David. S. Dummit, and Richard M.Foote, *Abstract Algebra*, Third Edition, New Delhi, Wiley, 2011
2. I N Herstein, *Topics in Algebra*, Second Edition, Wiley Eastern Ltd, Reprint: 1991
3. J B Fraleigh, *A First Course in Abstract Algebra*, Seventh Edition, Pearson Education Inc., 2003.
4. Michael Artin, *Algebra*, Second Edition, Pearson Education Inc., 2015.
5. Neils Lauritzen, *Concrete Abstract Algebra: : From Numbers to GrÃ*fj*bner Bases*, Cambridge University Press, 2012.
6. P.B. Bhattacharya, S.K. Jain and S.R. Nagpaul, *Basic Abstract Algebra*, Second Edition,U.K., Cambridge University Press, 2004.

Name of the Course: MEASURE THEORY

Course Outcomes: After the completion of the course students should be able to

CO-1 Create a frame work to generalise integration theory.

CO-2 Understand why and for what the theory of measures was introduced.

CO-3 Formulate complex problems using appropriate measure theory techniques.

CO-4 Apply the theory of measures to solve a variety of problems at an appropriate level of difficulty.

CO-5 Understand the notion of different types of convergence.

CO-6 Apply the theory of measures in probability theory

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X				X			
CO-2		X		X			X	
CO-3		X		X				
CO-4		X					X	X
CO-5	X			X				
CO-6			X			X		X

COURSE CONTENT

Module I

Introduction: Reasons for the development of the Lebesgue integral, comparison with the Riemann integral, the extended real number system

Measurable Functions: Measurable sets and functions, combinations, complex-valued functions, functions between measurable spaces

Measures: Measures, measure spaces, almost everywhere, charges.

Chapters 1,2,3

Module II

The Integral: Simple functions and their integrals, the integral of a non-negative extended real valued measurable function, the Monotone Convergence Theorem, Fatou's Lemma, properties of the integral.

Integrable Functions: Integrable real valued functions, positivity and linearity of the integral, the Lebesgue Dominated Convergence Theorem, integrands that depend on a parameter.

Chapters 4, 5

Module III

The Lebesgue Spaces L_p: Normed linear Spaces, the L_p spaces, Hölder's Inequality, Minkowski's Inequality, the Completeness Theorem, the space L_∞.

Modes of convergence: Relation between convergence in mean, uniform convergence, almost every where convergence, convergence in measure, and almost uniform convergence, Erogoff's Theorem,the Vitali Convergence theorem.

Relevent sections of Chapters 6,7

Module IV

Decomposition of Measures: Hahn and Jordan Decomposition Theorem, The Radon Nykodym Theorem, Lebesgue Decomposition Theorem, The Riesz Representation Theorem

Generation of Measures: Measures on algebra of sets,the extension of measure, Carathordeory and Hahn Extension Theorem, Lebesgue and Lebesgue Steiltjes measure(Theorem 9.9- Riesz rpresentation theorem need not be discussed)

Chapters 8,9

Module V

Volumes of Cells and Intervals- Cells Intervals, lengths, cell in $\mathbb{R}^p$, $p-$dimensional volume, translation invariance

Outer Measure: the outer measure in $\mathbb{R}^p$, properties of $m*$, translation invarient.

Chapters 11,12

Module VI

Measurable sets: Algebras, measure on a Algebra, the Caratheodory condition, The Caratheodory Theorem, Lebesgue sets and Lebesgue measure, uniqueness of Lebesgue measure, some usefull properties.

Examples of Measurable sets: Borel sets, null sets, translation invariance, existence of non Borel sets

Chapters 13, 14

Textbook: Robert G Bartle,The Elements of Integration and Lebesgue Measure, Wiley Classics Library Edition Published 1995

References

1. Athreya K. B. and Lahiri S. N., Measure Theory, Hindustan Book Agency, New Delhi, 2006.

2. Berberian S. K., Measure and Integration, The McMillan Company, New York, 1965.

3. De Barra G., Measure Theory and Integration, New Age International (P) Ltd. Publishers, New Delhi, second edition, 2013.

4. Halmos P. R., Measure Theory, Springer Verlag, 2014.

5. M.Thamban Nair, Measure and Integration A First Course,C R C press March 2018

6. Royden H. L., Real Analysis, Prentice Hall India,3rd edition 1988 .

7. Rudin W., Real and Complex Analysis, Tata McGraw Hill, New Delhi, 2006.

SEMESTER-II **COURSE CODE: MM 523**

Name of the Course: PARTIAL DIFFERENTIAL EQUATIONS AND INTEGRAL EQUATIONS

Course Outcomes: After the completion of the course students should be able to

CO-1 To understand the concepts of PDE's.

CO-2 To solve the real world problems using PDE's.

CO-3 To solve the wave equation and the heat equation.

CO-4 Understand the concepts, methods and structures of integral equation theory.

CO-5 To solve mathematical problems using techniques from integral equation theory.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X				X			
CO-2			X	X	X	X		
CO-3				X			X	
CO-4	X	X		X	X			
CO-5						X	X	X

COURSE CONTENT

Module I

Introduction: Preliminaries, Classification, Differential operators and the superposition principle.

First-order equations: Introduction, Quasilinear equations, The method of characteristics, Examples of the characteristics method, The existence and uniqueness theorem, The Lagrange method.

Text 1: Chapter 1 - 1.1, 1.2, 1.3; Chapter 2 - 2.1, 2.2, 2.3, 2.4, 2.5, 2.6;
(Including suitable problems from exercises).

Module II

Second-order linear equations in two independent variables: Introduction, Classification, Canonical form of hyperbolic equations, Canonical form of parabolic equations, Canonical form of elliptic equations.

Text 1: Chapter 3 - 3.1, 3.2, 3.3, 3.4, 3.5, 3.6

Module III

The one-dimensional wave equation: Introduction, Canonical form and general solution, The Cauchy problem and d'Alembert's formula, Domain of dependence and region of influence, The Cauchy problem for the nonhomogeneous wave equation.

The method of separation of variables: Introduction, Heat equation: homogeneous boundary conditions, Separation of variables for the wave equation, Separation of variables for nonhomogeneous equations.

Text 1: Chapter 4 - 4.1, 4.2, 4.3, 4.4, 4.5, 4.6; Chapter 5 - 5.1, 5.2, 5.3, 5.4; (Including suitable problems from exercises).

Module IV

Introductory concepts of linear integral equations: Definitions, Classification of linear integral equations, Solution of an integral equation, Converting Volterra equation to an ODE, Converting IVP to Volterra equation, Converting BVP to Fredholm equation.

Text 2: Chapter 1 - 1.1, 1.2 -1.2.1, 1.2.2, 1.2.3, 1.2.4, 1.2.5, 1.2.6, 1.3, 1.4 - 1.4.1, 1.5, 1.6.

Module V

Fredholm integral equations: Introduction, The variational iteration method, The Direct computation method, The successive approximations method, The method of successive substitutions, Homogeneous Fredholm integral equations, Fredholm integral equations of the first kind, The method of regularization.

Text 2: Chapter 2 - 2.1, 2.3, 2.4, 2.5, 2.6, 2.8, 2.9 - 2.9.1.

Module VI

Volterra integral equations: Introduction, The variational iteration method, The series solution method, Converting Volterra equation to IVP, Successive approximations method, The method of successive substitutions, Volterra integral equations of the first kind, The series solution method, Conversion of first kind to second kind.

Text 2: Chapter 3 - 3.1, 3.3, 3.4, 3.5, 3.6, 3.7, 3.9 - 3.9.1, 3.9.2.

Textbooks:

Text 1: Yehuda Pinchover and Jacob Rubinstein, *An Introduction to Partial Differential Equations*, Cambridge University Press, 2005.

Text 2: Abdul-Majid Wazwaz, *A First Course in Integral Equations*, 2nd Edn., World Scientific, 2015.

References:

1. A. Chakrabarti, *Elements of Ordinary Differential equations and special functions*, Wiley Eastern Ltd, New Delhi, 1990.

2. Amarnath T, *Partial Differential Equations*, Narosa, New Delhi, 1997.

3. A.Jerry, *Introduction to Integral Equations with Applications*, Wiley, New York, 1999.

4. R.P. Kanwal, *Linear Integral Equations*, Birkhauser, Boston, 1997.

SEMESTER-II **COURSE CODE: MM 524**

Name of the Course: ADVANCED TOPOLOGY

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand more about point-set topology and the concepts of algebraic topology

CO-2 Apply abstract algebra to understand the topological properties.

CO-3 Construct new topological spaces from existing ones and comparing their properties.

CO-4 Learn to use algebraic techniques to prove algebraic properties such as fundamental group and Brouwer fixed point theorem.

CO-5 Gain experience in applying algebraic topology to solve problems in other branches of mathematics and to carry out advanced research work in pure mathematics.

CO-6 To develop the students ability to handle abstract ideas of mathematics and mathematical proofs in topology.

CO-7 Develop capacity for mathematical reasoning through analyzing, proving and explaining concepts from algebraic topology.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X				X		X	
CO-2	X				X			X
CO-3	X	X			X			X
CO-4		X		X	X		X	X
CO-5				X		X	X	X
CO-6		X			X		X	
CO-7	X	X	X				X	

COURSE CONTENT

Module I

Quotients and Products - Finite and arbitrary products, Comparison of topologies, Quotient spaces.

Chapter 15 of Text I

Module II

Convergence- Nets and filters, Tychnoff 's Theorem

Chapter 16, Theorem 18.21 and Theorem 18.22 of Text I

Module III

T_0; T_1, T_2-spaces and regular spaces

Sections 8.1, 8.2 of Text II

Module IV

Normal spaces, Separation by continuous functions

Sections 8.3, 8.4 of Text II

Module V

The nature of algebraic topology, the fundamental group and the fundamental group of S^1.

Sections 9.1, 9.2, 9,3 of Text II

Module VI

Additional examples of fundamental groups and the Brouwer Fixed Point Theorem and related results.

Sections 9.4 and 9.5 of Text II

Textbooks:

1. Sheldon W. Davis, ”Topology”, Tata Mc Graw-Hill, 2006.
2. Fred H. Croom, ”Principles of Topology”, Dover Publications, 2016.

References

1. F.H. Croom, Basic Concepts of Algebraic Topology, Springer, First Edition, 1978.
2. G.F. Simmons, Topology and Modern Analysis, Mc Graw-Hill, New York, 13th Reprint, 2010.
3. James R. Munkres, Topology, PHI Learning Private Limited, Second Edition, 2009.
4. J. Arthur Seebach, Lynn Arthur Steen, Counter Examples in Topology, Dover Publications, 1995.
5. K. D. Joshi, Introduction to general topology, New Age International (P) Limited, First Edition, 1983.

SEMESTER-III **COURSE CODE: MM 531**

Name of the Course: COMPLEX ANALYSIS

Course Outcomes: After the completion of the course students should be able to

CO-1 Establish relationship between analytic functions and power series and to evaluate the radius of convergence of the power series

CO-2 Understand the concepts of Mobius transformations and apply the concepts to solve problems

CO-3 Solve problems related to integrals

CO-4 Classify Singularities and to find residues.

CO-5 Characterise the Conformal maps using Mobius transformations

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X			X	X			
CO-2	X				X	X		
CO-3				X		X		
CO-4	X	X					X	
CO-5				X	X			

COURSE CONTENT

Module I

Power series, Analytic functions , Analytic functions as mappings, Mobius transformations

The topics to be discussed can be found in Chapter III- Sections 3.1,3.2,3.3 of the text

Module II

Riemann-Stieltjes Integral, Power series representation of analytic functions, Zeros of analytic functions

The topics to be discussed can be found in Chapter IV- Sections 4.1, 4.2,4.3 of the text

Module III

The index of a closed curve, The Cauchy's theorem and Integral formula,Homotopic version of Cauchy's theorem and Simple connectivity

The topics to be discussed can be found in Chapter IV-Sections 4.4,4.5,4.6 of the text

Module IV

Counting zeros and Open Mapping theorem, Goursat's theorem.

The topics to be discussed can be found in Chapter IV- Sections 4.7,4.8 of the text

Module V

Classification of Singularities (Proof of Laurents series development omitted),Residues

The topics to be discussed can be found in Chapter V-Section 5.1,5.2,5.3 of the text

Module VI

The extended plane and its spherical representations,The maximum principle, Schwarz's lemma.

The topics to be discussed can be found in Chapter I-Section 1.6,Chapter VI-Sections 6.1,6.2 of the text

Textbook:

John.B.Conway,*Functions of Complex Variables*,Springer-Verlag,NewYork,1973(Indian Edition: Narosa)

References

1. H.A. Priestly, *Introduction to Complex analysis*, Oxford University Press, 2003
2. L.V.Ahlfors,*Complex Analysis*, Mc-Graw Hill,1966.
3. S.Lang, *Complex Analysis*, Mc-Graw Hill,1998.
4. S.Ponnusami and H.Silverman, *Complex Variables with Applications*, Birkhauser,2006
5. V.Karunakaran, *Complex Analysis*, Narosa Publishing House, 2002

SEMESTER-I **COURSE CODE: MM 532**

Name of the Course: FUNCTIONAL ANALYSIS - I

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand the basics of normed linear spaces, bounded linear maps

CO-2 Enable the students to realise different types of spectra and their relevance CO-3 Create an idea about different types of convergence of sequences in normed spaces and their relations.

CO-4 Develop the concepts of dual spaces and reflexive space.

CO-5 Enable the student to apply the knowledge of functional analysis to solve mathematical problems.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X							
CO-2		X			X			
CO-3					X		X	
CO-4		X		X				
CO-5				X		X		

COURSE CONTENT

Module I

Pre-requisite:

A quick review on : Metric spaces and continuous functions, L^p spaces.

[Chapter I: Section 3.1 to 3.7, 3.10, 3.12, 4.5, 4.6 of the Textbook] (Not to be considered for examination)

Normed spaces: Definition and examples, generation of new spaces, Riesz lemma, comparison of norm and its characterisation.

Continuity of Linear Maps: Various characterizations of continuity of linear maps,

[*Chapter II : Section 5(5.1, 5.2, 5.3, 5.4, 5.4, 5.6, 5.7); Section 6(6.1, 6.2, 6.3, 6.4, 6.5(a), 6.5(b), 6.6, 6.7* of the Textbook.]

Module II

Hahn-Banach Theorems: Hahn-Banach seperation theorem and its consequences, Hahn-Banach extension theorem and its computation, Taylor-Foguel theorem.

Banach Spaces: Definition of Banach space and its examples, summability and absolute summability of series in a norned space and their characterizations, notion of dual space.

[*Chapter II : Section 7(7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 7.10, 7.11); Section 8(8.1, 8.2, 8.3, 8.4)* of the textbook.]

Module III

Uniform Boundedness Principle: Uniform boundedness principle and Banach-Steinhaus theorem, resonance theorem.

Closed Graph and Open Mapping Theorems: Definition of closed linear map and examples, closed graph theorem, relation between projection theorem and closed linear map, definition of open map and its characterization, open mapping theorem and examples, bounded inverse theorem.

[*Chapter III: Section 9(9.1, 9.2, 9.3); Section 10(10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7(a), 10.7(b), 10.7(c); Section 11(11.1 only)* of the textbook.]

Module IV

Spectrum of a Bounded Operator: Definition of invertible operator and its characterization, definition of various spectrums, spectrum of finite rank operators, Neumann expansion, Gelfand-Mazur theorem, spectral radius formula.

[*Chapter III: Section 12(12.1, 12.2, 12.3, 12.5, 12.6, 12.7(a), 12.7(b), 12.8)* of the textbook]

Module V

Duals and Transposes: Separability of a normed space whenever its dual is separable, the duality of finite dimensional and infinite dimensional spaces, definition of the transpose of a linear map and its properties.

[*Chapter IV: Section 13 (13.1, 13.2, 13.3, 13.4, 13.5, 13.6)* of the textbook]

Module VI

Weak Convergence, Reflexivity: Definition of weak Convergence, its characterization and examples, definition of reflexivity and its properties, Statement of Eberlein theorem.

[*Chapter IV: Section 15 (15.1, 15.2 (a), 15.2(b)); Section 16 (16.1, 16.4, 16.5(without proof), 16.6) of the textbook*

Textbook: Balmohan V Limaye; Functional Analysis; *New Age International Publishers,* 3rd *Edition; 2017*

References

1. A N Kolmogrve, S V Fomin; Elements of the Theory of Functions and Functional Analysis; Graylock Press; Rochaster NY; 1972

2. E Kreyszig: Intoroductory Functional Analysis with Applications; John Wiley & Sons; 1978

3. M Thamban Nair: Functional Analysis: A First Course; Prentice Hall of India; 2022

4. V K Krishnan; Textbook of Functional Analysis; Prentice Hall of India; 2nd Edition; 2004

5. W Rudin; Functional Analysis; McGraw Hhill, Inc.; 2nd Edition; 1991

SEMESTER-III **COURSE CODE: MM 533.1**

AUTOMATA THEORY

(Elective-I)

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand the concept of abstract machines and their power to recognize languages.

CO-2 Employ finite state machines for modeling and solving computing problems.

CO-3 Design context free grammars for formal languages.

CO-4 Distinguish between decidability and undecidability.

CO-5 Gain proficiency with mathematical tools and formal methods.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X	X					X	
CO-2	X	X			X			X
CO-3			X	X		X		X
CO-4		X			X		X	
CO-5						X		X

COURSE CONTENT

Module I

Strings, Alphabets and Languages, Finite state systems, Basic definitions, Nondeterministic finite automata, Finite automata with ϵ moves. (Sections 1.1, 2.1 to 2.4)

Module II

Regular expressions, Two-way finite automata, Finite automata with output, Applications of finite automata. (Sections 2.5 to 2.8)

Module III

The pumping lemma for regular sets, Closure properties of regular sets, Decision algorithms for regular sets, The Myhill-Nerode theorem, Minimizing finite automata (Theorem 3.10, Lemma 3.2 and Theorem 3.11 without proof). (Sections 3.1 to 3.4)

Module IV

Motivation and introduction to CFG, Context-free grammars, Derivation trees, Simplification of context-free grammars, Chomsky normal form. (Section 4.1 to 4.5)

Module V

Informal description, Definitions, Pushdown Automata and Context free languages Theorem 5.3, 5.4 (without proof), The pumping lemma for CFL's, Closure properties of CFL's, Decision algorithms for CFL's. (Section 5.1 to 5.3 and 6.1 to 6.3)

Module VI

Introduction to Turing machine, The Turning Machine model, Computable language and functions, Unrestricted grammars, Context-sensitive languages, and relations between classes of languages. (Sections 7.1 to 7.3 and 9.2 to 9.4)

Textbook:

John E. Hopcroft and Jeffery D. Ullman, *Introduction to Automata Theory, Languages and Computation*, Narosa Publishing House, 2002.

References:

1. G.E.Revesz, *Introduction to Formal Languages*, Dover, 2012.
2. J.E. Hopcroft, R. Motwani and J.D. Ullman, *Introduction to Automata Theory, Languages and Computation*, 3 rd edition, Pearson, 2008.
3. K. L. P. Mishra, N. Chandrasekharan, *Theory of Computer Science: Automata Languages and Computation*, PHI, 2006.

4. M. Sipser, *Introduction to the Theory of Computation*, 3 rd edition, Cengage India Private Limited, 2014.

5. P.Linz, *An Introduction to Formal Languages and Automata*, 6 th edition, Jones & Bartlettudent Edition, 2012.

SEMESTER-III **COURSE CODE: MM 533.2**

Name of the Course: OPERATIONS RESEARCH

(Elective-I)

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand the characteristics of different types of decision making approaches and tools to be used in each type.

CO-2 Build and solve Transportation problems.

CO-3 Build and solve Assignment problems.

CO-4 Apply techniques of PERT and CPM for planning, scheduling and controlling of projects.

CO-5 Making and develop critical thinking and objective analysis of different game problems.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X			X	X			
CO-2			X	X		X		
CO-3		X	X	X		X		
CO-4			X	X		X	X	X
CO-5			X	X		X		

COURSE CONTENT

Module I

Linear Programming-Definitions, Graphical solution methods for L P Problems, Special cases in Linear programming.

Chapter 3 of text- sections 3.1, 3.2, 3.3 and 3.4

Simplex Method - Standard form of an LP Problem, simplex algorithm(Maximization)

Chapter 4 of text- sections 4.1, 4.2 and 4.3

Module II

Simplex algorithm(Minimization case)-Two phase method, Big-M method, Some complication and their solution, Types of Linear programming Solutions.

Chapter 4 of text- sections 4.4,4.5 and 4.6

Module III

Transportation Problem-Mathematical model of TP, The transportation algorithm, Methods for finding initial solution, Test for optimality, Variations in Transportation problem- unbalanced supply and demand, degeneracy and its Resolution.

Chapter 9 of text- sections 9.1, 9.2, 9.3, 9.4, 9.5 and section 9.6 - Upto 9.6.2

Module IV

Assignment Problem-Mathematical model of AP, solution methods of AP, Variations of the Assignment problem, A Typical Assignment problem and Travelling salesman problem.

Chapter 10.

Module V

Theory of Games- Two person zero-sum games, Pure strategies:games with saddle point, Mixed strategies:games without saddle point,the rules of Dominance,solution methods of games without saddle point- Algebraic method and Arithmetic method only.

Chapter 12 of text- sections 12.1 to 12.6.2

Module Outcomes:

Module VI

Project Management Basic difference between PERT and CPM, Phases of Project management.PERT/CPM network components and precedence relationship.Critical path analysis.

Chapter 13 of text- sections 13.1 to 13.6

Textbook:

J K Sharma. Operations Research- Theory and Applications, sixth Edition, 2016

References

1. Hamdy A Thaha, Operations Research- An Introduction, 10th edition, Pearson Education Ltd, 2012.

2. K. V. Mital and C. Mohan, Optimization Methods in Operation Research and Sysytems Analysis, 3rd edition,New Age Interntional Pvt. Ltd, 2022.

3. Ravindran A, Don T Philips and James J Solberg.,Operations Research Principle and Practice, 2nd edition, John Wiley and Sons, 1991.

SEMESTER-III **COURSE CODE: MM 533.3**

Name of the Course: ALGEBRAIC TOPOLOGY

(Elective-I)

Course Outcomes: After the completion of the course students should be able to

CO-1 Demonstrate accurate and efficient use of algebraic topology techniques.

CO-2 Demonstrate capacity for mathematical reasoning through analyzing, proving and explaining concepts from algebraic topology.

CO-3 Apply knowledge of algebraic topology to formulate and solve problems of geometrical and topological nature in mathematics.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X	X					X	X
CO-2	X	X					X	X
CO-3			X					

COURSE CONTENT

Module I

Introduction, Examples, Geometric Complexes and Polyhedra, Orientation of Geometric complexes. (Sections 1.1, 1.2, 1.3, 1.4 of Chapter 1)

Module II

Simplicial Homology Groups - Chains, cycles, Boundaries, Homology groups, examples of Homology Groups, The structure of Homology Groups, The Euler Poincare Theorem, Pseudo manifolds and the Homology Groups of Sn. (Sections 2.1, 2.2, 2.3, 2.4, 2.5 of chapter 2).

Module III

Simplicial Approximation- Introduction, Simplicial Approximation, Induced Homomorphisms on the Homology groups, the Browerfixed point theorem and related results . (Sections 3.1, 3.2, 3.3, 3.4 of Chapter 3)

Module IV

The Fundamental group - Introduction, Homotopic paths and the fundamental group, the covering homotopy property for S1, Examples of Fundamental group, the relation between $H_1(K)$ and $\pi_1(|K|)$. (Sections 4.1,4.2,4.3, 4.4 and 4.5 of chapter 4)

Module V

Covering Spaces-Definition and examples, basic properties of Covering spaces, Classification of covering spaces

(Section 5.1, 5.2, 5.3 of Chapter 5)

Module VI

Universal Covering spaces, Applications

(Sections 5.4 and 5.5 of Chapter 5)

Textbook :

Fred H. Croom, Basic Concepts of Algebraic Topology, Springer-Verlang, 1978

References

[1] Allen Hatcher, Algebraic Topology , Cambridge University Press, 2001.

[2] I.M Singer, J.A Thorpe, Lecture Notes on Elementary Topology and Geometry, Springer International Edition, Springer (India) Private Limited, New Delhi, 2004.

[3] Satya Deo, Algebraic Topology A Primer, Hindustan Book Agency, New Delhi, 2003.

Semester III **Coure code: MM 533.4**

Name of the Course: COMMUTATIVE ALGEBRA

(Elective-I)

Course Outcomes: After the completion of the course students should be able to

CO-1 Explain the fundamental concepts, constructions, and theorems related to Noetherian rings, modules, Artinian rings etc.

CO-2 Apply this knowledge to analyze particular rings,

CO-3 Communicate eloquently, through an oral presentation, the material they have learned.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X	X					X	X
CO-2	X	X					X	X
CO-3			X					

COURSE CONTENT

Module I

Rings and Ideals, Local Rings and Localization of Rings, Radicals,

(Sections 1.1 to 1.3 from Chapter 1 of the Text 1)

Module II

Modules, Finiteness Conditions and the Snake Lemma

(Sections 1.4 and 1.5 from Chapter 1 of the Text 1)

Module III

The Theory of Noetherian Rings, Primary Decomposition of Ideals, Artinian Rings and Modules,

(Sections 2.1 and 2.2 from Chapter 2 of the Textbook)

Module IV

The Artin-Rees Lemma, Krull Dimension

(Sections 2.3 to 2.4 from Chapter 2 of Textbook)

Module V

Integral Extensions, Integral Dependence, Noether Normalization and Hilbert's Nullstellensatz, The Cohen-Seidenberg Theorems

(Sections 3.1 to 3.3 from Chapter 3 of the Textbook)

Module VI

Extension of Coefficients and Descent, Tensor Products, Flat Modules, Extension of Coefficients

(Sections 4.1 to 4.3 from Chapter 4 of the Textbook)

Textbook:

Siegfried Bosch, Algebraic geometry and commutative algebra, Second Edition, Springer-Verlag 2022

References

[1] David Eisenbud, Commutative Algebra-with a view toward algebraic geometry, Springer-Verlag

[2] Ernst Kunz, Introduction to commutative algebra and algebraic geometry, Birkhauser, 1985

[3] H. Matsumura, Commutative Algebra, Revised and modernized edition, Free digital book by TEXromancers

[4] M F Atiyah and I G Mac Donald, Introduction to Commutative Algebra, Addison Weley

SEMESTER-III **COURSE CODE: MM 533.5**

Name of the Course:

NUMERICAL ANALYSIS WITH PYTHON

(Elective-I)

Course Outcomes: After the completion of the course students should be able to On completion of the course a student will be able to:

CO-1 Do Mathematical Computation using the programming language Python

CO-2 Use Math specific packages in Python for visualising data, solving Calculus problems etc.

CO-3 Use various Numerical Methods for finding real roots of equation and solving system of linear equations

CO-4 Use various Numerical Methods for integration, differentiation and solving initial value problems of ordinary differential equations

COURSE CONTENT

Module I

In this unit we discuss the basics of Python based on chapters 4,5,6,8, 9, 10 and 18 of Text 1. All topics of chapters 4-9 must be discussed using examples from mathematics. In chapter 10, only sections 10.1-10.4 need to be discussed. Chapter 18 also should be discussed to get an overview of the packages in Python. The students should be encouraged to write programmmes related to mathematical problems. (Some of the problems are listed in the syllabus)

Module II

Visualising Data with Graphs:

Learn a powerful way to present numerical data: by drawing graphs with Python. The unit is based on Chapter 2 of Text 3. The sections Creating Graphs with Mat-plotlib and Plotting with Formulas must be done in full. In the section Progra mming Challenges, the problems Exploring a quadratic function visually, Visualizing your expenses and Exploring the relationship between the Fibonacci Sequence and the Golden Ratio must also be discussed.

Module III

The unit is based on chapters 4 and 7 of Text 3. Here we discuss Algebra and Symbolic Math with SymPy and Solving Calculus Problems. In Chapter 4 the sections Defining Symbols and Symbolic Operations, Working with Expressions, Solving Equations and Plotting Using SymPy should be done in full. In the section Programming Challenges, the problems Factor Finder, Graphical Equation Solver, Summing a Series and Solving Single-Variable Inequalities also should be discussed. In chapter 7, some problems discussed namely, Finding the Limit of Functions, Finding the Derivative of Functions, Higher-Order Derivatives and Finding the Maxima and Minima and Finding the Integrals of Functions are to be done. In the section Programming Challenges, the problems Verify the Continuity of a Function at a Point, Area Between Two Curves and Finding the length of a curve also should be discussed.

Module IV

In this unit we discuss some numerical methods for solving system of linear equations, for finding roots of equations and polynomial interpolation from Text 2.We first discuss Bisection method, methods of Newton, Secant method and Method of False Position for solving equations of the form $f(x) = 0$. The topics can be found in sections
(only upto example 2) and 2.3. Interpolation and the Lagrange Polynomial as per section 3.1 (only upto example 2) is to be discussed. Next we discuss Gauss Elimination with backward substitution method and LU decomposition method as per sections 6.1 (only upto Algorithm 6.1) and 6.5 (Theorem 6.19 statement only and exclude subsection Permutation Matrices. Also avoid the discussion of matrix factorization using Maple). Students should be encouraged to do problems and write Python programme for each method (see ref 1).

Module V

Here we discuss some numerical methods for integration, differentiation and solving initial value problems of ordinary differential equations from Text 2. The methods for approximating derivative of a function as per section 4.1 are to be discussed.

They include forward-difference formula, (n+1)-point formula, in particular three-point formulae. Rest of the topics in this section need not be discussed. Next we discuss the methods for numerical integration. Trapezoidal rule and Simpson's rules are to be discussed from section 4.3. Then we discuss (n+1)-point closed Newton-Cotes formula and derive Trapezoidal, Simpson's rule and Simpson's 3/8 rules from it. Remaining topics in the section need not be done. We also discuss Composite Simpson's rule and Composite Trapezoidal rule from section 4.4 (theorems 4.4 and 4.5 only). Students should be encouraged to do problems and write Python programme for each method (see ref 1).

Module VI

Our discussion about numerical methods for solving initial value problems of ordinary differential equations include Euler's method, Runge-Kutta methods of second and fourth order. The topics can be found in sections 5.2 (excluding subsection Error Bounds for Euler's Method) and section 5.4 (only Midpoint Method for Runge-Kutta Methods of order two and Runge-Kutta method of order four need to be discussed without any proof). Students should be encouraged to do problems and write Python programme for each method (see ref 1).

Some problems for Unit I are listed below

- Factorial of a number
- Checking primality of a number
- Listing all primes below a given number
- Prime factorization of a number
- Finding all factors of a number
- GCD of two numbers using the Euclidean Algorithm
- Finding the multiples in Bezout's Identity
- checking the convergence and divergence of sequences and series.

(For more problems visit:

https://www.nostarch.com/doingmathwithpython/

https://doingmathwithpython.github.io/author/amit-saha.html

https://projecteuler.net/.)

Evaluation:

- The end semester evaluation should contain a theory and a practical examinations.
- The duration of the theory examination will be 3 hours, with a maximum of 50 marks.
- In the question papers for the theory examination, importance should be given to the definition, concepts and methods discussed in each units, and not for writing long programmes.
- Practical examination shall also be of 3 hours duration for a maximum of 25 marks.
- Weightage of marks for theory and a practical examinations is listed below

<table>
<tr><th>Module</th><th>Theory</th><th>Practical</th></tr>
<tr><td>I</td><td rowspan="3">10 (one question out of two)</td><td>10 (two questions out of four)</td></tr>
<tr><td>II</td><td>5 (one question out of two)</td></tr>
<tr><td>III</td><td>5 (one question out of two)</td></tr>
<tr><td>IV</td><td>20 (two questions out of four)</td><td rowspan="3">5(one question out of two)</td></tr>
<tr><td>V</td><td>10 (one question out of two)</td></tr>
<tr><td>VI</td><td>10 (one question out of two)</td></tr>
</table>

- Continuous evaluation follows the pattern - 5 marks for attendance, 10 marks for the internal examination and 10 marks for the practical record. The record should contain at least 20 programmes.
- The practice of writing the record should be maintained by each student throughout the course and it should be dually certified by the teacher in charge/internal examiner and evaluated by the external examiner of practical examination.

Textbook:

1. Vernon L. Ceder, *The Quick Python Book*, Second Edition, Manning.
2. Richard L. Burden and J. Douglas Faires, *Numerical Analysis*, Ninth Edition, Brooks/Cole, Cengage Learning.
3. Amit Saha, *Doing Math with Python*, No Starch Press, 2015.

References

1. Jaan Kiusalaas, *Numerical Methods in Engineering with Python3*, Cambridge University Press, 2013.
2. NumPy Reference Release 1.17.0, Written by the NumPy community. (available at https://docs.scipy.org/doc/)
3. https://docs.python.org/3/tutorial/

‘

SEMESTER-IV **COURSE CODE: MM 534.1**

Name of the Course: APPROXIMATION THEORY

(Elective-II)

Course Outcomes: After the completion of the course students should be able to

CO-1 Analyse the existence and characterization of best approximation for polynomials and rational functions.

CO-2 Apply algorithms for finding an approximate solution for the approximation problems.

CO-3 Construct polynomials for a given function at a certain finite number of given points.

CO-4 Apply the concept of best approximation from finite dimensional subspaces.

CO-5 Analyse the existence of best rational approximation

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1		X		X				
CO-2					X	X		
CO-3	X				X		X	X
CO-4			X		X			
CO-5		X	X				X	X

COURSE CONTENT

Module I

Metric spaces- an existence theorem for best approximation from a compact subset ; Normed linear spaces, Inner product spaces (Sections 1,2,3,4 of Chapter 1)

Module II Convexity -Caratheodary’s theorem - Theorem on linear inequalities -an existence theorem for best approximation from finite dimensional subspaces - uniform convexity - strict convexity.

(Sections 5,6,7 of Chapter 1)

Module III

The Tchebycheff solution of inconsistent linear equations -Systems of equations with one unknown- Three algebraic algorithms; Characterization of best approximate solution for m equations in n unknowns- The special case $m = n + 1$; Polya's algorithm. (Section 1,2,3,4,5 of Chapter 2)

Module IV

Interpolation- The Lagrange formula-Vandermonde's matrix- The error formula- Hermite interpolation; The Weierstrass Theorem. Bernstein polynomials- Monotone operators-Fejer's Theorem; General linear families- Characterization Theorem- Haar conditions- Alternation Theorem. (Sections 1,2,3,4, of Chapter 3)

Module V

Rational approximation- Conversion or rational functions to continued fractions; Existence of best rational approximation- Extension of the classical Theorem; Generalized rational approximation- the characterization of best approximation- An alternation Theorem- The special case of ordinary rational functions; Unicity of generalized rational approximation. (Sections 1,2,3,4 of Chapter 5)

Module VI

The Stone Approximation Theorem, The Muntz Theorem - Gram's lemma, Approximation in the mean- Jackson's Unicity Theorem- Characterization Theorem, Marksoff's Therem. (Section 1,2,6 of Chapter 6)

Textbook:

Cheney E.W.,Introduction to Approximation Theory , MC Graw Hill, 1966

References

1. Davis P. J, Interpolation and Approximation, Blaisdell Pub., 1964.

SEMESTER-III **COURSE CODE: MM 534.2**

Name of the Course: GEOMETRY OF NUMBERS (Elective-II)

Course Outcomes: After the completion of the course students should be able to

CO-1 Student acquires knowledge about various concepts in the area of Geometry of Numbers.

CO-2 Student develops a deep level of understanding of mathematical concepts in this area.

CO-3 Students apply acquired concepts to solve problems in the area of Geometry of Numbers.

CO-4 They develop skills in problem-solving and applying the learned concepts in related areas.

CO-5 Improve skills in mathematical reading, writing, and communication.

CO-6 Appreciate the importance of the Geometry of Numbers as an area of mathematics, with connections to other branches of knowledge.

CO-PSO MAPPING

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X						X	
CO-2	X	X	X	X				
CO-3	X	X	X	X	X	X		
CO-4	X	X	X	X	X	X	X	X
CO-5	X		X			X	X	
CO-6	X				X	X	X	X

COURSE CONTENT

Module I

Lattice points and straight lines, Counting of lattice points (Chapters 1 and 2)

Module II

Lattice points and area of polygons, Lattice points in circles
(Chapters 3 and 4)

Module III

Minkowski's fundamental Theorem and related results. (Chapter 5)

Module IV

Applications of Minkowski's fundamental Theorem (Chapter 6)

Module V

Linear transformation and integral lattices, Geometric interpretations of Quadratic forms (Chapters 7 and 8)

Module VI

Blichfieldt's Theorem and applications, Minkowski Theorem and applications. (Chapter 9 and 10)

Textbook:

D.D Olds, Anneli Lax and Guiliana P. Davidoff, The Geometry of Numbers, The Mathematical Association of America 2000

References

1. C.I Siegel, Lectures in Geometry of Numbers, Springer Verlag 1989.

2. J.W.S Cassells, Introduction to Geometry of Numbers, Springer Verlag 1997

SEMESTER-III **COURSE CODE: MM 534.3**

Name of the Course: DIFFERENTIAL GEOMETRY

(Elective-II)

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand the geometry of curves and surfaces using differential calculus tools.

CO-2 Identifying the tangent vectors of points of surfaces.

CO-3 Get familiar with parametrizations of surfaces and use it to study various features of surfaces.

CO-4 Deep understanding of vector fields and various parametrized curves.

CO-5 Get an idea of geometry of curves and surfaces by exploring various curvatures.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X							
CO-2	X						X	
CO-3		X			X		X	
CO-4		X					X	X
CO-5		X		X		X		

COURSE CONTENT

Module I

Graphs and Level Sets, Vector Fields (Chapter 1, 2 of Text)

Module II

Tangent Spaces, Surfaces (Chapter 3, 4 of Text)

Module III

Vector fields on Surfaces, Orientation, The Gauss map (Chapter 5, 6 Text)

Module IV

Geodesics, Parallel Transport (Chapter 7, 8 Text)

Module V

The Weingarten map, Curvature of Plane Curves. (Chapter 9, 10 of Text)

Module VI

Universal Covering spaces, Applications

(Sections 5.4 and 5.5 of Chapter 5)

Textbook: John.A. Thorpe, Elementary Topics in Differential Geometry, Springer Verlag

References

1. I Singer and J.A Thorpe, Lecture notes on Elementary Topology and Geometry, Springer- Verlag

2. M Spivak, Comprehensive introduction to Differential Geometry (Vols 1 to 5), Publish or Perish Boston.

SEMESTER-III **COURSE CODE: MM 534.4**

Name of the Course: GRAPH THEORY
(Elective-II)

Course Outcomes: After the completion of the course students should be able to Students are able to

CO-1 Explain the concepts of graph isomorphism, cut-vertices, blocks, connectivity and demonstrate the relation between groups and graphs

CO-2 Determine whether a graph is Eulerian or Hamiltonian and to establish the relation between Hamiltonian walks and numbers

CO-3 Describe the properties of strong digraphs, tournaments, matching and factorizations

CO-4 Apply the concepts of vertex coloring, edge coloring and Ramsey number of graphs for solving real life problems

CO-5 Understand the concepts of center of graphs, different distant vertices, locating numbers, Detour and directed distance

CO-6 Solve real life problems using the concepts of graph theory and use these concepts in research area in related topics

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X				X			
CO-2		X			X			
CO-3	X					X		
CO-4						X	X	
CO-5				X	X			
CO-6								X

COURSE CONTENT

An overview of the concepts-Graphs, Connected graphs, Multi graphs, Degree of a vertex, Degree Sequence, Trees.(These topics are not to be included for end semester examination)

Module I

Definition of isomorphism, Isomorphism as a relation, Graphs and groups, Cut-vertices, Blocks, Connectivity.

(Sections 3.1, 3.2, 3.3, 5.1, 5.2 and 5.3)

Module II

Eulerian graphs, Hamilton graphs, Hamilton walks and numbers

(Sections 6.1, 6.2 and 6.3)

Module III

Strong digraphs, Tournaments

(Sections 7.1, 7.2)

Module IV

Matchings, Factorization.

(Sections 8.1, 8.2)

Proofs of Hall's theorem and Tutte's theorem are omitted.

Module V

The Four color problem, Vertex coloring, Edge coloring, The Ramsey number of graphs (Sections 10.1, 10.2, 10.3, 11.1)

Module VI

The center of a graph, Distant vertices, Locating numbers, Detour and Directed distance.

(Sections 12.1, 12.2, 12.3, 12.4)

Textbook:

Gary Chartrand and Ping Zhang , Introduction to Graph Theory, Tata Mc Graw Hill, Edition 2006

References

1. Bondy J.A and Murthy U.S.R, 'Graph Theory with Applications', the Macmillan Press Limited.
2. Hararay F.,'Graph Theory'Addison-Wesley
3. Suesh Singh G.,'Graph Theory', PHI Learning Private Limited
4. Vasudev.C ,'Graph Theory Applications'.
5. West D.B,'Introduction to Graph Theory', PHI Learning Private Limited

Semester III **Coure code: MM 534.5**

Name of the course: FRACTAL GEOMETRY

(Elective II)

Course Outcomes: Upon successful completion of this course students should be able to:

CO-1 Understand the concept of fractals.

CO-2 Acquire the skills in sketching Julia sets and Mandelbrot set.

CO-3 Relate the concept of Hausdorff dimensions, Box counting dimension and topological dimension.

CO-4 Compute the dimensions of various fractals

CO-5 Apply the concept of fractals and their dimension in topologicalÂ spaces

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X	X						
CO-2				X	X			
CO-3					X	X		
CO-4						X		
CO-5	X		X					

COURSE CONTENT

Module I

Basic set theory , Functions and limits, Measures and mass distributions, (sections 1.1,1.2,1.3 of the text)

Module II

Box-counting dimensions, properties of box - counting dimensions (sections 2.1,2.2 of text)

Module III

Hausdorff measure, Hausdorff dimension, Calculation of Hausdorff dimension, Basic method for calculating dimensions.

(sections 3.1,3.2,3.3,4.1 of text)

Module IV

Iterated functions systems, Dimensions of self similar sets, Some variations, Continued fraction examples

(sections 9.1,9.2,9.3,10.2 of text)

Module V

Dimensions of Graphs, The Weierstrass function and self -affine graphs, Repellers and iterated function system, The logistic map

(sections 11.1,13.1,13.2 of text)

Module VI

General theory of Julia sets, The Mandelbort set, Julia sets of quadratic functions

(sections 14.1,14.2,14.3 of text)

Textbook:

Kenneth Falconer, Fractal Geometry Mathematical Foundation and Application, Third edition, Wiley, 2014

References

[1] Barnsley M F, Fractals Every where, , Dover publication, Newyork,3rd edition, 2012

[2] Falconer K.J, The Geometry of Fractal sets ,Cambridge University Press, Cambridge, 1986

SEMESTER-IV **COURSE CODE: MM 541**

Name of the Course: NUMBER THEORY AND CRYPTOGRAPHY

Course Outcomes: After the completion of the course students should be able to Students are able to

CO-1 Find whether a number is a quadratic residue or non-residue

CO-2 Acquire knowledge about different arithmetical functions and work with problems related to arithmetical functions

CO-3 Understand the concept of Diophantine equations and existence of solutions of the Diophantine equation

CO-4 Get an idea about algebraic numbers, algebraic integers and their properties

CO-5 Explain the concepts of simple crypto systems and Enciphering Matrices and describe public key and RSA

CO-6 Solve problems using the concepts of number theory and use these concepts in research area in related topics

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X	X						
CO-2				X		X		
CO-3	X						X	
CO-4	X				X			
CO-5						X	X	
CO-6					X	X	X	

COURSE CONTENT

Module I

Quadratic reciprocity

(Sections 3.1, 3.2, 3.3 of Chapter 3 in Text [1])

Module II

Some functions of Number Theory

(Sections 4.1,4.2,4.3,4.4, 4.5 of Chapter 4 in Text [1])

Module III

Some Diophantine Equations

(Sections 5.1, 5.2, 5.3, 5.4 of Chapter 5 in Text [1])

Module IV

Algebraic numbers and Algebraic integers

(Sections 9.1, 9.2, 9.3, 9.4 of Chapter 9 in Text [1])

Module V

Cryptography

(Sections 1 and 2 of Chapter 3 in text [2].)

Module VI

Public key

(Sections 1 and 2 of Chapter 4 in text [2].)

Textbooks:

1. Niven H S Zuckerman, HL Montgomery, An introduction to Theory of Numbers, John Wiley & Sons, New York (5 th Edition)

2. Koblitz Neal, A Course in Number Theory and Cryptography, Springer-Verlag, Newyork, 1994(2 nd Edition)

References

1. Douglas R. Stinson, Maura B. Paterson, Cryptography Theory and Practice,CRC press, Taylor and Fransis,2019 (4 th Edition)

2. G H Hardy and E M Wright, Introduction to the Theory of Number, Oxford press

3. Kenneth Ireland, Michael Rosen, A classical Introduction to Modern Number Theory, Second Edition, Springer, 1990

4. T M Apostol, An Introduction to Analytic Number Theory, Springer international,Students'edition

SEMESTER-IV **COURSE CODE: MM 542**

Name of the Course: FUNCTIONAL ANALYSIS - II

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand the basic concepts and fundamental principles of inner product space.

CO-2 Develop the concepts of compact linear operator and its spectrum.

CO-3 Realise the geometry of Hilbert space.

CO-4 Create an idea of compact linear operators on Hilbert space and the behaviour of spectrum of such operators.

CO-5 Apply the spectral analysis of compact self-adjoint operators for finding the solution of integral equations.

CO-6 Application to many areas of mathematics such as classical analysis, probability theory, approxinmation and optimization theory.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X							
CO-2		X			X			
CO-3		X	X	X				
CO-4		X			X			X
CO-5				X		X		
CO-6						X	X	X

COURSE CONTENT

Module I

Compact Linear Maps: Definition, properties of compact linear operators on normed space, Schauder theorem, relation between compact linear maps and weak convergence and reflexivity. Spectrum of compact operator on a normed space.

[*Chapter V : Section 17(17.1, 17.2, 17.3, 17.4(a), 17.5); Section 18(18.1, 18.2, 18.3, 18.4, 18.5, 18.7(a) of the textbook*]

Module II

Inner Product Spaces: Definition and examples, polarization identity, Schwarz inequality, parallelogram law.

Orthonormal Sets: Pythagoras theorem, Gram-Schmidt orthonormalization, Bessel's inequality, Riesz-Fischer theorem, Fourier expansion and Parseval formula, characterisation of a Hilbert space having countable orthonormal basis.

[*Chapter VI : Section 21(21.1, 21.2, 21.3(a), 21.3(b), 21.3(c); Section 22(22.1, 22.2, 22.3, 22.4, 22.5, 22.6, 22.7, 22.8(a), 22.9) of the textbook*]

Module III

Approximation and Optimization: Definition, properties and examples of best approximation, various characterisation for best approximation.

Projection and Riesz Representation Theorem: Projection theorem, Riesz Representation theorem and counterexamples, unique Hahn-Banach extension theorem, weak convergence and weak boundedness.

[*Chapter VI: Section 23(23.1, 23.2, 23.3, 23.4, 23.5); Section 24(24.1, 24.2, 24.3, 24.4, 24.5, 24.5, 24.7, 28.8) of the textbook*]

Module IV

Bounded Operators and Adjoints: Notion of the adjoint of a bounded operator, definition and its properties, bounded below operators and relation with its range space.

Normal, Unitary and Self-adjoint Operators: Definition and properties of normal, unitary and self-adjoint operators, positive operators and generalised Schwarz inequality.

[*Chapter VII: Section 25(25.1(a), 25.2, 25.3, 25.4(a), 25.5); Section 26(26.1, 26.2, , 26.4, 26.5) of the textbook*]

Module V

Spectrum and Numerical Range: Spectrum of bonded operators on Hilbert space and its properties, Definition of numerical range and its properties, bounds for the spectrum of self-adjoint operators on Hilbert space.
[*Chapter VII: Section 27(27.1, 27.2, 27.3, 27.4, 27.5, 27.7)*]

Module VI

Compact Self-adjoint Operator: Definition of compact self-adjoint operators and its properties, Hilbert-Schmidt operator, spectral theorem for compact self-adjoint operators.
[*Chapter VII: Section 28(28.1, 28.2, 28.3(a), 28.4, 28.5, 28.6) of the textbook*]

Textbook: Balmohan V Limaye; Functional Analysis; *New Age International Publishers,* 3rd **Edition; 2017**

References

1. A N Kolmogrve, S V Fomin; Elements of the Theory of Functions and Functional Analysis; Graylock Press; Rochaster NY; 1972
2. E Kreyszig: Intoroductory Functional Analysis with Applications; John Wiley & Sons; 1978
3. M Thamban Nair: Functional Analysis: A First Course; Prentice Hall of India; 2022
4. V K Krishnan; Textbook of Functional Analysis; Prentice Hall of India; 2nd Edition; 2004
5. W Rudin; Functional Analysis; McGraw Hhill, Inc.; 2nd Edition; 1991

SEMESTER-IV **COURSE CODE: MM 543.1**

Name of the Course: DIFFERENCE EQUATIONS (Elective-III)

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand the concept of difference equations.

CO-2 Classify difference equations with respect to their order and nature.

CO-3 Apply solution techniques to autonomous equations.

CO-4 Analyse the convergence behaviour of various difference equations.

CO-5 Use Z-transform to solve difference equations

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X			X				
CO-2		X		X				
CO-3				X		X		
CO-4		X			X		X	X
CO-5		X				X		

COURSE CONTENT

Module I

Difference calculus – General theory of linear difference equations – Linear homogenous equations with constant coefficients (Chapter 2: Sections: 2.1 to 2.3)

Module II

Linear non-homogenous equations – Method of undetermined coefficients – Autonomous (time invariant) systems (Chapter 2, Section 2.4, Chapter 3: Section 3.1)

Module III

The basic theory – The Jordan form: Autonomous (time–invariant) systems – Linear Periodic Systems. (Chapter 3: Sections 3.2 to 3.4)

Module IV

Definitions and examples —Properties of Z-Transform — The inverse Z-Transform and solutions of difference equations — Power series method — Partial fraction method — Inversion integral method. (Chapter 6: Sections: 6.1,6.2)

Module V

Three-term difference equations — Self-adjoint second order equations — Nonlinear difference equations, (Chapter 7: Sections: 7.1 to 7.3)

Module VI

Tools of approximations — Poincare's theorem — Asymptotically diagonal systems. (Chapter 8: Sections: 8.1 to 8.3)

Textbook:

Saber N.Elaydi, An Introduction to Difference Equations, Third Edition, Springer International Edition, First Indian Reprint, New Delhi, 2008.

References

1. Ronald E.Mickens, Difference Equations, ' Van Nostrand Reinhold Company, New York, 1987.
2. S.Goldberg, Introduction to Difference Equations, Firs, Dover Publications, 1986.
3. Sudhir K.Pundir, Rimple Pundir, Difference Equations (UGC Model Curriculum), Pragati Prakashan, First Edition, Meerut, 2006.
4. V.Lakshmikantham, DonatoTrigiante, Theory of Difference Equations: Numerical Methods and Applications, Second Edition, Marcel Dekker, Inc, New York, 2002.
5. Walter G.Kelley, Allan C.Peterson, Difference Equations An Introduction with Applications, Second Edition, Academic Press, Indian Reprint, New Delhi, 2006.

SEMESTER - IV **COURSE CODE: MM 543.2**

Name of the Course: THEORY OF WAVELETS (Elective-III)

Course Outcomes: After the completion of the course students should be able to

CO - 1 Understand the fundamentals of Wavelet Theory and its related constructions.

CO - 2 Provide mathematical methods to construct wavelet basis leading to applications in Signal processing and image compression, etc.

CO - 3 Familiarize with fundamental examples of Wavelets in finite and infinite dimensional spaces and enhance learners to develop their own techniques in developing wavelets.

CO - 4 Familiarize with the applications of Fourier transforms.

CO - 5 Develop critical thinking and promote Research in Wavelet Theory.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X							
CO-2		X				X		
CO-3				X				
CO-4			X			X		
CO-5		X						X

COURSE CONTENT

Module I

Construction of Wavelets on $\mathbb{Z}_n$: the first stage

(Chapter 3 of Textbook - Section 3.1)

Module II

Construction of Wavelets on $\mathbb{Z}_n$ the iteration steps, Examples - Shannon, Daubechies and Haar

(Chapter 3 of Textbook - Sections 3.2, 3.3)

Module III

$l^2(\mathbb{Z})$, Complete Orthonormal sets, $L^2([-\pi,\pi])$ and Fourier Series

(Chapter 4 of Textbook - Sections 4.1, 4.2 and 4.3)

Module IV

Fourier Transforms and Convolution on $l^2(\mathbb{Z})$.

(Chapter 4 of Textbook - Section 4.4)

Module V

First stage wavelets on $\mathbb{Z}$

(Chapter 4 of Textbook - Section 4.5)

Module VI

The iteration step for wavelets on $\mathbb{Z}$, Examples - Shannon, Daubechies and Haar

(Chapter 4 of Textbook - Section 4.6, 4.7)

Textbook : Michael Frazier, *An Introduction to Wavelets through Linear Algebra*, Springer,2014

References

1. Chui. C , *An Introduction to Wavelets*, Academic Press, Boston, 1992.
2. Mayor , *Wavelets and Operators*, Cambridge University Press, 1993.

SEMESTER-IV **COURSE CODE: MM 543.3**

Name of the Course: CODING THEORY (Elective-III)

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand the basics of error detection and correction in communication systems.

CO-2 Use various mathematical structures and methods for error correction.

CO-3 Construct and implement algorithms for coding.

CO-4 Understand how the use of mathematical structures and methods reduce the complexity of error correction.

CO-5 Construct efficient codes for error correction.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1					X	X		X
CO-2	X		X		X	X	X	
CO-3				X				
CO-4		X		X	X	X	X	
CO-5	X		X	X	X	X		

COURSE CONTENT

Module I

Introduction to Coding theory - Error Detection, Correction and Decoding - Basics of Finite Fields. *(Chapters 1, 2 and Sections 3.1, 3.2 , 3.3 of the Text)*

Module II

Linear Codes - Generator and Parity check matrices - Coding and decoding of linear codes. *(Chapter 4 of the Text)*

Module III

Some Bounds in Coding theory - Sphere Covering bound - Hamming bound and Perfect codes - Binary Hamming codes - Singleton bound and MDS codes. *(Sections 5.1, 5.2, 5.3.1, 5.4 of the Text)*

Module IV

Constructions of linear codes - Propagation rules - Reed Muller Codes - Introduction to Cyclic codes. *(Sections 6.1, 6.2, 7.1 of the Text)*

Module V

Generator and Parity check polynomials of cyclic codes- Generator and parity check matrices of cyclic codes- Decoding of Cyclic codes. *(Sections 7.2, 7.3, 7.4 of the Text)*

Module VI

(A review of Section 3.4 of the Text may be done as a prerequisite to this Unit)

BCH Codes - Decoding of BCH Codes - Reed Solomon Codes *(Sections 8.1, 8.2 of the Text)*

Textbook: San Ling and Chaoping Xing,Coding Theory, A First Course, Cambridge Univ.Press, 2004.

References:

1. F.J.MacWilliams and N.J.A.Sloane, The Theory of Error Correcting Codes, North Holland, Amsterdam, 1998.

2. R. Lidl and H.Neiderreiter, Introduction to Finite Fields and their Applications, Cambridge University Press, 1983.

3. Shu Lin and Daniel J.Costello, Error Control Coding -Fundamentals and Applications, Pearson Education India, 2011.

SEMESTER-IV **COURSE CODE: MM 543.4**

Name of the Course: Optimization Techniques in Operations Research

(Elective-III)

Course Outcomes: After the completion of the course students should be able to

CO-1 Apply the technique of Revised simplex method to solve LPP.

CO-2 Apply various methods to solve integer LP problems.

CO-3 Understand the goals and objectives of inventory management.

CO-4 Use Kuhn- Tucker solution methods for nonlinear optimization problems.

CO-5 Apply the techniques of DP to solve problems.

CO-6 Distinguish between various models in queues.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1				X		X	X	
CO-2						X		X
CO-3		X	X	X		X		
CO-4		X		X	X	X		
CO-5					X		X	X
CO-6	X		X			X		

COURSE CONTENT

Module I

Revised Simplex Method:- Standard forms for Revised Simplex Method, Computational Procedure for Standard Form I, Comparison of Simplex Method and Revised Simplex Method

Chapter 26 of text II

Module II

Integer Linear Programming:- Types of integer programming problems, Enumeration and cutting plane solution concept, Gomory's All integer and mixed integer cutting plane methods, .

Chapter 7 of text-II - sections 7.1 to 7.5

Module III

Kuhn Tucker Theory and Nonlinear Programming:-Lagrangian function, saddle point,Kuhn Tucker conditions, Primal and Dual problems, Quadratic programming.

Chapter 8 of text-I - sections 1-6

Module IV

Dynamic Programming:-Minimum path, Dynamic Programming problems,computational economy in Dynamic Programming,serial multistage model, Examples of failure, Decomposition, backward recursion.

Chapter 10 of text-I - sections 1-10

Module V

Deterministic Inventory Control Models: - The meaning of Inventory control, functional role of inventory, Reasons for carriying Inventory, Factors involved in Inventory problem Analysis, Inventory model building, Single item inventory control models without shortages.

Chapter 14 of Text -II- Sections: 14.1 to 14.7

Module VI

Queuing Systems: Structure of a queueing system, Performance measures of a queueing system, Probability distributions in queueing systems Classification of queueing models, single server queueing models.

Chapter 16 of text-II - sections 16.1-16.6

Textbook-I: K V Mital, C Mohan. Optimization methods in Operations Research and system analysis, Third Edition,Age International Publishers, New Delhi, 1995

Textbook: II: J K Sharma. Operations Research- Theory and Applications, sixth Edition, 2016

References

1. Hamdy A.Taha, Operations Research An Introduction, Tenth edition, Pearson, 2012

2. Man Mohan, P K Gupta and Kanti Swarup, Operations Research, Sultan Chand and Sons, 2022.

3. Ravindran A, Don T Philips and James J Solberg, Operations Research Principle and Practice, 2nd edition, John Wiley and Sons, 1991.

SEMESTER-IV **COURSE CODE: MM 543.5**

Name of the Course: CRYPTOGRAPHY
(Elective-III)

Course Outcomes: After the completion of the course students should be able to

CO-1 To ensure the preservation of information properties through mathematically sound

CO-2 Application of probability theory to cryptography

CO-3 To be able to secure a message over insecure channel by various means

CO-4 To learn about how to maintain the Confidentiality, Integrity and Availability of a data.

CO-5 To understand various protocols for network security to protect against the threats in the networks.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X			X				
CO-2					X		X	
CO-3		X		X				
CO-4	X							
CO-5	X		X		X	X		X

COURSE CONTENT

Module I

Cryptosystems and Basic Cryptographic Tools :,Secret-key Cryptosystems, Public-key Cryptosystems, Block and Stream Ciphers, Hybrid Cryptography, Message Integrity, Message Authentication Codes, Signature Schemes, Nonrepudiation, Cer-tificates, Hash Functions, Cryptographic Protocols, Security

Classical Cryptography : Some Simple Cryptosystems, The Shift Cipher, The

Substitution Cipher, The Affine Cipher, The Vigen'ere Cipher, The Hill Cipher, The Permutation Cipher , Stream Ciphers. [Chapter 1 and chapter 2(section 2.1)]

Module II

Cryptanalysis : Cryptanalysis of the Affine Cipher, Cryptanalysis of the Substitution Cipher, Cryptanalysis of the Vigen'ere Cipher, Cryptanalysis of the Hill Cipher, Cryptanalysis of the LFSR Stream Cipher

Shannons Theory : Elementary Probability Theory, Perfect Secrecy, Entropy, Huffman Encodings, Properties of Entropy, Spurious Keys and Unicity Distance,

[Chapter 2(section 2.2) and Chapter 3]

Module III

Block Ciphers and Stream Ciphers:Introduction, Substitution-Permutation Networks, Linear Cryptanalysis, The Piling-up Lemma, Linear Approximations of S-boxes, A Linear Attack on an SPN , Differential Cryptanalysis , The Data Encryption Standard Description of DES , Analysis of DES, The Advanced Encryption tandard Description of AES , Analysis of AES , Modes of Operation, Padding Oracle Attack on CBC, Mode Stream Ciphers, Correlation Attack on a Combination Generator, Algebraic Attack on a Filter Generator,Trivium [Chapter 4]

Module IV

Hash Functions and Message Authentication:Hash Functions and Data Integrity, Security of Hash Functions, The Random Oracle Model, Algorithms in the Random Oracle Model, Comparison of Security Criteria, Iterated Hash Functions, The Merkle-Damgard Construction, Some Examples of Iterated Hash Functions, The Sponge Construction, SHA-3 , Message Authentication Codes, Nested MACs and HMAC , CBC-MAC, , Authenticated Encryption , Unconditionally Secure MACs , Strongly Universal Hash Families, Optimality of Deception Probabilities[Chapter 5]

Module V

The RSA Cryptosystem : Introduction to Public-key Cryptography, More Number Theory, The Chinese Remainder Theorem , Other Useful Facts, The RSA Cryptosystem, Implementing RSA , Primality Testing, Legendre and Jacobi Symbols, The Solovay-Strassen Algorithm, The Miller-Rabin Algorithm, Square Roots Modulo n [Chapter 6 Section 6.1 to 6.5]

Module VI

Factoring Integers : Factoring Algorithms, The Pollard p-1 Algorithm,The Pollard Rho Algorithm, Dixon's Random Squares Algorithm, Factoring Algorithms in Practice, Other Attacks on RSA, The Decryption Exponent, Wiener's Low Decryption Exponent Attack, The Rabin Cryptosystem , Security of the Rabin Cryptosystem, Semantic Security of RSA , Partial Information Concerning Plaintext Bits, Obtaining Semantic Security[Chapter 6 Section 6.6 to 6.9]

Textbook: Douglas R. Stinson and Maura B. Paterson, Cryptography Theory and Practice, CRC Press, Taylor and Francis, 4th Edition, 2019.

References:

1. Alfred J. Menezes, Paul C. van Oorschot and Scott A. Vanstone: Handbook of Applied Cryptography, CRC Press, 1996.
2. H. Deffs & H. Knebl: Introduction to Cryptography, Springer Verlag, 2002.
3. Jeffrey Hoffstein: Jill Pipher, Joseph H. Silverman, An Introduction to Mathematical Cryptography, Springer International Edition, 2010.
4. .William Stallings: Cryptography and Network Security Principles and Practice, Third Edition, Prentice-hall India, 2003.

SEMESTER-IV **COURSE CODE: MM 544.1**

Name of the Course: ADVANCED COMPLEX ANALYSIS (Elective-IV)

Course Outcomes: After the completion of the course students should be able to

CO-1 Draw connections among ideas between space of continuous functions and space of analytic functions

CO-2 Formulate an analytic function with given zeros of infinite number and given multiplicity

CO-3 Apply Weierstrass Factorization Theorem to factorise certain complex valued functions

CO-4 Identify the equivalent conditions of simply connected regions

CO-5 Describe the method of extending the domain of analytic functions

CO-6 Describe Harmonic functions on a disk

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X				X			
CO-2		X		X			X	
CO-3		X			X			
CO-4					X			X
CO-5		X			X			X
CO-6	X				X			

COURSE CONTENT

Module I

The Space of Continuous functions $C(G, \Omega)$,Space of analytic functions,The Riemann Mapping Theorem(Proofs of the theorem and succeeding lemma are omitted)

The topics to be discussed can be found in Chapter VII-Section 7.1,7.2,7.4 of the text

Module II

Weierstrass Factorization Theorem, Factorization of the Sine function

The topics to be discussed can be found in Chapter VII- Sections 7.5,7.6 of the text

Module III

The Gamma function, The Riemann- Zeta function.

The topics to be discussed can be found in Chapter VII- Sections 7.7 ,7.8 of the text

Module IV

Runge's Theorem, Simple Connectedness, Mittag-Leffler's theorem

The topics to be discussed can be found in Chapter VIII- Sections 8.1,8.2,8.3 of the text

Module V

Schwarz Reflection Principle, Analytic Continuation Along a Path, Monodromy Theorem

The topics to be discussed can be found in Chapter IX- Sections 9.1,9.2,9.3 of the text

Module VI

Basic properties of harmonic functions. Harmonic functions on a disc, Jensen's Formula

The topics to be discussed can be found in Chapter X-Sections 10.1,10.2,Chapter XI-Section 11.1 of the text

Textbook:

John.B.Conway,*Functions of Complex Variables*,Springer-Verlag,NewYork,1973(Indian Edition: Narosa)

References

1. H.A. Priestly, *Introduction to Complex analysis*, Oxford University Press,1990.
2. L.V.Ahlfors,*Complex Analysis*, Mc-Graw Hill,1966.
3. S.Lang, *Complex Analysis*, Mc-Graw Hill,1998.
4. S.Ponnusami and H.Silverman, *Complex Variables with Applications*, Birkhauser,2006.
5. V.Karunakaran, *Complex Analysis*, Narosa Publishing House, 2002

Name of the Course: SPECTRAL GRAPH THEORY

(Elective-IV)

Course Outcomes: After the completion of the course students should be able to

CO-1 Developing an insight on the interdisciplinary nature of development of knowledge

CO-2 Associate matrices to graphs and estimate the various parameters of the associated matrices.

CO-3 Exploring the structural properties of various graphs using the associated matrices.

CO-4 Devoloping a knowledge on bounds relating graph eigenvalues to graph invariants and other combinatorial properties.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X							X
CO-2	X	X						
CO-3								X
CO-4						X	X	
CO-5				X				

COURSE CONTENT

Module I

A quick review of Chapter I, Invariants-Chromatic number,(Section 2.1 of Chapter II), Eigen values of graphs-Adjacency and Laplacian Eigen Values-First Properties, First Examples(Chapter 7 of Text)

Module II

Eigen Value Computations- Cayley Graphs and Bi Cayley graphs of abelian groups,Strongly regular graphs,Two gems, Design graphs(Chapter 8)(Except Example 8.10 and Example 8.23)

Module III

Largest Eigen values-Extremal eigen values of symmetric matrice, Largest adjacency eigen value, The average degree, A spectral Turan Theorem, Largest Laplacian eigen value of bipartite graphs, Subgraphs, Largest eigenvalues of trees(Chapter 9)

Module IV

More Eigen Values- Eigen values of symmetric matrices: Courant-Fischer, A bound for the Laplacian Eigen Values, Eigen Values of Symmetric matrices: Cauchy and weyl , Sub graphs(Chapter 10)

Module V

Spectral bounds-Chromatic number and independence number, Isoperimetric constant, edge counting(Chapter 11)

Textbook:

Bogdam Nica, A Brief Introduction to Spectral Graph Theory, European Mathematical Society Publishing House, 2018

References

1. Andries E Brouwer, William H Haemers, Spectra of Graphs- Monograph, Springer 2011
2. D Cvetkovic , M Doob, H Sachs, Spectra of Graphs- theory and Application, Academic Press , Newyork, 1980

SEMESTER-IV **COURSE CODE: MM 544.3**

Nameof the Course: MECHANICS
(Elective-IV)

Course Outcomes: After the completion of the course students should be able to

CO-1 To acquire a basic understanding of advanced concepts and formulation of classical mechanics.

CO-2 Students will be able to apply mathematical techniques such as calculus, differ- ential equations, and vector calculus to solve problems in classical mechanics.

CO-3 Students will be able to apply the concepts of force, work, energy, and power to solve problems related to classical mechanics.

CO-4 Students will be able to apply the Lagrangian and Hamiltonian formalisms to derive equations of motion and solve problems in mechanics.

CO-5 To develop and sharpen high-level problem solving skills.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1			X				X	
CO-2	X			X				
CO-3			X	X	X	X		
CO-4				X	X		X	
CO-5		X		X	X	X		X

COURSE CONTENT

Module I

Newtonian Particle Mechanics: Inertial Frames and the Galilean Transformation, Newton's Laws of Motion, One-Dimensional Motion: Drag Forces, Oscillation in One-Dimensional Motion, Resonance, Motion in Two or Three Dimensions, Systems of Particles, Conservation Laws, Collisions and Forces of Nature (Chapter 1 of text)

Module II

The Variational Principle: Fermat's Principle, The Calculus of Variations, Geodesics, Brachistochrone, Several Dependent Variables, Mechanics from a Variational Principle. (Sections 3.1, 3.2, 3.3, 3.4, 3.5 and 3.6)

Module III

Lagrangian Mechanics: Nonconservative Forces, Forces of Constraint and Generalized Coordinates, Hamilton's Principle, Generalized Momenta and Cyclic Coordinates, Systems of Particles, The Hamiltonian (Sections 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6)

Module IV

Constraints and Symmetries: Contact Forces, Symmetries and Conservation Laws: A Preview, Cyclic Coordinates and Generalized Momenta, A Less Straightforward Example. (Sections 6.1, 6.2, 6.3 and 6.4)

Module V

Gravitation: Central Forces, The Two-Body Problem, The Effective Potential Energy, The Shape of Central-Force Orbits, Orbital Dynamics, The Virial Theorem in Astrophysics (Sections 7.1 to 7.4, 7.6 and 7.7)

Module VI

Rigid-Body Dynamics: Rotation About a Fixed Axis, Euler's Theorem, Rotation Matrices and the Body Frame, The Euler Angles, Infinitesimal Rotations, Angular Momentum, Principal Axes. (Sections 12.1 to 12.7)

Textbook:

1. T. M. Helliwell and V. V. Sahakian, Modern Classical Mechanics, Cambridge University Press, Cambridge, 2021.

References:

1. Herbert Goldstein, Charles P. Poole and John Safko, Classical Mechanics, Third Edition, Pearson, 2011.
2. N.C. Rana and P.S. Jog, Classical Mechanics, Tata McGraw Hill, 2001.
3. Synge J.L and Griffith B.A, Principles of Mechanics, McGraw Hill, 1960.

SEMESTER-IV **COURSE CODE : MM 544.4**

Name of the Course: REPRESENTATION THEORY OF FINITE GROUPS

(Elective-IV)

Course Outcomes : After the completion of the course students should be able to

CO-1 Understand the concept of representation theory and its applications.

CO-2 Understand G-module, representation of groups, reducibility and group characters

CO-3 Identify representation of different groups and their characters.

CO-4 Apply representation theory to solve some group theoretical problems.

CO-5 Analyse the properties of abstract groups using concrete groups.

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X							
CO-2	X				X		X	X
CO-3		X				X		
CO-4			X	X			X	
CO-5					X			X

COURSE CONTENT

Module I

Introduction, G-modules, Characters, Reducibility, Permutation representations, Complete reducibility, Schur's lemma.

The topics to be discussed can be found in Chapter 1, Sections 1.1, 1.2, 1.3, 1.4, 1.5, 1.6 and 1.7

Module II

The commutant (endomorphism) algebra, Orthogonality relations, The group algebra. *The topics to be discussed can be found in Chapter 1, Sections 1.8, Chapter 2, Sections and 2.2*

Module III

The character table, Finite abelian groups, The lifting process, Linear characters. *The topics to be discussed can be found in Chapter 2, Sections 2.3, 2.4, 2.5 and 2.6*

Module IV

Induced representations, The reciprocity law, The alternating group A_5, Normal subgroups.

The topics to be discussed can be found in Chapter 3, Sections 3.1, 3.2, 3.3 and 3.4

Module V

Transitive groups, The symmetric group, Induced characters of S_n.

The topics to be discussed can be found in Chapter 4, Sections 4.1, 4.2, and 4.3

Module VI

Algebraic numbers, Representation of the group algebra, Burnside's (p, q) theorem, Frobenius group.

The topics to be discussed can be found in Chapter 5, Sections 5.1, 5.2, 5.3 and 5.4

Textbook: Walter Ledermann, *Introduction to Group Characters*, Cambridge University Press, Second Edition, 1987.

References

1. Benjamin Steinberg, *Representation Theory of Finite Groups: An Introductory Approach*,Springer, 2012.

2. Gordon James, *Representations and Characters of Groups*, Cambridge University Press, Second Edition, 2001.

3. I. Martin Isaacs, *Character Theory of Finite Groups*, Dover Books, 2011.

4. S.Lang, *Algebra*, Addison Wesley, 1970. https://math24.files.wordpress.com/2013/02/algebra-serge-lang.pdf

SEMESTER-IV **COURSE CODE: MM 544.5**

Name of the Course: ADVANCED GRAPH THEORY

(Elective - IV)

Course Outcomes: After the completion of the course students should be able to

CO-1 Understand different distance related graph algorithms.

CO-2 Analyse various convexity concepts related to geodesics in graphs.

CO-3 Understand the concept of distance heriditary and associated graphs.

CO-4 Understand and apply several concepts which involve minimizing the distance to a path in a graph.

CO-5 Apply different graph operations in various situations

Mapping

	PSO-1	PSO-2	PSO-3	PSO-4	PSO-5	PSO-6	PSO-7	PSO-8
CO-1	X				X			
CO-2		X	X					
CO-3	X				X			
CO-4		X			X	X		
CO-5		X				X	X	
CO-6			X	X			X	X

COURSE CONTENT

Module I

Graphs: Graphs as Models, Paths and connectedness, Cutnodes and Blocks, Graph Classes and Graph Operations. (Chapter 1 of Text)

Module II

The Center and Eccentricity, Self Centered Graphs, The Median, Central Paths . (Chapter 2, Sections 2.1, 2.2, 2.3, 2.4.)

Module III

External Distance Problems: Radius, Small Diameter, Diameter, Long Paths and Long Cycles (Chapter 5 of Text)

Module IV

Convexity: Closure in variants, Metrics on Graphs, Geodetic Graphs, Distance Hereditary Graphs.

(Chapter 7 of Text)

Module V

Distance Sequences: The eccentric sequences, Distance sequence, The Distance distribution. (Chapter 9- Sections 9.1, 9.2,9.3,of Text)

Module VI

Digraphs: Digraphs and connectedness, Acyclic Digraphs, Matrices and Euclidean Digraphs, Long paths in Digraphs(Chapter 10-sections 10.1,10.2,10.3,10.4)

Textbook:

Fred Buckley, Frank Harary, Distance in Graphs, Addison-Wesley Publishing Company,1990

References

1. Bondy and Murthy, Graph Theory with Applications, The Macmillan Press Limited,1976
2. Chartrand G and L.Lesniak, Graphs and Diagraphs, Prindle, Weber and Schmidt, Boston, 1986
3. Garey M.R, D.S Johnson , Computers and Intractability, A Guide to the Theory of NP-Completeness, Freeman, San Francisco 1979.
4. Harary. F, Graph Theory, Addison Wesley Reading Mass 1969 (Indian Edition, Narosa)
5. K.R Parthasarathy, Basic Graph Theory, Tata Mc Graw-Hill, Publishing Co, New Delhi, 1994.