COURSE STRUCTURE AND DETAILED SYLLABUS
FOUR YEAR PROGRAM UNDER NEP 2020

PREPARED BY DEPARTMENT OF MATHEMATICS
SAMBALPUR UNIVERSITY

COURSE STRUCTURE FOR UNDER GRADUATE MATHEMATICS

(As per NEP guideline provided by Department of Higher Education, Government of Odisha)

SUMMARY SHEET FOR ALL UG PROGRAMS (MATHEMATICS)

Semester		Fourth Year Hons. without Research	Fourth Year Hons. with Research	Three Degree Course with Single Major and Two Minor	Three Degree Course with Double Major	Three Year Degree Courses with Three Core without Major
I	1)	Calculus and Analytic Geometry	Calculus and Analytic Geometry	Calculus and Analytic Geometry	Calculus and Analytic Geometry	Calculus and Analytic Geometry
	2)	Introduction to Algebra & Number Theory	Introduction to Algebra & Number Theory	Introduction to Algebra & Number Theory	Introduction to Algebra & Number Theory	
II	3)	Real Analysis-I	Real Analysis-I	Real Analysis-I	Real Analysis-I	Introduction to Algebra & Number Theory
	4)	Algebra-I	Algebra-I	Algebra-I	Algebra-I	
III	5)	Probability	Probability	Probability	Probability	Real Analysis-I
	6)	Differential Equations-I	Differential Equations-I	Differential Equations-I	Differential Equations-I	Algebra-I
	7)	Linear Algebra	Linear Algebra	Linear Algebra	Linear Algebra	
IV	8)	Real Analysis-II	Real Analysis-II	Real Analysis-II	Real Analysis-II	Differential Equations-I
	9)	Complex Analysis-I	Complex Analysis-I	Complex Analysis-I	Complex Analysis-I	
	10)	Algebra-II	Algebra-II	Algebra-II	Algebra-II	
V	11)	Differential Equations-II	Differential Equations-II	Differential Equations-II	Differential Equations-II	Linear Algebra
	12)	Real Analysis-III	Real Analysis-III	Real Analysis-III	Real Analysis-III	
	13)	Numerical Analysis & Scientific Computing	Numerical Analysis & Scientific Computing	Numerical Analysis & Scientific Computing	Numerical Analysis & Scientific Computing	
VI	14)	Multivariable Calculus	Multivariable Calculus	Multivariable Calculus	Multivariable Calculus	Complex Analysis-I
	15)	Differential Geometry	Differential Geometry	Differential Geometry	Differential Geometry	
VII	16)	Measure Theory & Integration	Measure Theory & Integration			
	17)	Algebra-III	Algebra-III			
	18)	Topology	Topology			
	19)	Mathematical Methods				
VIII	20)	Functional Analysis	Functional Analysis			
	21)	Analytic Number Theory	Analytic Number Theory			
	22)	Complex Analysis-II				
	23)	Differential Equations-III				
Total		**23x4=92**	**20x4=80**	**15x4=60**	**12x4=48**	**7x4=28**

COURSE STRUCTURE FOR UNDER GRADUATE MATHEMATICS

(As per NEP guideline provided by Department of Higher Education, Government of Odisha)

Table-I: Structure for Certificate Courses Exit After First Academic Year

[(One academic year (First & Second Semesters and a Summer/Vocational Course and Community Work)]

Semester	Core-I	Core-II	Core-III	Multidisciplinary	AEC	SEC	VAC	Community Engagement & Services/ Fieldwork/ Internships	Total Minimum Credit
I	**2X4=8**	**1X4=4**		**1X3=3**	**1X4=4**		**1x3=3**		**22**
	Paper-I: Calculus & Analytic Geometry **Paper-II**: Introduction to Algebra & Number Theory	Calculus & Analytic Geometry		Discrete Mathematics	Odia		Environmental Studies and Disaster management		
II	**2X4=8**		**1X4=4**	**1X3=3**	**1X4=4**	**1x3=3**			**22**
	Paper-III: Real Analysis-I **Paper-IV**: Algebra-I		Calculus & Analytic Geometry	Linear Programing Problem	English	Type setting in latex (Practical)			
Total	**4x4=16**	**1X4=4**	**1X4=4**	**2x3=6**	**2x4=8**	**1x3=3**	**1x3=3**		**44**
Vocational Course of 4credits for Certificate									

NB: However, multidisciplinary courses can be chosen from Appendix A without repetition as per the availability of teaching hands and resources in the institute.

<u>Table-II:</u> Structure for Diploma Certificate Course Exit After Second Academic Year

[Two academic years (*First, Second, Third & Four Semesters and a Summer Vocational Course and Community Work***)]**

Semester	Core-I	Core-II	Core-III	Multidisciplinary	AEC	SEC	VAC	Community Engagement & Services/ Fieldwork/ Internships	Total Minimum Credit
I	**2X4=8**	**1X4=4**		**1X3=3**	**1X4=4**		**1x3=3**		**22**
	Paper-I: Calculus & Analytic Geometry **Paper-II**: Introduction to Algebra & Number Theory	Calculus & Analytic Geometry		Discrete Mathematics	Odia		Environmental Studies and Disaster management		
II	**2X4=8**		**1X4=4**	**1X3=3**	**1X4=4**	**1x3=3**			**22**
	Paper-III: Real Analysis-I **Paper-IV**: Algebra-I		Calculus & Analytic Geometry	Linear Programing Problem	English	Type setting in latex (Practical)			
									44
III	**3X4=12**	**1X4=4**		**1X3=3**			**1x3=3**		**22**
	Paper-V: Probability **Paper-VI**: Differential Equations-I **Paper-VII**: Linear Algebra	Introduction to Algebra & Number Theory		Programing on C++					
IV	**3X4=12**		**1X4=4**					**1x4=4**	**20**
	Paper-VIII: Real Analysis-II **Paper-IX**: Complex Analysis-I **Paper-X**: Algebra -II		Introduction to Algebra & Number Theory						
									42
Total	**10x4=40**	**2x4=8**	**2x4=8**	**3x3=9**	**2x4=8**	**1x3=3**	**2x3=6**	**1x4=4**	**86**
Vocational Course of 4 credits for Diploma Certificate									

Core-II and Core-III are interchangeable.

NB: However, multidisciplinary courses can be chosen from Appendix A without repetition as per the availability of teaching hands and resources in the institute.

Table-III: Three Year Degree Course with Single Major and Two Minors

Semester	Core-I	Core-II	Core-III	Multi-disciplinary	AEC	SEC	VAC	Community Engagement & Services/ Fieldwork/ Internships	Total Minimum Credit
I	**2X4=8**	**1X4=4**		**1X3=3**	**1X4=4**		**1x3=3**		**22**
	Paper-I: Calculus & Analytic Geometry **Paper-II**: Introduction to Algebra & Number Theory	Calculus & Analytic Geometry		Discrete Mathematics	Odia		Environmental Studies and Disaster management		
II	**2X4=8**		**1X4=4**	**1X3=3**	**1X4=4**	**1x3=3**			**22**
	Paper-III: Real Analysis-I **Paper-IV**: Algebra-I		Calculus & Analytic Geometry	Linear Programing Problem	English	Type setting in latex (Practical)			
									44
III	**3X4=12**	**1X4=4**		**1X3=3**			**1x3=3**		**22**
	Paper-V: Probability **Paper-VI**: Differential Equations-I **Paper-VII**: Linear Algebra	Introduction to Algebra & Number Theory		Programing on C++					
IV	**3X4=12**		**1X4=4**					**1x4=4**	**20**
	Paper-VIII: Real Analysis-II **Paper-IX**: Complex Analysis-I **Paper-X**: Algebra -II		Introduction to Algebra & Number Theory						
									42
V	**3X4=12**	**1X4=4**				**1x3=3**	**1x3=3**		**22**
	Paper-XI: Real Analysis-III **Paper-XII**: Differential Equations-II **Paper-XIII**: Numerical Analysis & Scientific Computing	Real Analysis-I				Introduction to Python			
VI	**2X4=8**		**1X4=4**			**1x3=3**	**1x3=3**		**18**
	Paper-XIV: Multivariable Calculus **Paper-XV**: Differential Geometry		Real Analysis-I			Programing with Mathematica			
									40
Total	**15X4=60**	**3X4=12**	**3X4=12**	**3X3=9**	**2X4=8**	**3x3=9**	**4x3=12**	**1x4=4**	**126**

NB: However, multidisciplinary courses can be chosen from Appendix A without repetition as per the availability of teaching hands and resources in the institute.

Table-IV: Three Year Degree Course Double Major Course

Semester	Core-I	Core-II	Multi-disciplinary	AEC	SEC	VAC	Community Engagement & Services/ Fieldwork /Internship	Total Minimum Credit
I	**2X4=8**	**2X4=8**	**1x3=3**	**1X4=4**		**1x3=3**		**26**
	Paper-I: Calculus & Analytic Geometry **Paper-II**: Introduction to Algebra & Number Theory	**Paper-I**: Calculus & Analytic Geometry **Paper-II**: Introduction to Algebra & Number Theory	Discrete Mathematics	Odia		Environmental Studies and Disaster management		
II	**2X4=8**	**2X4=8**	**1X3=3**	**1X4=4**	**1X3=3**			**26**
	Paper-III: Real Analysis-I **Paper-IV**: Algebra-I	**Paper-III**: Real Analysis-I **Paper-IV**: Algebra-I	Linear Programing Problem	English	Type setting in latex (Practical)			
								52
III	**3X4=12**	**2X4=8**	**1X3=3**			**1X3=3**		**26**
	Paper-V: Probability **Paper-VI**: Differential Equations-I **Paper-VII**: Linear Algebra	**Paper-V**: Differential Equations-I **Paper-VI**: Linear Algebra	Programing on C++					
IV	**3X4=12**	**2X4=8**					**1x4=4**	**24**
	Paper-VIII: Real Analysis-II **Paper-IX**: Complex Analysis-I **Paper-X**: Algebra -II	**Paper-VII**: Complex Analysis-I **Paper-VIII**: Algebra -II						
								50
V	**3X4=12**	**2X4=12**			**1x3=3**	**1x3=3**		**29**
	Paper-XI: Real Analysis-III **Paper-XII**: Differential Equations-II **Paper-XIII**: Numerical Analysis & Scientific Computing	**Paper-IX**: Differential Equations-II **Paper-X**: Numerical Analysis & Scientific Computing			Introduction to Python			
VI	**2X4=8**	**3X4=12**			**1x3=3**	**1x3=3**		**29**
	Paper-XIV: Multivariable Calculus **Paper-XV**: Differential Geometry	**Paper-XI**: Multivariable Calculus **Paper-XII**: Differential Geometry			Programing with Mathematica			
								58
Total	**15X4=60**	**12X4=48**	**3X3=9**	**2X4=8**	**09**	**12**	**1x4=4**	**150**

NB: However, multidisciplinary courses can be chosen from Appendix A without repetition as per the availability of teaching hands and resources in the institute.

Table-V: Three Year Degree Course with Three Core without Major

Semester	Core-I	Core-II	Core-III	Multidisciplinary	AEC	SEC	VAC	Community Engagement& Services/Fieldwork / Internship	Total Minimum Credit
I	**1X4=4**	**1X4=4**	**1X4=4**	**1X3=3**	**1X4=4**		**1x4=3**		**22**
	Paper-I Calculus & Analytic Geometry	**Paper-I** Calculus & Analytic Geometry	**Paper-I** Calculus & Analytic Geometry	Discrete Mathematics	Odia		Environmental Studies and Disaster management		
II	**1X4=4**	**1X4=4**	**1X4=4**	**1X3=3**	**1X4=4**	**1X3=3**			**22**
	Paper-II Introduction to Algebra & Number Theory	**Paper-II** Introduction to Algebra & Number Theory	**Paper-II** Introduction to Algebra & Number Theory	Linear Programing	English	Type setting in latex (Practical)			
									44
III	**2X4=8**	**1X4=4**	**1X4=4**	**1X3=3**			**1X3=3**		**22**
	Paper-III Real Analysis-I **Paper-IV** Algebra-I	**Paper-III** Real Analysis-I	**Paper-III** Real Analysis-I	Programing on C++					
IV	**1X4=4**	**2X4=8**	**1X4=4**					**1x4=4**	**20**
	Paper-V Differential Equations-I	**Paper-IV** Algebra-I **Paper-V** Differential Equations-I	**Paper-IV** Algebra-I						
									42
V	**1X4=4**	**1X4=4**	**2X4=8**			**1x3=3**	**1x3=3**		**22**
	Paper-VI Linear Algebra	**Paper-VI** Linear Algebra	**Paper-V** Differential Equations-I **Paper-VI** Linear Algebra			Introduction to Python			
VI	**1X4=4**	**1X4=4**	**1X4=4**			**1x3=3**	**1x3=3**		**18**
	Paper-VII Complex Analysis-I	**Paper-VII** Complex Analysis-I	**Paper-VII** Complex Analysis-I			Programing with Mathematica			
									40
Total	**7X4=28**	**7X4=28**	**7X4=28**	**3X3=9**	**2X4=8**	**3X3=9**	**4X3=12**	**1x4=4**	**126**

NB: However, multidisciplinary courses can be chosen from Appendix A without repetition as per the availability of teaching hands and resources in the institute.

Table-VI: Fourth Year Hons. Without Research

Semester	Core-I	Core-II	Core -III	Multidisciplinary	AEC	SEC	VAC	Community Engagement & Services/ Field work /Internship	Total Minimum Credit
I	**2X4=8**	**1X4=4**		**1X3=3**	**1X4=4**		**1x3=3**		**22**
	Paper-I: Calculus & Analytic Geometry **Paper-II**: Introduction to Algebra & Number Theory	Calculus & Analytic Geometry		Discrete Mathematics	Odia		Environmental Studies and Disaster management		
II	**2X4=8**		**1X4=4**	**1X3=3**	**1X4=4**	**1x3=3**			**22**
	Paper-III: Real Analysis-I **Paper-IV**: Algebra-I		Calculus & Analytic Geometry	Linear Programing Problem	English	Type setting in latex (Practical)			
									44
III	**3X4=12**	**1X4=4**		**1X3=3**			**1x3=3**		**22**
	Paper-V: Probability **Paper-VI**: Differential Equations-I **Paper-VII**: Linear Algebra	Introduction to Algebra & Number Theory		Programing on C++					
IV	**3X4=12**		**1X4=4**					**1x4=4**	**20**
	Paper-VIII: Real Analysis-II **Paper-IX**: Complex Analysis-I **Paper-X**: Algebra -II		Introduction to Algebra & Number Theory						
									42
V	**3X4=12**	**1X4=4**				**1x3=3**	**1x3=3**		**22**
	Paper-XI: Real Analysis-III **Paper-XII**: Differential Equations-II **Paper-XIII**: Numerical Analysis & Scientific Computing	Real Analysis-I				Introduction to Python			
VI	**2X4=8**		**1X4=4**			**1x3=3**	**1x3=3**		**18**
	Paper-XIV: Multivariable Calculus **Paper-XV**: Differential Geometry		Real Analysis-I			Programing with Mathematica			
									40
VII	**4x4=16**	**1x4=4**							**20**
	Paper-XVI: Measure Theory & Integration **Paper-XVII**: Algebra-III **Paper-XVIII**: Topology **Paper-XIX**: Mathematical Methods	Linear Algebra							
VIII	**4x4=16**	**1x4=4**							**20**
	Paper-XX: Functional Analysis **Paper-XXI**: Analytic Number Theory **Paper-XXII**: Complex Analysis-II **Paper-XXIII**: Differential Equations-III	Multivariable Calculus							
									40
Total	**23X4=92**	**5X4=20**	**3X4=12**	**3X3=9**	**2X4=8**	**3X3=9**	**4X3=12**	**1X4=4**	**166**

Table-VII: Fourth Year Hons. with Research

Semester	Core-I	Core-II	Core-III	Multidisciplinary	AEC	SEC	VAC	Community Engagement & Services/ Field work /Internship	Total Minimum Credit
I	**2X4=8**	**1X4=4**		**1X3=3**	**1X4=4**		**1x3=3**		**22**
	Paper-I: Calculus & Analytic Geometry **Paper-II**: Introduction to Algebra & Number Theory	Calculus & Analytic Geometry		Discrete Mathematics	Odia		Environmental Studies and Disaster management		
II	**2X4=8**		**1X4=4**	**1X3=3**	**1X4=4**	**1x3=3**			**22**
	Paper-III: Real Analysis-I **Paper-IV**: Algebra-I		Calculus & Analytic Geometry	Linear Programing Problem	English	Type setting in latex (Practical)			
									44
III	**3X4=12**	**1X4=4**		**1X3=3**			**1x3=3**		**22**
	Paper-V: Probability **Paper-VI**: Differential Equations-I **Paper-VII**: Linear Algebra	Introduction to Algebra & Number Theory		Programing on C++					
IV	**3X4=12**		**1X4=4**					**1x4=4**	**20**
	Paper-VIII: Real Analysis-II **Paper-IX**: Complex Analysis-I **Paper-X**: Algebra -II		Introduction to Algebra & Number Theory						
									42
V	**3X4=12**	**1X4=4**				**1x3=3**	**1x3=3**		**22**
	Paper-XI: Real Analysis-III **Paper-XII**: Differential Equations-II **Paper-XIII**: Numerical Analysis & Scientific Computing	Real Analysis-I				Introduction to Python			
VI	**2X4=8**		**1X4=4**			**1x3=3**	**1x3=3**		**18**
	Paper-XIV: Multivariable Calculus **Paper-XV**: Differential Geometry		Real Analysis-I			Programing with Mathematica			
									40
VII	**3x4=12**	**2x4=8**							**20**
	Paper-XVI: Measure Theory & Integration **Paper-XVII**: Algebra-III **Paper-XVIII**: Topology	1. Linear Algebra 2.Multivariable Calculus							

VIII	**2x4=8**							**12**	**20**
	Paper-XIX: Functional Analysis **Paper-XX**: Analytic Number Theory							**Research**	
									40
Total	**20X4=80**	**5X4=20**	**3X4=12**	**3X3=9**	**2X4=8**	**3X3=9**	**4X3=12**	**16**	**166**

NB: However, multidisciplinary courses can be chosen from Appendix A without repetition as per the availability of teaching hands and resources in the institute.

APPENDIX

Appendix-A

MULTI-DISCIPLINARY COURSES

1) Discrete Mathematics
2) Programming in C++
3) Numerical Methods
4) Mathematical Finance
5) Mathematical Modelling
6) Linear Programming
7) Introduction to Programming with MATLAB
8) Introduction to Machine Learning

Appendix-B

THRUST AREAS FOR DISSERTATION/PROJECT WORK

The student should work for his dissertation in a topic in one of these areas or any area related to these:

1. Topics in Number theory and its applications to Cryptography, Coding theory, etc.
2. Topics in recent development in Group theory, Ring and Field theory
3. Special topics in Number theory like Ramanujan Sum, Distribution of primes
4. Fibonacci and Lucas numbers, Riemann Zeta function, etc.
5. Linear algebra, Matrix theory and applications.
6. Representation theory.
7. Topics in Ordinary Differential Equations such as Stability theory, Oscillation theory.
8. Bifurcation and Catastrophe theory.
9. Finite element method.
10. Initial and boundary value problems in Ordinary and Partial differential equation.
11. Difference equations.
12. Discrete dynamical system such as Julia sets, Horse shoes, Cellular Automata. etc., with topological properties and applications.
13. Fractional calculus.
14. Complex analysis.
15. Fractals and their applications.
16. Geometric function theory including univalent (harmonic) mappings, Quasi conformal maps in one and several variables.
17. Orthogonal polynomials in **R** and **C**, q-Calculus and Moments problem.
18. P-adic analysis and P-adic fields.
19. Measure theory.
20. Functional analysis and applications.
21. Summability theory.
22. Geometry of Banach spaces.
23. Ergodic theory.
24. Information theory.
25. Fourier analysis.
26. Wavelets.
27. Fixed point theory.
28. General Topology.
29. Combinatorial Topology.
30. Differential Topology.
31. Algebraic topology including Homology, Homotopy theory, Fundamental groups, Covering spaces, CW complexes, etc.
32. Algebraic Geometry and related topics.
33. Normed algebras.
34. Topics in Operator theory and Operator algebras.
35. Operators on function Spaces including Composition operators, Toeplitz operators, Hankel operators, etc.

36. Spectral theory for bounded and unbounded operator on Hilbert space including Scattering theory.
37. Mathematical modeling (Pollution modeling, Epidemic modeling, Population modeling, etc.).
38. Mathematical Biology including Mathematics of life sciences.
39. Differentiable manifolds, differential forms and related topics.
40. Lie Groups and Lie algebras.
41. Knots and Braids.
42. Relativity, Cosmology and Gravitation, etc.
43. Nonlinear programing problems and applications.
44. Queuing theory.
45. Optimization and Combinatorial optimization.
46. Topics in Artificial Intelligence, Machine learning, Manifold learning and Principal component analysis, etc.
47. Data structure and Data base management, etc.
48. Fuzzy theory and Rough sets.
49. Topics in applications of Probability, Stochastic models including Markov Process, Brownian process, Birth and Death processes, Renewal and Branching, and Reliability, etc.
50. Time series and Forecasting.
51. Topics in Integrable Models such as KDV and KP equation , Toda Lattice, Veselov Novikov, Davey Stewartson and Benney equations, etc.
52. Topics in Image Processing, Signal processing, discrete Image processing, etc.
53. Topics in Graph theory and Combinatorics.
54. Topics in Numerical analysis, Numerical solution for ODE and PDE, etc.
55. Time scale calculus.
56. Computational fluid dynamics.
57. Projective geometry.
58. Finite Field

Appendix-C
SKILL ENHANCEMENT COURSE

1. Introduction to Python
2. Programing with Mathematica
3. Latex

Appendix-D
VALUE ADDED COURSE

1. R-programming
2. Mathematica
3. Maple
4. Sagemath
5. Scilab

COURSE STRUCTURE FOR UNDER GRADUATE MATHEMATICS

(As per NEP guideline provided by Department of Higher Education, Government of Odisha)

DETAILED SYLLABUS OF THE CORE COURSES

CALCULUS & ANALYTIC GEOMETRY

Objective: The main emphasis of this course is to equip the student with necessary analytic and technical skills to handle problems of mathematical nature as well as practical problems. More precisely, main target of this course is to explore the different tools for higher order derivatives to plot the various curves and to solve the problems associated with differentiation and integration of vector functions.

Learning Outcomes: After completing the course the student will be able to

CO1: trace a curve and find asymptotes.
CO2: calculate integrals of typical type using reduction formulae, etc.
CO3: calculate arc length, surface of revolution and know about conics
CO4: calculate triple products, gradient divergence, curl, etc.

UNIT-I

Hyperbolic functions, higher order derivatives, Leibnitz rule and its applications to problems of the type $e^{ax+b}sinx$, $e^{ax+b}cosx$, $(ax+b)^n sinx$, $(ax+b)^n cosx$, concavity and inflection points, asymptotes, curve tracing in Cartesian coordinates, tracing in polar coordinates of standard curves, L'Hospital rule, application in business, economics and life sciences.

UNIT-II

Riemann integration as a limit of sum, integration by parts, reduction formulae, derivations and illustrations of reduction formulae of the type $\int sin^n x dx$,$\int cos^n x dx$,$\int tan^n x dx$,$\int sec^n x dx$, $\int (logx)^n dx$,$\int sin^n x cos^n x dx$, definite integral, integration by substitution.

UNIT-III

Volumes by slicing, disks and washers methods, volumes by cylindrical shells, parametric equations, parameterizing a curve, arc length, arc length of parametric curves, area of surface of revolution, techniques of sketching conics, reflection properties of conics, rotation of axes and second degree equations, classification into conics using the discriminant, polar equations of conics.

UNIT-IV

Triple product, introduction to vector functions, operations with vector-valued functions, limits and continuity of vector functions, differentiation, partial differentiation, div, curl and integration of vector functions, tangent and normal components of acceleration.

BOOKS RECOMMENDED:

1. H. Anton, I. Bivens and S. Davis: Calculus,10th Ed., John Wiley and Sons (Asia) Pvt. Ltd., Singapore, 2002.
2. Shanti Narayan, P. K. Mittal: Differential Calculus, S. Chand, 2014.
3. R. J. T Bell: An elementary Treatise on coordinate geometry, MacMillan and Company Limited, 2005.

BOOKS FOR REFERENCE:

1. James Stewart: Single Variable Calculus, Early Transcendental, 8th edition, Cengage Learning, 2016.
2. G.B. Thomas and R. L. Finney: Calculus, 9th Ed., Pearson Education, Delhi, 2005.
3. M. J. Strauss, G. L. Bradley and K. J. Smith: Calculus, 3rd edition, Dorling Kindersley (India) Pvt. Ltd. (Pearson Education), Delhi, 2007.
4. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
5. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

INTRODUCTION TO ALGEBRA & NUMBER THEORY

Objectives: To present a systematic introduction to number theory and a basic course on algebra.

Learning Outcomes: After completing the course the student will be able to

CO1: understand the equivalence relations and concept of group with different examples.
CO2: understand the properties of cyclic groups, rings, and integral domain.
CO3: know divisibility and division algorithm and find *gcd* using Euclidean Algorithm.
CO4: solve linear Diophantine equations, find least common multiples, solve linear congruence applying the Chinese remainder theorem.

UNIT -I

Integers and equivalence relations**,** properties of integers, modular arithmetic, mathematical inductions, equivalence relations, Introduction to groups**,** symmetries of a square, the dihedral groups, definitions and examples of groups, elementary properties of groups, subgroups, examples of subgroups.

UNIT-II

Cyclic groups, properties of cyclic groups, classification of subgroups of cyclic groups, definitions and examples of normal subgroups, Introduction to rings, definition and examples of rings, properties of rings, subrings, definition and examples of integral domain and fields.

UNIT-III

Divisibility**,** division algorithms, prime and composite numbers, Fibonacci and Lucas numbers, Fermat numbers, greatest common divisor, Euclidean algorithm.

UNIT-IV

Fundamental theorem of arithmetic, least common multiple, linear Diophantine equations, congruence, linear congruence, Chinese remainder theorem, Wilson's theorem, Fermat little theorem, Euler's theorem.

BOOKS RECOMMENDED:

1. Joseph A. Gallian, Contemporary Abstract Algebra (4th Edition), Narosa Publishing House, New Delhi, 1999.(IX Edition 2010).
2. Thomas Koshy, Elementary Number Theory with Applications (2nd Edition), Academic Press, 2007.

BOOKS FOR REFERENCE:

1. I. N. Herstein: Topics in Algebra, Wiley Eastern Limited, India, 1975.
2. David M. Burton: Elementary Number Theory (6th Edition), Tata McGraw-Hill Edition, Indian Reprint, 2007.
3. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
4. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org.

REAL ANALYSIS-I

Objective: The objective of the course is to introduce the basics of real number system and the properties of sequence and series of real numbers. The ideas of completeness, least upper bound property, denseness, limit, continuity and uniform continuity will also be introduced. This is one of the core courses essential to start doing mathematics.

Learning Outcomes: On successful completion of this course, students will be able to
CO1: learn basics of real number system and test countability of a set.
CO2: know on sequence of real numbers and their basic properties.
CO3: test convergence of an infinite series.
CO4: find limit and continuity of functions and test uniform continuity of functions.

UNIT-I

Finite and infinite sets, countable and uncountable sets, examples, algebraic and order Properties of R, uncountability of R, completeness property of **R,** applications of the supermom property, Intervals, nested interval property, denseness of rationals in R.

UNIT-II

Sequence and their limits, limit theorems, monotone sequences, monotone Convergence theorem, subsequences, divergence criteria, monotone subsequence theorem, Bolzano Weierstrass theorem for sequences, Cauchy sequence, Cauchy's convergence criterion.

UNIT-III

Infinite series, convergence and divergence of infinite series, Cauchy criterion, Tests for convergence: comparison test, limit comparison test, ratio test, Cauchy's nth root test, Raabe's test, integral test, alternating series, Leibniz test, absolute and conditional convergence.

UNIT-V

Limits of functions, limit theorems, some extensions of limit concept, continuous functions and their combinations, continuous functions on intervals, boundedness theorem, maximum minimum theorem, intermediate value theorem, uniform continuity, examples, uniform continuity theorem.

BOOKS RECOMMENDED:

1. R. G. Bartle and D. R. Sherbert, *Introduction to Real Analysis,* 3rd Edn., John Wiley and Sons (Asia) Pvt. Ltd., Singapore, 2002.
2. G. Das and S. Pattanayak, *Fundamentals of Mathematical Analysis*, TMH Publishing Co., 30th reprints, 2021.

BOOKS FOR REFERENCE:

3. S. C. Mallik and S. Arora, *Mathematical Analysis*, New Age International Publications.
4. A. Kumar, S. Kumaresan, *A basic course in Real Analysis*, CRC Press, 2014.
5. Brian S. Thomson, Andrew. M. Bruckner, and Judith B. Bruckner, *Elementary Real Analysis,* Prentice Hall, 2001.
6. Gerald G. Bilodeau , Paul R. Thie, G. E. Keough, *An Introduction to Analysis,* Jones & Bartlett, Second Edition, 2010.
7. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org
8. Suggested digital platform: NPTEL/SWAYAM/MOOCs.

ALGEBRA-I

Objectives: To present a systematic and rigorous study on algebraic structures like groups, rings and some important results with their applications. After pursuing this course, one can opt for advanced topics in groups, rings and their applications to problems in physics, computer science and engineering.

Learning Outcomes: After completing this course, students will able to

CO1: understand permutation groups with some results and application in Rubik's cube.
CO2: understand the concept of homomorphisms, isomorphisms, normal subgroups and factor groups.
CO3: explore more properties of rings and ideals rigorously.
CO4: get introduced to the concept of reducibility and irreducibility of polynomials and concept of unique factorization domain.

Unit -I

Permutation groups, definition and notations, cyclic notation, properties of permutations, isomorphisms, definition and examples, Cayley's theorem, properties of isomorphisms, automorphisms, cosets, properties of cosets, Lagrange's theorem and consequences, an application of cosets to permutation groups, an application of cosets to Rubik's cube.

Unit-II

External direct products, definition and examples, properties of external direct products, the group of units modulo n as an external direct product, applications, normal subgroups, factor groups, application of factor groups, internal direct products, group homomorphisms, definition and examples, properties of homomorphisms, the first isomorphism theorem.

Unit-III

Characteristic of a ring, ideals, factor rings, prime ideals and maximal ideals, ring homomorphisms, definition and examples, the field of quotients, polynomial rings, notations and terminology, division algorithm and consequences.

Unit-IV

Factorization of polynomials, reducibility test, irreducibility test, unique factorization in Z[x], divisibility in integral domains, irreducible, primes, unique factorization domain, Euclidean domain.

BOOKS RECOMMENDED:

1. Joseph A. Gallian, Contemporary Abstract Algebra (9th Edition), Narosa Publishing House, New Delhi, 2010.
2. I. N. Herstein, Topics in Algebra, Wiley Eastern Limited, India, 1975.

BOOKS FOR REFERENCE:

3. John B. Fraleigh, A First Course in Abstract Algebra, 7th Ed., Pearson, 2002.
4. D. S. Dummit, R. M. Foote, Abstract Algebra, Wiley-India edition, 2013.
5. Joseph 1. Rotman, An Introduction to the Theory of Groups, 4th Ed., Springer Verlag, 1995.
6. M. Artin, Abstract Algebra, 2nd Ed., Pearson, 2011.
7. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
8. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

PROBABILITY

Objective: The objective of the course is to make the student understand basics of probability which is of use in everyday life.

Learning Outcomes: After completing the course the student will be able to
CO1: learn the basics of probability and random variables with axioms of probability.
CO2: know the discrete and continuous distributions and learn how to calculate mean, variance and moments of them.
CO3: learn on limit theorems with their applications and know about the conditional expectations.
CO4: learn on Markov chains and their applications.

UNIT-I

Sample space and events, probability axioms, probability defined on events, conditional probabilities, Independent events, Bayes formula, real random variables, discrete and continuous random variables, probability distribution function, probability mass/density functions, mathematical expectation, and properties, variance and standard deviation.

UNIT-II

Discrete distributions: uniform, binomial, Poisson, geometric, negative binomial, continuous distributions: uniform, normal, exponential, their expectations and variance, moments, moment generating function, characteristic function and computation of these for the distributions, joint distribution function and its properties, joint probability density functions, marginal and conditional distributions, independent random variables.

UNIT-III

Limit theorems: Markov inequality, Chebyshev's inequality, statement and interpretation of (weak) law of large numbers and strong law of large numbers, application to problems, conditional probability and conditional expectation, discrete case, continuous case, applications, expectation of function of two random variables, conditional expectations, bivariate normal distribution, correlation coefficient, joint moment generating function and calculation of covariance, linear regression for two variables.

UNIT-IV

Central limit theorem for independent and identically distributed random variables with finite variance, Markov chains, Chapman-Kolmogorov equations, classification of states, Gambler Ruin problem.

BOOK RECOMMENDED

1. Sheldon Ross, *Introduction to Probability Models* (9th Edition), Academic Press, Indian Reprint, 2007.
2. Robert V. Hogg, Joseph W. McKean and Allen T. Craig, *Introduction to Mathematical Statistics,* Pearson Education, Asia, 2007.
3. Kai Lai Chung, *Elementary Probability Theory with Stochastics Process,* Springer International Students Edition, (Narosa Publ.)

BOOK FOR REFERENCE

4. Alexander M. Mood, Franklin A. Graybill and Duane C. Boes, *Introduction to the Theory of Statistics,* (3rd Edition), Tata McGraw- Hill, Reprint 2007.

5. Chow Y S , Teicher H Probability theory Springer International edition
6. Irwin Miller and Marylees Miller, *John E. Freund's Mathematical Statistics with Applications* (7th Edition), Pearson Education, Asia, 2006.
7. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org
8. Suggested digital platform: NPTEL/SWAYAM/MOOCs.

DIFFERENTIAL EQUATIONS-I

Objective: Differential Equations introduced by Leibnitz in 1676 models almost all Physical, Biological, Chemical systems in nature. The objective of this course is to familiarize the students to various methods of solving differential equations, partial differential equations and to have a qualitative applications through models. The students have to solve problems to understand the methods.

Learning Outcomes: After completing the course the student will be able to

CO1: get the idea to solve first order linear ordinary differential equations of different types those are arising in physical problems.
CO2: get the idea to solve second order linear ordinary differential equations of different types those are arising in physical problems.
CO3: get basic ideas of first order partial differential equations, its formulation in two, three variables and variable separable method for identify the solutions.
CO4: get idea to solve various mathematical models of ODEs and PDEs which may be helpful for simulation process.

UNIT-I

Differential equations and mathematical models, general, particular, explicit, implicit and singular solutions of a differential equation, exact differential equations and integrating factors, separable equations and equations reducible to this form, linear equations and Bernoulli's equation, compartmental model, population model for single species.

UNIT-II

General solution of homogeneous equation of second order, principle of superposition, Wronskian, its properties and applications, method of undetermined coefficients, method of variation of parameters, linear homogeneous and non-homogeneous equations of higher order with constant coefficients, Euler's equations.

UNIT-III

Partial Differential Equations - Basic concepts and definitions, origin of first order PDEs, Classification of first order PDEs, Pfaffian differential forms and equations, solution of Pfaffian differential equations in three variables, Cauchy's problem for first order PDEs, linear equations of first order, integral surfaces passing through a given curve, Cauchy's method of characteristics, compatible systems, method of separation of variables for solving first order and second order partial differential equations.

UNIT-IV (PRACTICAL)

The students will implement the following problems in the computer Lab using *Matlab* / *Mathematica* / *Maple* etc.

1. Plotting of second order solution family of differential equations.
2. Plotting of third order solution family of differential equations.
3. Population growth model (exponential case only).
4. Population decay model (exponential case only).
5. Solution of Cauchy problem for first order PDEs.
6. Finding the characteristics for the first order PDEs.
7. Plot the integral surfaces of a given first order PDE with initial data.

BOOKS RECOMMENDED:

1. J. Sinha Roy and S. Padhy: *A course of Ordinary and Partial differential equations,* Kalyani Publishers, New Delhi,2018.
2. Belinda Barnes and Glenn R. Fulford, *Mathematical Modeling with Case Studies, A Differential Equation Approaching Maple and Matlab,* 2nd Edn. Taylor and Francis group, London and New York, 2009.
3. Sneddon; Elements of Partial Differential Equations, McGraw-Hill, International Students Edition, 1957.

BOOKS FOR REFERENCE:

4. G. F. Simmons, Differential equation, Tata McGraw Hill, 1991.
5. J. N. Sharma and Kehar Singh, PDE for Engineers and Scientists, Narosa, New Delhi, 2009.
6. Martin Braun, Differential Equations and their Applications, Springer International Student Ed.1978.
7. S. L. Ross, Differential Equations, 3rd Edition, John Wiley and Sons, India, 2014.
8. C.Y. Lin, Theory and Examples of Ordinary Differential Equations, World Scientific, 2011.
9. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
10. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

LINEAR ALGEBRA

Objective: The objective of this course is to acquaint students with matrix operations, solution of system of equations, vector spaces and linear transformations. In addition, the student will learn about eigenvalues, diagonalization, canonical forms, etc., which has many applications in almost all areas of science and engineering.

Learning Outcomes: After completing the course the student will be able to

CO1: determine basis and the dimension of a finite-dimensional vector space, know the relation between rank and nullity of a linear transformation.
CO2: the relation between matrix and linear transformation.
CO3: to find solution of system of linear equations, compute eigenvalues, eigenvectors of a matrix and linear transformation.
CO4: about orthogonality of vectors and application of it to different form of matrix, introduced to different operators.

UNIT-I

Vector spaces, subspaces, span of a set, more about subspaces, linear dependence, independence, product and quotient space, dimension and basis, linear transformations, range and kernel of a linear map, rank and nullity of linear map.

UNIT-II

Inverse of linear transformation, consequences of rank – nullity theorem, the space L(U, V), composition of linear maps, matrix associated with linear map, linear map associated with matrix, rank and nullity of a matrix, determinant minors and rank of a matrix, transpose of a matrix and special type of matrices, elementary row operations

UNIT-III

System of linear equations, matrix inversion, application of determinant to linear equations, eigenvalues and eigenvectors, similarity of matrices, invariant subspaces, minimal polynomial (eigenvalues and the minimal polynomial), upper triangular matrices, diagonalizable operators (diagonal matrices, conditions for diagonalizability).

UNIT-IV

Inner product space: inner products and norms, orthonormal bases, orthogonal complements, self-adjoint and normal operators, spectral theorems, isometries, unitary operators, characteristic polynomial, Cayley – Hamilton theorem, Jordan form, trace, quadratic form, application to reduction of quadrics.

BOOKS RECCOMMENDED:

1. V. Krishnamurthy. V.P. Mainra, J. L. Arora, *An introduction to linear algebra*, Affiliated East – West press Pvt. Ltd., New Delhi, 1976.
2. Sheldon Axler, *Linear algebra done right* (Fourth edition),Springer, 2024.

BOOKS FOR REFERENCES:

3. Seymour Lipschutz and Marc Lars Lipson, *Linear Algebra* (Schaum's outlines, Fourth Edition), McGraw Hill, New York, 2009.
4. A. Ramachandra Rao and P. Bhimsankaram, *Linear Algebra (Second* Edition*)*, Hindustan Book Agency, 2000.
5. Stephen H. Friedberg, Arnold J. Insel, Lawrence E. Spence, *Linear Algebra* (Fourth Edition), Prentice-Hall of India Pvt. Ltd., New Delhi, 2004.
6. Gilbert Strang, Linear Algebra and its Applications, Thomson, 2007.
7. S. Kumaresan, *Linear Algebra- A Geometric Approach*, Prentice Hall of India, 1999.
8. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
9. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org ; https://linear.axler.net; and

https://library.oapen.org/handle/20.500.12657/85067

REAL ANALYSIS-II

Objective: As a second course in real analysis, the objective is to learn on the concept of differentiation, Riemann Integration and their applications. The series of functions and the improper integrals have also been introduced.

Learning Outcomes: After completing the course the student will be able to
CO1: learn working out problems on derivatives of function and their applications.
CO2: learn about Riemann Integration and their properties including Improper Integrals.
CO3: learn on pointwise and uniform convergence of power series.
CO4: learn to calculate value of improper integrals.

UNIT-I

Differentiability of a function at a point and in an interval, Caratheodory's theorem, algebra of differentiable functions, relative extrema, interior extremum theorem. Rolle's theorem, Mean value theorems, Cauchy's mean value theorem, Lagrange mean value theorem, intermediate value property of derivatives, Darboux's theorem, applications of mean value theorem, Taylor's theorem and applications.

UNIT-II

Riemann integration: partitions, conditions of integrability, definition of Riemann integral properties of the Riemann integral, Riemann integral as limit of a sum, mean value theorem for integrals, integration by parts, Fundamental theorems of calculus, Taylor theorem with remainder.

UNIT-III

Pointwise and uniform convergence of sequence of functions, Cauchy criterion for uniform convergence and Weierstrass M-test, uniform convergence and continuity, term by term integration and differentiation of a series, power series, Abel's theorem, Weierstrass approximation theorem, Taylor series

Unit IV

Improper integrals, integration of unbounded functions with finite limits of integration, comparison tests of convergence, infinite range of integration, integrand as product of functions convergent at infinity, absolutely convergent integral,tests of convergence, convergence of Beta and Gamma functions, applications.

BOOKS RECOMMENDED:

1. R.G. Bartle D.R. Sherbert, *Introduction to Real Analysis,* John Wiley and Sons (Asia) Pvt. Ltd., Singapore
2. G. Das and S. Pattanayak, *Fundamentals of Mathematics Analysis*, TMH Publishing Co.
3. S. C. Mallik and S. Arora, *Mathematical Analysis*, New Age International Ltd., New Delhi.

BOOK FOR REFERENCE:

4. K. A. Ross, *Elementary Analysis: The theory of Calculus*, Undergraduate Texts in Mathematics, Springer (SIE), Indian reprint, 2004.
5. Charles G. Denlinger, *Elements of Real Analysis*, Jones and Bartlett (Student Edition), 2011.\
6. A. Kumar, S. Kumaresan, *A basic course in Real Analysis*, CRC Press, 2014
7. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org
8. Suggested digital platform: NPTEL/SWAYAM/MOOCs.

COMPLEX ANALYSIS-I

Objectives: The objective of the course is to introduce the theories for functions of a complex variable. The concepts of analyticity and complex integration and its applications, are discuss in detail. This course is prerequisite to many other advance analysis courses such as advanced complex analysis, geometric functions, theory, potential theory, theory of entire and meromorphic functions, etc.

Learning Outcomes: After completing the course the student will be able to

CO1: understand the geometric aspects of complex numbers system, convergence of series of complex numbers.
CO2: understand the significance of complex differentiability, analyticity and construction of analytic functions from

given harmonic functions.

CO3: relate the notion of line integral, Cauchy fundamental theorems on integrals and its applications.

CO4: classify the nature of singularities, properties of zeros and poles and be able to know the applications of residue theorem.

UNIT- I

Basic properties of complex number and, Stereographic projection, power series, absolute convergence, uniform convergence, Cauchy-Hadamard formula for the radius of convergence, circle of convergence, exponential, logarithmic, sine and cosine functions for complex numbers.

UNIT-II

Continuity and differentiability of a complex valued function, analytic function, necessary and sufficient conditions for analytic functions, Cauchy-Riemann equations (Cartesian and polar form), harmonic and conjugate harmonic functions, construction of analytic function (Milne-Thomson's method).

UNIT-III

Line integral, path independence, complex integration, Green's theorem, anti-derivative theorem, Cauchy-Goursat theorem, Cauchy integral formula, Cauchy's inequality, derivative of analytic function and its generalizations, Liouville's theorem, Morera's theorem, Taylor's and Laurent's theorem, expansion of analytical function in Taylor and Laurent series.

UNIT-IV

Zeroes of an analytic function, singularities of complex functions and its classifications, residues, Cauchy's residue theorem, residue at infinity, residues at poles and its examples, maximum modulus theorem.

BOOKS RECOMMENDED:

1. Elias M. Stein & Rami Shakarchi: Complex Analysis, Princeton University press, Princeton and Oxford, 2003.
2. Joseph Bak and Donald J. Newman: Complex analysis (3rd Edition), Undergraduate Texts in Mathematics, Springer-Verlag, NewYork, 1997.

BOOKS FOR REFERENCE:

3. S. Ponnusamy and Herb Silverman: Complex variables with Applications: Birkhauser, (2006) (Indian Edition 2012).
4. H. A. Priestly: Introduction to Complex Analysis, Oxford University Press, 2008.
5. Donald Sarason: Complex Function Theory: AMS, Second Edition, 2007.
6. James Ward Brown and Ruel V.Churchill: Complex Variables and Applications (Eighth Edition), McGraw-Hill International Edition, 2009.
7. Suggested digital platform: NPTEL/SWAYAM/MOOCs
8. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

ALGEBRA-II

Objectives: To present a systematic study on finite abelian groups, Sylow's theorems and Modules.

Learning Outcomes: After completing the course the student will be able to

CO1: know on finite abelian groups, the class equation and Sylow's theorems.

CO2: know on applications of Sylow's theorems and test the simplicity of groups.

CO3: learn on group action, composition series, nilpotent groups and solvable groups.

CO4: solve problems in modules and related results.

UNIT -I

Fundamental theorem of finite abelian groups, isomorphism classes of abelian groups, proof of the fundamental theorem, Sylow's theorems, conjugacy classes, the class equation, Sylow's first theorem, Cauchy theorem, Sylow's second and third theorems.

UNIT-II

Application of Sylow's theorem, finite simple groups, non-simplicity tests, the simplicity of alternating group A_5, free groups,

classification of groups of order up to 15, characterization of dihedral groups.

UNIT-III

Group actions and permutation representations, composition series and holder programs, nilpotent groups, solvable groups.

UNIT-IV

Introduction to modules, definition and examples, direct sum, free modules, quotient modules, homomorphisms, simple modules, modules over PIDs.

BOOKS RECOMMENDED:

1. Joseph A. Gallian, Contemporary Abstract Algebra (4th Edition), Narosa Publishing House, New Delhi, 1999.(IX Edition 2010).
2. D. S. Dummit, R. M. Foote, Abstract Algebra, Wiley-India edition, 2013.
3. C. Musili, Introduction to Rings and Modules, Narosa Publishing House.

BOOKS FOR REFERENCE:

4. John B. Fraleigh, A First Course in Abstract Algebra, 7th Ed., Pearson, 2002.
5. I. N. Herstein, Topics in Algebra, Wiley Eastern Limited, India, 1975.
6. M. Artin, Abstract Algebra, 2nd Ed., Pearson, 2011.
7. S. Nanda, Topics in Algebra, Allied Publishers, New Delhi.
8. Suggested digital platform: NPTEL/SWAYAM/MOOCs
9. e-Learning Source http://ndl.iitkgp.ac.in; http://ocw.mit.edu; http://mathforum.org

REAL ANALYSIS-III

Objective: After a first course in real analysis in undergraduate program, the ideas of uniform continuity, uniform convergence and approximation by polynomials are crucial in analysis. In addition to the functions of bounded variation and their integrators, the student has to learn differentiating functions from R^n to R^m. The techniques of integration of a function with respect to another function and the basic ideas of finding a Fourier series are also included.

Learning Outcomes: After completing the course the student will be able to

CO1: find the Fourier series of a function.
CO2: calculate Riemann Stieltjes integrals and know whether a function is of bounded variation or not.
CO3: learn how to define derivatives on R^n including the existence of partial derivatives, inverse function theorem and implicit function theorem.
CO4: learn about metric spaces and their topological properties.

UNIT-I

Basic concepts of Fourier series, Fourier series of even and odd functions, half range series, Fourier series on other intervals, orthogonal systems of functions, theorem on best approximation, properties of Fourier coefficients, Riesz-Fisher theorem, Riemann-Lebesgue lemma, Dirichlet integral, Integral representation for the partial sum of a Fourier series**,** convergence of Fourier series.

UNIT-II

Function of bounded variation, examples, total variation, function of bounded variation expressed as difference of increasing functions, rectifiable paths, Riemann-Stieltjes integrals, properties and techniques, necessary and sufficient condition for existence of the integral, mean value theorem for Riemann-Stieltjes integrals, reduction to Riemann integrals.

UNIT-III

Differentiation in R^n, partial derivatives, directional derivatives, sufficient condition for differentiability, chain rule, , mean value theorem, Jacobians, contraction mapping principle, inverse function theorem, implicit function theorem, rank theorem, differentiation of integrals, Taylor theorem in many variables.

UNIT-IV

Metric spaces, definitions and examples, open and closed sets, interior and exterior points, convergence and completeness, continuity and uniform continuity, compactness, connectedness.

BOOKS RECOMMENDED:

1. W. Rudin, Principles of Mathematical Analysis, McGraw Hill, 3rd edition.
2. T. Apostol, Mathematical Analysis, Pearson, 2nd edition.
3. S C Malik and Savita Arora, Mathematical Analysis- New Age International, 5th edition

BOOKS FOR REFERENCE:

4. Terrence Tao, *Analysis-I*, Hindustan book agency.
5. Terrence Tao, *Analysis-II*, Hindustan book agency
6. K. A. Ross, *Elementary Analysis: The theory of Calculus*, Undergraduate Texts in Mathematics, Springer (SIE), Indian reprint, 2004.
7. Charles G. Denlinger, *Elements of Real Analysis*, Jones and Bartlett, Student Edition, 2011.
8. Suggested digital platform: NPTEL/SWAYAM/MOOCs
9. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

DIFFERENTIAL EQUATIONS-II

Objective: The objective of this course is to understand basic methods for solving nonlinear first order ordinary differential equations and existence of solutions along with some special type of second order ordinary differential equations of mathematical physics. Also, students will be exposed to second order partial differential equations arising in thermal physics and thermodynamics.

Learning Outcomes: After completing the course the student will be able to

CO1: understand first order nonlinear ordinary differential equations and existence of solutions
CO2: learn the methods to find solutions of second order linear ordinary differential equations with constant coefficients and variable coefficients.
CO3: the different methods for solving first and second order partial differential equations and can take more courses on wave equation, heat equation, diffusion equation, gas dynamics, nonlinear evolution equations etc. All these courses are important in engineering and industrial applications for solving boundary value problems.
CO4: get idea to solve various mathematical models of ODE and PDE which may be helpful for simulation process.

UNIT-I

Existence and Uniqueness of Solutions: Lipschitz condition, Gronwall type inequality, successive approximations, Picard's theorem, non-uniqueness of solutions, continuation and dependence on initial conditions, existence of solutions in the large.

UNIT-II

Solution of second order ODE with constant coefficients, power series solutions of ordinary and singular points, and special functions of Legendre's differential equations, Bessel's differential equations and their properties.

UNIT-III

Charpit's method, special types of first order PDE, Jacobi's method, Linear second order PDE, canonical forms of second order PDE and characteristics curves, one dimensional wave equation, its origin and elementary solutions, vibration of an infinite string, vibration of a semi finite string, vibration of a string of finite length, existence of unique solution.

UNIT-IV (PRACTICAL)

Laboratory work for the following problems using *MATLAB* / *Mathematica* / *Maple* etc.

1) Plot the Fourier series of the following functions:
   i. $f(x) = x^2, x \in [-1, 1]$
   ii. $f(x) = \{1, \ \ 0 < x < \pi \ -1, -\pi < x < 0$
   iii. $f(x) = sin\ sin\ x, \ \ 0 < x < \frac{\pi}{2}$
2) Solution of wave equation $\frac{\partial^2 u}{\partial t^2} - c^2 \frac{\partial^2 u}{\partial x^2} = 0$ for the following associated conditions:
   (i) $u(x,0) = \varphi(x), u_t(x,0) = \sigma(x), x \in R, t > 0$
   (ii) $u(x,0) = \varphi(x), u_t(x,0) = \sigma(x), u(0,t) = 0\ x \in (0,\infty), t > 0$
   (iii) $u(x,0) = \varphi(x), u_t(x,0) = \sigma(x), u_x(0,t) = 0\ x \in (0,\infty), t > 0$
   (iv) $u(x,0) = \varphi(x), u_t(x,0) = \sigma(x), u(0,t) = 0, \ u(l,t) = 0, \ 0 < x < l, t > 0$
3) Solution of one dimensional heat equation $\frac{\partial u}{\partial t} - k \frac{\partial^2 u}{\partial x^2} = 0$ for the following conditions
   (i) $u(x,0) = \varphi(x), u(0,t) = a, u(l,t) = b, 0 < x < l, t > 0$

(ii) $u(x,0) = \varphi(x), x \in R, 0 < t < T$

(iii) $u(x,0) = \varphi(x), u(0,t) = a, x \in (0,\infty), t \geq 0.$

BOOKS RECOMMENDED:

1) Deo and Raghavendra, *Text Book of Ordinary Differential Equations*, Tata McGraw-Hill Pub. Company Ltd, New Delhi,2017.
2) Simmons G F, *Differential equation*, Tata McGrawHill,1991.(Ch-5. 28-30, Ch-8. 44-47, Ch-6, 33-36)
3) I. Sneddon, *Elements of Partial Differential Equations*,McGraw-Hill, International Students Edition.(Ch-2. 10,11,13; Ch-3. 4-7; Ch-5. 1,2), 2006.
4) Tyn Myint-U and Lokenath Debnath, *Linear Partial Differential Equations for Scientists and Engineers,* 4th edition, Birkhauser, Indian reprint,2014.

BOOKS FOR REFERENCE:

5) J. N. Sharma and Kehar Singh, *PDE for Engineers and Scientists*, Narosa, New Delhi,2009.
6) T Amarnath, *An Elementary Course in Partial Differential Equations*, Narosa Publications, 2003.
7) Martin Braun, *Differential Equations and their Applications*, Springer International Student Ed. 1978.
8) S. L. Ross, *Differential Equations*, 3rd Edition, John Wiley and Sons, India, 2014.
9) C.Y. Lin, *Theory and Examples of Ordinary Differential Equations*, World Scientific, 2011.
10) e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org
11) Suggested digital platform: NPTEL/SWAYAM/MOOCs

NUMERICAL ANALYSIS & SCIENTIFIC COMPUTING

Objectives: The objective of this course is to acquaint the students with a wide range of numerical methods to solve algebraic and transcendental equations, linear system of equations, interpolation and curve fitting problems, numerical integration, initial and boundary value problems, etc. Develop adequate skills to apply those methods in real world problems.

Learning Outcomes: After completing the course the student will be able to

CO1: understand the errors in computation, find the roots of algebraic and transcendental equations, familiarize with convergence, advantages and limitations of those numerical techniques, learn to apply Gauss−Jacobi, Gauss−Seidel methods to solve system of linear equations.
CO2: get aware of using interpolation techniques to solve polynomials.
CO3: learn numerical differentiation and integrations by using different techniques.
CO4: understand the techniques to find approximate solutions of ODE and PDE.

UNIT-I

Errors in approximation, absolute, relative and percentage errors, round-off error, solution of algebraic and transcendental equations: bisection method, Regula-Falsi method, secant method, method of iteration, Newton Raphson method, order of convergence, systems of simultaneous equations: Gauss elimination method, Gauss Jordon method, LU decomposition method, Iterative methods: Jacobi method and Gauss-Seidel method.

UNIT-II

Finite differences, interpolation techniques for equal intervals-Newton forward and backward, Gauss forward, Gauss backward, interpolation, interpolation with unequal intervals-Newton's divided difference method, Lagrange method, Hermite interpolation,

Numerical differentiation using Newton forward and backward formulae, numerical integration using Newton-Cotes formulas, trapezoidal rule, Simpson rules, Gauss-Legendre, Gauss-Chebyshev formulas.

UNIT-III

Solution of ordinary differential equations: Taylor series method, Picard's method, Euler method, Euler modified method, Runge–Kutta methods.

UNIT-IV (PRACTICAL)

Practical / Lab work to be perform in Computer Lab:

Use of computer algebra system (CAS) software: Python/ Sage Math / Mathematica/ MATLAB/ Maple/ Maxima/ Scilab/ R or any other (open source) software etc., for developing at least the following numerical programs:

1. Bisection method, Newton-Raphson method and Secant method.
2. LU decomposition method.
3. Gauss−Jacobi method and Gauss−Seidel method.

4. Lagrange interpolation and Newton interpolation.
5. Trapezoidal rule and Simpson's rules.
6. Taylor series method, Picard's method, Euler method, Euler modified method and Runge−Kutta Methods.

Note: **Non-programmable scientific calculator is allowed in the examination.**

BOOKS RECOMMENDED:

1. M. K. Jain, S. R. K. Iyengar & R. K. Jain: Numerical Methods for Scientific and Engineering Computation, New Age International Publisher, India, 2016.
2. R. K. Gupta: Numerical Methods: Fundamentals and Applications, Cambridge University Press, 2019.

BOOKS FOR REFERENCE:

1. Brian Bradie: A Friendly Introduction to Numerical Analysis. Pearson Education India. Dorling Kindersley (India) Pvt. Ltd. Third impression, 2011.
2. Curtis F. Gerald & Patrick O. Wheatley: Applied Numerical Analysis, Pearson Education. India, 2007.
3. S. D. Conte & S. de Boor: Elementary Numerical Analysis: An Algorithmic Approach, 1980.
4. Suggested digital platform: NPTEL/SWAYAM/MOOCs
5. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

MULTIVARIABLE CALCULUS

Objectives: The primary objective of this course is to introduce students, the extension of the studies of single variable differential and integral calculus to functions of two or more independent variables with the geometry and visualization of curves and surfaces. To aware the students about the techniques multiple integrations and higher order derivatives.

Learning Outcomes: After completing the course the student will be able to

CO1: learn the concept of limit, continuity and differentiations of functions of more than one.
CO2: understand the maximization and minimization of multivariable functions with the given constraints on variables.
CO3: learn about inter-relationship amongst the line integral, double, and triple integral formulations.
CO4: familiarize with the Green's, Stokes' and Gauss divergence theorems and their applications.

UNIT-I

Functions of several variables, limit and continuity of functions of two variables: partial differentiation, total differentiability, sufficient condition for differentiability, chain rule for one and two independent parameters, directional derivatives, the gradient, maximal and normal property of the gradient, tangent planes.

UNIT-II

Extrema of functions of two variables, method of Lagrange multipliers, constrained optimization problems, double integration over rectangular region, double integration over non rectangular region, double integrals in polar co-ordinates.

UNIT-III

Triple integrals, triple integral over a parallelepiped and solid regions, volume by triple integrals, cylindrical and spherical co-ordinates, change of variables in double integrals and triple integrals.

UNIT-IV

Definition of vector field, divergence and curl, line integrals, applications of line integrals: mass and work, fundamental theorem for line integrals, conservative vector fields, independence of path, Green's theorem, surface integrals, integrals over parametrically defined surfaces. Stokes' theorem, the divergence theorem.

BOOKS RECOMMENDED:

1. M. J. Strauss, G. L. Bradley and K. J. Smith: Calculus, 3rd Edition, Dorling Kindersley (India) Pvt. Ltd. Pearson Education, Delhi, 2007.
2. E. Marsden, A. J. Tromba and A. Weinstein: Basic Multivariable Calculus, Springer Student International Edition, Indian reprint, 2005.

BOOK FOR REFERENCES:

1. S. C. Mallik and S. Arora: Mathematical Analysis, New Age International Publications, New Delhi, 2005.
2. Tom Apostol: Mathematical Analysis, Narosa Publishing House, 2002.
3. G. B. Thomas and R. L. Finney: Calculus, 9th Ed., Pearson Education, Delhi, 2005.
4. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
5. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

DIFFERENTIAL GEOMETRY

Objective: The objective of this course is to explore geometry of curves and surfaces in R^2 and R^3 with their intrinsic properties and curvatures.

Learning Outcomes: After completing the course the student will be able to

CO1: understand the notion of plane curves, space curves, curvature, torsion and the existence of space curves.
CO2: learn the theory of sur faces and learn to calculate first fundamental forms.
CO3: learns on geodesics on a surface and learns to calculate curvatures.
CO4: Learns calculating second fundamental forms, curvatures and discovers minimal surfaces.

UNIT-I

Theory of Space Curves: space curves, arc length, tangent, normal and binormal, osculating plane, curvature, torsion, Serret-Frenet formulae, contact between curves and surfaces, osculating circles and spheres, involute and evolutes, existence of space curves, Helices.

UNIT-II

Theory of surfaces: parametric curves on surfaces, surfaces of revolution, helicoids, metric, direction coefficients. First Fundamental forms.

UNIT-III

Geodesics, canonical geodesic equations, nature of geodesics on a surface of revolution, normal property of geodesics, Torsion of a geodesic: geodesic curvature, Gauss-Bonnet theorem, Gaussian curvature, surfaces of constant curvature.

UNIT-IV

Second Fundamental forms, principal curvatures, lines of curvature, Rodrigue's formula, conjugate and asymptotic lines. Developables, developable associated with space curves and curves on surfaces, minimal surfaces. Fundamental Theory of surfaces.

BOOKS RECOMMENDED:

1. T.J. Willmore, *An Introduction to Differential Geometry,* Dover Publications, 2012.
2. Pressley, Elementary Differential Geometry, Springer International Edition, 2014

BOOKS FOR REFERENCES:

3. O'Neill, *Elementary Differential Geometry,* 2nd Ed., Academic Press, 2006.
4. C.E. Weatherburn, *Differential Geometry of Three Dimensions,* Cambridge University Press 2003.
5. D.J. Struik, *Lectureson Classical Differential Geometry,* Dover Publications, 1988.
6. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
7. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

MEASURE THEORY & INTEGRATION

Objectives: The aim of this course is to provide a foundation for student to many branches of mathematics such as functional analysis, harmonic analysis, ergodic theory, and probability theory, etc.. In this course, the students will be introduced to, Lebesgue measure and integration, signed measures, Hahn-Jordan decomposition, Radon-Nikodym derivative and product measures.

Learning Outcomes: After completing the course the student will be able to

CO1: calculate Riemann-Stieltjes integrals and Lebesgue integrals of simple measurable functions..

CO2: know how to calculate Lebesgue Integral of any measurable functions and learn how to apply monotone and dominated convergence theorems .
CO3: learn the concept of measure on abstract spaces and work on various modes of convergence of a sequence of measurable functions.
CO4: learn on complex measures, Radon Nikodym derivatives and related results.

Unit-I

Lebesgue outer measure, measurable sets, Borel sets, regularity, measurable functions, Borel and Lebesgue measurability, non-measurable sets, integration of nonnegative functions, simple functions, Lebesgue integration of simple function.

Unit-II

Approximation of measurable functions by simple functions, Lebesgue integral of measurable functions and properties, Fatou's lemma, monotone convergence theorem, Lebesgue dominated convergence theorem, integration of series, Riemann and Lebesgue integrals, differentiation, Dini derivatives, Lebesgue differentiation theorem.

Unit-III

Abstract measure spaces, measure and outer measure, extension of a measure, uniqueness of the extension, completion of a measure, integration with respect to a measure, Modes of convergence, convergence in measure, almost uniform convergence, fundamental in measure convergence, Egorov's theorem.

Unit-IV

Signed measure, absolute continuity, Hahn decompositions, Jordan decomposition, Lebesgue decomposition, Radon-Nikodym theorem, applications of Radon Nikodym Theorem, product measure, Fubini theorem.

BOOKS RECOMMENDED:

1. G. De Barra: Measure Theory and Integration, New age International, 1981.
2. H. L. Royden: Real Analysis, Pearson, Fourth Edition, 2010.

BOOKS FOR REFERENCE:

3. H. L. Royden and P. M. Fitzpatrick: Real Analysis, Fourth Edition, Pearson Asia Education Ltd and China Machine Press, 2010.
4. C. D. Aliprantis, O. Burkinshaw: Principles of Real Analysis, Elsevier, 2011.
5. J . Yeh: Real Analysis (Theory of Measure and Integration), 3rd Edition, World Scientific Publication, 2024.
6. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
7. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

ALGEBRA-III

Objectives: To present a systematic study of field theory and Galois theory.

Learning Outcomes: After completing the course the student will be able to

CO1: understand the basic concept of field extension, and splitting fields.
CO2: understand the significance of separable extension, cyclotomic polynomials, Galois group.
CO3: understand the structures and properties of finite fields, composite extensions, simple extensions.
CO4: determine the Galois group of a polynomial and understand the conditions under which polynomial equations can be solved using radicals.

UNIT -I

Basic theory of field extension, algebraic extension, classical straightedge and compass construction, splitting fields and algebraic closures.

UNIT-II

Separable and inseparable extension, Cyclotomic polynomials and extensions, Galois theory, basic definitions, The fundamental theorem of Galois theory.

UNIT-III

Finite fields, Composite extensions and simple extensions, cyclotomic extensions and abelian extensions over Q, Galois groups of polynomials over Q.

UNIT-IV

Solvability and radical extension, Insolvability of quintic, computations of Galois group over Q.

BOOKS RECOMMENDED:

1. D. S. Dummit, R. M. Foote, Abstract Algebra, Wiley-India edition, 2013.
2. Joseph A. Gallian, Contemporary Abstract Algebra (4th Edition), Narosa Publishing House, New Delhi, 1999.(IX Edition 2010).

BOOKS FOR REFERENCE:

3. John B. Fraleigh, A First Course in Abstract Algebra, 7th Ed., Pearson, 2002.
4. I.N. Herstein, Topics in Algebra, Wiley Eastern Limited, India, 1975.
5. e-Learning Source http://ndl.iitkgp.ac.in; http://ocw.mit.edu; http://mathforum.org
6. Suggested digital platform: NPTEL/SWAYAM/MOOCs.

TOPOLOGY

Objective: This is an introductory course in Topology. The objective of this course is to have knowledge on topological spaces, continuity, connectedness, compactness and separation axioms. Topology on quotient spaces, product spaces and metric spaces are also discussed. The student will also learn on basic ideas of algebraic topology such as homotopy, fundamental groups and covering spaces.

Learning Outcomes: After taking the course the student will be able to

CO1: Know on basics of topological spaces with examples and is able to construct new topologies using idea of product topology, quotient topology, etc .
CO2: solve problems involving continuous maps , homeomorphisms between two spaces , connectedness and compactness.
CO3: learn examples and properties of Hausdorff, regular, normal, separable, first and second countable spaces.
CO4: understand more results in separation axioms and learn on basic concepts of algebraic topology like homotopy, fundamental groups, and covering spaces.

UNIT-I

Cartesian product of a family of sets, Axiom of choice and its equivalents(without proof),Topological spaces, examples, open sets, closed sets, basis and subbasis for a topology, closure and interior of sets, subspace topology, order topology, continuous functions, homeomorphisms, product topology, quotient topology.

UNIT-II

Metric topology, standard topology, uniform topology, lower limit topology, connectedness, examples, local connectedness, Path-connectedness, connected subsets of real line, compact spaces, examples, locally compacts spaces, sequential compactness, limit point compactness, compact subsets of real line.

UNIT-III

Countability axioms, first and second countable spaces, separable and Lindolf spaces, separation axioms, regular & completely regular space, normal spaces, Urysohn Lemma.

UNIT-IV

Urysohn metrization theorem, Tychonoff theorem, compactness in metric spaces, compact open topology homotopy of paths, fundamental group, covering space.

BOOKS RECOMMENDED:

1. J R Munkres, *Topology: A First Course*, Pearson, 2nd edition, 2000.
2. M A Armstrong, *Basic Topology*. Springer, 1983.

BOOKS FOR REFERENCE:

3. K. D. Joshi, *Introduction to General Topology,* Wiley Eastern Limited.
4. T. S. Singh, *Elements of Topology*, CRC press (special Indian Edition) 2015.
5. O. Viro, O Ivanov, V Kharlamov and N Netsvetaev, *Elementary Topology, problem Text book*, American Mathematical society, 2008.
6. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
7. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

MATHEMATICAL METHODS

Objective: The objective of this course is to prepare a student in basics of Integral transforms, Integral equations and calculus of variations. These tools have applications in other science and engineering fields and are necessary to understand.

Learning Outcomes: After completing the course the student will be able to

CO1: Calculate Laplace transform, Fourier transform and apply them in areas of differential equations immediately.
CO2: find solutions of Volterra integral equations.
CO3: find solutions of Fredholm integral equations.
CO4: use methods in calculus of variations to solve extremal problems in Differential equations and physics.

Unit-I

Laplace transforms: definitions, properties, Laplace transforms of some elementary functions, convolution theorem, inverse Laplace transformation and applications. Fourier transforms: definitions, properties, Fourier transforms of some elementary functions, convolution, Fourier transform of derivatives, Fourier transforms as a limit of Fourier series.

Unit-II

Volterra Integral Equations: Basic concepts, relationship between linear differential equations and Volterra integral equations, resolvent kernel of Volterra integral equations, solution of integral equations by resolvent kernel, The method of successive approximations, convolution type equations, solutions of integral differential equations with the aid of Laplace transforms.

Unit-III

Fredholm integral equations: Fredholm equations of the second kind, fundamentals, iterated kernel, constructing the resolvent kernel with the aid of iterated kernels, integral equations with degenerate kernels, characteristic numbers and eigen functions, solution of homogeneous integral equations with degenerate kernel, non homogeneous symmetric equations, Fredholm alternatives.

Unit-IV

Calculus of variations: extremal of functional, The variation of a functional and its properties, Euler's equations, field of extremals, sufficient conditions for the extremum of a functional, conditional extremum moving boundary problem, discontinuous problems, one sided variations, Ritz method.

BOOKS RECOMMENDED:

1. A. J. Jerri; *Introduction to Integral Equations with Applications*, John-Wiley & SONS, INC., 1999.
2. Lokenath Debnath; *Integral Transforms and Their Applications*, CRC Press, New York.
3. A. S. Gupta; *Calculus of Variations with Applications*, PHI, Pvt. Ltd., New Delhi.

BOOKS FOR REFERENCE:

4. I. Sneddon, *The use of Integral Transformations* (Tata McGraw Hill), 1972.
5. Murray R Spiegel*, Laplace Transforms,* Schaum's Series, 1965.
6. Gelfand and Fomin, *Calculus of Variations*, Dover Pub, 2003.
7. Krasnov, *Problems and Exercises in Calculus of Variations,* Mir Publ., 1970.
8. Ram P Kanwa, *Linear Integral Equations* (Academic Press), 2013.
9. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
10. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

FUNCTIONAL ANALYSIS

Objective: The objective of this course is to introduce students to L^p spaces, Banach Spaces, Hilbert Spaces etc. Students will also be exposed to bounded linear operators on Hilbert spaces which is required to study quantum mechanics, scattering theory and spectral theory, etc. Knowledge of real Analysis, measure theory and linear algebra is pre requisite for this course

Learning Outcomes: After completing the course the student will be able to

CO1: handle inequalities in L^p spaces, and normed linear spaces.
CO2: learn all basic results on Hilbert spaces for further application.
CO3: know on Fourier series with respect to an orthonormal basis and related results and basic results of Banach space
CO4: Know on more results on Banach spaces and bounded linear operators with spectrum on Banach spaces.

Unit - I

Review of Metric spaces (not a part of examination), L^p and l^p spaces, inequalities (Holder, Minkowski, Jensen), completeness of *Lp*, denseness and separability, normed linear spaces, properties of normed linear spaces, continuity of linear maps.

Unit -II

Inner product spaces, examples, Hilbert spaces, examples, closed subspaces, existence of a unique element of smallest norm, orthogonal complements and properties, projection theorem, Riesz representation theorem, orthonormal sets, Gram-Schimdt orthonormalization.

Unit - III

Orthonormal basis, Fourier expansion, Bessel's inequality, Riesz-Fischer theorem, Parseval's formula, Banach spaces, examples, Hahn Banach theorem, Baire's category theorem.

Unit - IV

Open mapping theorem, closed graph theorem, uniform boundedness principle, duals of $L^p[a, b]$, bounded linear operators on Banach spaces, spectrum of a bounded operators and properties, resolvent set and examples.

BOOKS RECOMMENDED:

1. B. V. Limaye -Functional Analysis, 3rd Ed, 2014.
2. E. Kreyszig-Functional Analysis –Wiley-India, 2007.

BOOKS FOR REFERENCE

3. Goffman and Pedrick A first Course in Functional Analysis, AMS, 2017.
4. J. B. Conway, A course in Functional Analysis, 2nd Ed., Springer, 2006
5. P. K. Jain and O. P. Ahuja, Functional Analysis, 2nd Ed., New Age International Publication, New Delhi, 2004
6. Markus Haase, Functional Analysis: An Elementary Introduction, American Mathematical Society, 2014.
7. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
8. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

ANALYTIC NUMBER THEORY

Objectives: The aim of this course is to study number theory by using analytic tools such as inequalities, limits, calculus, etc.

Learning Outcomes: After completing the course the student will be able to

CO1: understand the arithmetical functions and their relations.
CO2: find the average order of multiplicative functions and know the distribution of prime numbers.
CO3: know the prime number theorem and Ramanujan's sum
CO4: know the basic theory of Riemann zeta function and related L-function.

UNIT –I

The arithmetical functions and their relations, Mobius function, Euler totient function, Mangolt function, Liouville's function, The, divisor function, The Dirichlet product of arithmetical functions, Dirichlet inverses and Mobius inversion formula, multiplicative functions. The Bell series of an arithmetical function and Dirichlet multiplications, Derivatives of arithmetical functions, The Selberg identity.

UNIT-II

The big oh notation, Euler's summation formula, some elementary asymptotic formulas, averages of arithmetical functions, The average order of divisor functions, The average order of Euler totient function, The average order of Mobious and Mangoldt functions, The partial sums of a Dirichlet product, applications to the Mobius and Mangoldt functions, some elementary theorems on distribution of prime numbers, Chebyshev's functions and their relations with $\pi(x)$.

UNIT-III

Some equivalent forms of the prime number theorem, Shapiro Tauberian theorem, The partial sums of the Mobius function, brief sketch of an elementary proof of the prime number theorem, Ramanujan's sum and generalizations, quadratic residues, Legendre's symbol and its properties, Gauss's lemma, The quadratic reciprocity law, The Jacobi symbol.

UNIT-IV

The half-plane of absolute convergence of a Dirichlet series, Euler products, analytic properties of Dirichlet series, mean value formulas for Dirichlet series, an integral formulas for the coefficients and the partial sums of a Dirichlet series, The Riemann zeta function and the L-function, properties of the gamma function, integral representation for the Hurwitz zeta function, analytic continuation of the Hurwitz zeta function, analytic continuation of the Riemann zeta function and the L-function.

BOOKS RECOMMENDED:

1. T. M. Apostol, Introduction to Analytic Number Theory, Springer International Edition, 2010.
2. Analytic Number Theory: Exploring the Anatomy of Integers, Jean-Marie De Koninck, Florian Luca, American Mathematical Society, 2012.

BOOKS FOR REFERENCE:

3. A Primer of Analytic Number Theory: From Pythagoras to Riemann, Jeffrey Stopple, Cambridge University Press, 2003.
4. Suggested digital platform: NPTEL/SWAYAM/MOOCs.
5. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

COMPLEX ANALYSIS-II

Objectives: This course introduces the basic concepts of conformal mappings, entire functions, Weierstrass infinite products, Hadamard's factorization theorem, Gamma function, Zeta function and normal family.

Learning Outcomes: On the completion of this course, students will be able to

CO1: solve problems involving conformal mappings.
CO2: understand the applications of Cauchy integrals and properties of harmonic functions.
CO3: handle Gamma function, Riemann zeta function and familiarize with analytic continuations.
CO4: solve problems involving infinite products, equicontinuity and normal family.

UNIT-I

Mappings of elementary functions and cross ratio, bilinear transformations and its properties, mapping of some elementary functions, mappings of z^2, e^z, z, $log\ log\ z$, z+1/z, etc., conformal mappings.

UNIT-II

Maximum modulus theorems, Schwartz lemma, Argument principle, Rouche's theorem, applications to fundamental theorem of calculus, uniqueness and identity theorems, Hurwitz's theorem, Harmonic functions, mean value theorem, Poisson integral formula, Harnack's inequality and theorem, Hadamard three circle theorem.

UNIT-III

Weierstrass' factorization theorem, Gamma function and its properties, Riemann zeta function, Riemann's functional equation, Mittag-Leffler's expansion theorem and its applications, analytic continuation, uniqueness of direct analytic continuation, uniqueness of analytic continuation.

UNIT-IV

Canonical products, Jensen's formula, Poisson-Jensen formula, Hadamard's three circles theorem, order of an entire function, exponent of convergence, Borel's theorem, Hadamard's factorization theorem. equicontinuity, normal family, families of analytic functions.

BOOKS RECOMMENDED:

1. L. V. Ahlfors: Complex Analysis: McGraw Hill, 3rd Edition (2017).
2. S. Ponnusamy and Herb Silverman: Complex variables with Applications: Birkhauser, (2006) (Indian Edition 2012).

BOOKS FOR REFERENCES:

3. J. Bak and D. J. Newman: Complex analysis (3rd Edition), Undergraduate Texts in Mathematics, Springer-Verlag, NewYork, 1997.
4. H. A. Priestly: Introduction to complex analysis, Oxford University Press, 2008.

5. D. Sarason: Complex Function Theory: AMS, Second Edition, 2007.
6. E. M. Stein and R. Shakarchi: Complex analysis: Princeton University Press, 41 William Street, Princeton, New Jersey, 2003.
7. John B. Conway: Function of one complex variable: Springer International Student Edition, Narosa Publishing House, Second Edition, 2002.
8. R. V. Churchill, J. W. Brown and R. F. Verhey: Complex variables and applications, McGraw Hill, 9th Edition, 2013.
9. Suggested digital platform: NPTEL/SWAYAM/MOOCs
10. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

DIFFERENTIAL EQUATIONS-III

Objective: The objective of this course is to

i) understand the basic methods for qualitative behavior of solutions of ordinary differential equations and boundary value problems,

ii) understand the basic methods to solve system of differential equations,

iii) expose students about some of the real life problems using the system of differential equations,

iv) expose the students to canonical forms of hyperbolic, elliptic and parabolic PDEs.

Learning Outcomes: On the completion of this course, students will be able to

CO1: handle oscillation properties of ordinary differential equations and sturm Liouville differential equations
CO2: know existence and uniqueness theorems and application to mathematical modelling.
CO3: learn solutions of heat equation and various boundary value problems for Laplace equation
CO4: solve various PDEs using Green's function

UNIT-I

Oscillation of Second Order Linear Differential Equations: Fundamental results, Sturm's Comparison Theorem and Hille-Wintner type oscillation.
Second Order Boundary Value Problem: Sturm-Liouville differential equation, eigen value problems, Green's function and Picard's Theorem.

UNIT-II

System of first order equations, existence and uniqueness theorems, fundamental matrix, homogeneous and nonhomogeneous linear systems with constant coefficient, mathematical formulation of Predatory-pray model, epidemic model of influenza, battle model and their solutions.

UNIT-III

One dimensional heat equation and its origin, Heat conduction problem for an infinite rod and finite rod, existence and uniqueness of solution, two dimensional heat equation and Laplace equation, boundary value problems, maximum and minimum principles, uniqueness and continuity theorems, Dirichlet problem for a circle, Dirichlet problem for annulus, Neumann problem for a circle.

UNIT-IV

Solution of heat equation, wave equation, Laplace equation and Helmholz equation by Green's function method and examples.

BOOKS RECOMMENDED:

1) Deo and Raghavendra; *Text Book of Ordinary Differential Equations*, Tata McGraw-Hill Pub. Company Ltd, New Delhi, 2017.
2) Belinda Barnes and Glenn R. Fulford; *Mathematical Modeling with Case Studies, A Differential Equation Approaching Maple and Matlab,* 2nd Ed., Taylor and Francis group, London and NewYork,2009.
3) Tyn Myint-U and Lokenath Debnath; *Linear Partial Differential Equations for Scientists and Engineers,* 4th edition, Birkhauser, Indian reprint,2014.

BOOKS FOR REFERENCES:

4) K. Shankar Rao, Introduction to partial differential equations, PHI learning private Ltd., 2011.
5) J. N. Sharma, K. Singh, Partial Differential Equations for Engineers and Scienists, Narosa, 2nd Edition, 2009.
6) Robert C.McOwen: Partial Differential Equations, Pearson Education Inc., 2002.
7) Martin Braun, Differential Equations and their Applications, Springer International Student Ed., 1978.
8) S.L. Ross, *Differential equations,*3rd Ed., John Wiley and Sons, India, 2014.
9) Suggested digital platform: NPTEL/SWAYAM/MOOCs
10) e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

MULTI-DISCIPLINARY COURSE
DISCRETE MATHEMATICS

Objectives: The main objectives of this course are to introduce topics and techniques of counting principles, combinatorics, and graph theory to understand problems in almost all areas of knowledge.

Learning Outcomes: On the completion of this course, students will be able to

CO1: learn core ideas in logic and relations.
CO2: know the concept of the Pigeon-hole principle and solve recurrence relations.
CO3: learn lattices and Boolean algebra.
CO4: get a good knowledge of the basics of Graph theory.

UNIT-I

Propositional logic, proportional equivalences, predicates and quantifiers, nested quantifiers, rules of inference, methods of proof, relations and their properties, n- ary relations and their applications.

UNIT-II

The basic counting principle, The Pigeon-hole principle, generalized permutations and combinations, recurrence relations, counting using recurrence relations, solving linear homogeneous recurrence relations with constant coefficients, generating functions, solving recurrence relations using generating functions.

UNIT-III

Partially ordered sets, Hasse diagram of partially ordered sets, maps between ordered sets, duality principle, lattices, Boolean algebra .

UNIT-IV

Graphs, basic concepts and graph terminology, representing graphs and graph isomorphism, distance in a graph, cut vertices and cut edges, connectivity, Euler and Hamiltonian path, shortest-path problems, planar graphs and graph coloring.

BOOKS RECOMMENDED:

1) Kenneth H. Rosen, Discrete Mathematics and Applications (Sixth Edition), Tata McGraw Hill Publications, 2007.
2) Edgar G. Goodaire and Michael M. Parmenter, Discrete Mathematics with Graph Theory (2nd Edition), Pearson Education (Singapore) Pte. Ltd., Indian Reprint 2003.

BOOKS FOR REFERENCE:

3) 1. B A. Davey and H. A. Priestley, Introduction to Lattices and Order, Cambridge University Press, Cambridge, 1990.
4) 2. Rudolf Lidl and Gnter Pilz, Applied Abstract Algebra (2nd Edition), Undergraduate Texts in Mathematics, Springer (SIE), Indian reprint, 2004.
5) 3. Kevin Ferland-Discrete Mathematical Structures, Cengage Learning India Pvt. Ltd.,2009.
6) Suggested digital platform: NPTEL/SWAYAM/MOOCs
7) e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

MULTI-DISCIPLINARY COURSE
LINEAR PROGRAMING

Objective: The objective of this course is to familiarize industrial problems to students with various methods of solving linear programming problems, transportation problems, assignment problems and their applications. Also, students will know the application of linear programming method in Game theory.

Learning Outcomes: On the completion of this course, students will be able to

CO1: know how to solve the two dimensional problems graphically and learn algorithms for higher dimensional problems.
CO2: know fundamental theorem of duality, dual simplex method and revised simplex algorithm.
CO3: solve the transportation problems in business sectors and job oriented assignment problems. Also, students will be aware of game theory with different problems and formulation of solutions.

CO4: design the programing for the linear programing problems which are essential in industrial sectors.

UNIT-I

Introduction to linear programming problems(LPP), solution of LPP by graphical method, canonical forms, theory of simplex method, optimality and unboundedness, the simplex algorithm, simplex method in tableau format, two-phase method, Big-M method.

UNIT-II

Duality, formulation of the dual problem, primal-dual relationships, examples, fundamental theorem of duality, dual simplex method, revised simplex method with examples.

UNIT-III

Transportation problem and its mathematical formulation, methods for initial basic feasible solution. Vogel approximation algorithm for solving transportation problem, assignment problems and its mathematical formulation, Hungarian method for solving assignment problem, game theory, formulation of two person zero sum games, solving two person zero sum games, games with mixed strategies, graphical solution procedure and LPP method.

UNIT-IV (PRACTICAL)

Practical / Lab work to be perform in Computer Lab:

Use of computer algebra system (CAS) software: Python/ Sage Math / Mathematica/ MATLAB/ Maple/ Maxima/ Scilab/ R or any other (open source) software etc., for developing at least the following:

1) Graphical method
2) LPP method
3) Two-phase method
4) Primal-dual problem
5) Dual simplex method
6) Revised simplex method
7) Vogel's approximation method
8) Hungarian method for assignment problem
9) Two-person zero-sum game
10) Graphical method for (*2 x m*) and (*n x 2*) games
11) LPP method for (*m x n*) game.

BOOKS RECOMMENDED:

1) Kanti Swarup, Operations Research, Sultan Chand & Sons, New Delhi. Books.
2) Hamdy A.Taha, *Operations Research: An Introduction* (10th edition), Pearson, 2017

BOOKS FOR REFERENCE:

3. Mokhtar S.Bazaraa, John J.Jarvis and Hanif D.Sherali, *Linear Programming and Network Flows* (2nd edition), John Wiley and Sons, India, 2004.
4. Hillier and G.J. Lieberman, *Introduction to Operations Research-Concepts and Cases* (9th Edition), Tata Mc Graw Hill, 2010.
5. G. Hadley, *Linear Programming,* Narosa Publishing House, New Delhi, 2002.
6. Suggested digital platform: NPTEL/SWAYAM/MOOCs
7. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

MULTI-DISCIPLINARY COURSE
PROGRAMING IN C++

Objective: The objective of the course is to learn the basics about C++ programming language such as variables, data types, arrays, pointers, functions and classes etc. On successful completion this course, students will acquire a good understanding about the concept of object-oriented programming using C++ and be able to write and read basic C++ code.

Learning Outcome: On the completion of this course, students will be able to

CO1: learn to understand different types of data by C++ language.

CO2: learn different symbols used in the programming language representing the text variables and constants.

CO3: learn to develop various operators, loops and nested control statements.

CO4: learn to generate functions, local and global variables, 1D and 2D array in C++ programe.

UNIT-I

Introduction to structured programming: data types- simple data types, floating data types, character data types, string data types, arithmetic operators and operators precedence.

UNIT-II

Variables and constant declarations, expressions, input using the extraction operator >>and cin, output using the insertion operator << and cout, preprocessor directives, increment (++) and decrement (--) operations.

UNIT-III

Creating a C++ program, input output, relational operators, logical operators and logical expressions, if and if-else statement, switch and break statements, for, while and do-while loops, continue statement, nested control statement.

UNIT-IV

Functions, value returning functions, value versus reference parameters, local and global variables, one dimensional array, two dimensional array, pointer data and pointer variables.

BOOKS RECOMMENDED

1) D. S. Malik: C++ Programming Language, Course Technology, Cengage Learning, India Edition, 2009.
2) E. Balaguruswami: Object oriented programming with C++, fifth edition, Tata Mc Graw Hill Education Pvt. Ltd., 2008

BOOKS FOR REFERENCE

3) R. Johnsonbaugh and M. Kalin-Applications Programming in ANSI C, Pearson Education.
4) S. B. Lippman and J. Lajoie, C++ Primer, 3rd Ed., Addison Wesley, 2000.
5) BjarneStroustrup , The C++ Programming Language, 3rd Ed., Addison Welsley, 2010.
6) Suggested digital platform: NPTEL/SWAYAM/MOOCs
7) e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

MULTI-DISCIPLINARY COURSE
INTRODUCTION TO MACHINE LEARNING

Objective:

1. Differentiate between supervised, unsupervised machine learning approaches
2. Ability to choose appropriate machine learning algorithm for solving a problem
3. Design and adapt existing machine learning algorithms to suit applications
4. Understand the underlying mathematical relationships across various machine learning algorithms
5. Design and implement machine learning algorithms to real world applications

Learning Outcomes: On the completion of this course, students will be able to

CO1: learn to understand the concept of machine learning and its application.

CO2: learn software for Machine Learning to plot data oriented vectors, matrices and their properties using the MATLAB tool.

CO3: learn to develop various types of data oriented regressions with one and multiple variables.
CO4: learn to develop some advanced data oriented regressions with one and multiple variables.

UNIT-I

Concept of Machine Learning, Applications of Machine Learning, Key elements of Machine Learning, Supervised vs Unsupervised Learning, Statistical Learning: Bayesian Method, The Naive Bayes Classifier

UNIT-II

Software's for Machine Learning and Linear Algebra Overview: Plotting of Data, Vectorization, Matrices and Vectors:

Addition, Multiplication, Transpose and Inverse using Available Tool such as MATLAB.

UNIT-III

Linear Regression: Prediction using Linear Regression, Gradient Descent, Linear Regression with one Variable, Linear Regression with Multiple Variables, Polynomial Regression, Feature Scaling/Selection.

UNIT-IV

Logistic Regression: Classification using Logistic Regression, Logistic Regression vs. Linear Regression, Logistic Regression with one Variable and with Multiple Variables .Regularization and its Utility: The problem of Overfitting, Application of Regularization in Linear and Logistic Regression, Regularization and Bias/Varia

BOOKS RECOMMENDED

1. Ethem Alpaydin, "Introduction to Machine Learning"2nd Edition, The MIT Press, 2009.
2. Tom M. Mitchell, "Machine Learning", First Edition by Tata McGraw-Hill Education, 2013.
3. Christopher M.Bishop, "Pattern Recognition and Machine Learning" by Springer,2007.
4. Mevin P. Murphy, "Machine Learning: A Probabilistic Perspective" by The MIT Press, 2012
5. Suggested digital platform: NPTEL/SWAYAM/MOOCs
6. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

MULTI-DISCIPLINARY COURSE
MATHEMATICAL FINANCE

Objective: The objective of this course is to learn the mathematical tools used for understanding the financial dynamics and stock exchange with a numerical analysis background.

Learning Outcomes: A student well versed in this course learns good statistical methods, computing and simulation methods and is able to pursue courses in computational finance later.

CO1: This course has market value helping a student in employment as well as daily life dealings.

CO2: Knowledge in marketing will lead to understand the floating rate and immunization.

CO3: A student will get to know about the random returns which is vital in business sectors upon money investment.

UNIT-I

Basic principles: Comparison, arbitrage and risk aversion, interest (simple and compound, discrete and continuous), time value of money, inflation, net present value, internal rate of return (calculation by bisection and Newton-Raphson methods),

UNIT-II

Comparison of NPV and IRR. Bonds, bond prices and yields. Floating-rate bonds, immunization.

Asset return, short selling, portfolio return, (brief introduction to expectation, variance, covariance and correlation),

UNIT-III

Random returns, portfolio mean return and variance, diversification, portfolio diagram, feasible set, Markowitz model (review of Lagrange multipliers for 1 and 2 constraints).

BOOKS RECOMMENDED:

1. David G. Luenberger, *Investment Science*, Oxford University Press, Delhi, 1998.
2. John C. Hull, Options, *Futures and Other Derivatives,* 6th Ed., Prentice-Hall India, Indian reprint, 2006.
3. Sheldon Ross, *An Elementary Introduction to Mathematical Finance*, 2nd Ed., Cambridge University Press, USA, 2003.
4. Suggested digital platform: NPTEL/SWAYAM/MOOCs
5. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

MULTI-DISCIPLINARY COURSE
MATHEMATICAL MODELLING

Objective: The course is designed to impart knowledge on application of differential equations in different physical problems like, electric circuit problem, conduction of heat in solids, vibrating string, etc. To promote the students opt for more modelling courses using stochastic process, Optimization methods, finite elements, wavelets learning techniques etc.

Learning Outcomes: On the completion of this course, students will be able to

CO1: know the basic ideas about the mathematical modelling and modelling through the first order ordinary and system of equations.
CO2: learn more mathematical modellings on system of differential equations.
CO3: know about more mathematical modellings on linear motions, planetary motions and conduction of heat.
CO4: expose about the ideas of discrete mathematical modelling including fractals.

UNIT-I

Techniques, classification and characteristics of mathematical modeling. mathematical modeling through first order ODE: Linear and nonlinear growth and decay model, Prey-Predator model, modelling on population dynamics.

UNIT-II

Applications of differential equations: Art forgery problem, explaining Tacoma bridge disaster radioactive decay problem, mixture problems, epidemic model, compartment models, models in arms race and battles.

UNIT-III

Free damped motion, forced motion, resonance phenomena, vibrating string, vibrating membrane, conduction of heat in solids, gravitational potential and conservation laws.

UNIT-IV

Basics of discrete dynamics, fixed points, periodic points, orbits, repelling points, attracting points, hyperbolic dynamics, bifurcation, Logistic maps, modeling problems involving logistic maps, fractals.

BOOKS RECOMMENDED:

1. Shepley L. Ross, *Differential Equations*, 3rd Ed., John Wiley and Sons, 1984.
2. Brown M, Differential equation,.Narosa (Springer)
3. Tyn Myint U, Partial differential equations in Mathematical physics, Elsevier
4. Holmes, Discrete dynamical system, Springer

BOOKS FOR REFERENCE

5. J. N. Kapur, Mathematical Modelling, Wiley Eastern Limited, New Age International Ltd. New Delhi.
6. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org
7. Suggested digital platform: NPTEL/SWAYAM/MOOCs

MULTI-DISCIPLINARY COURSE
INTRODUCTION TO PROGRAMING WITH MATLAB

Objective: The objective of this course is to encourage the students for computer programing using MATLAB. This training will help students to see the mathematical problems physically before proceeding for simulation. Knowledge in MATLAB is a tool in research not only in Mathematics but also in science & engineering.

Learning Outcomes: Completing this course, a student will
CO1: understand the fundaments of procedural and functional programming;
CO2: understand MATLAB data types and structures;
CO3: be able to set up simple real- life numerical problems such that they can be solved and visualized using basic codes in MATLAB
CO4: be ready to use advanced coding in MATLAB in their subsequent studies

UNIT 1

Introduction to MATLAB programming-basics of MATLAB programming, array operations in MATLAB, loops and execution control, working with files: Scripts and functions, plotting and program output, approximations and errors-defining errors and precision in numerical methods, truncation and round-off errors, error propagation, global and local truncation errors.

UNIT II

Linear equations-Linear algebra in MATLAB, Gauss elimination, LU decomposition and partial pivoting, Iterative methods: Gauss Siedel method

UNIT III

Regression and Interpolation-Introduction, linear least squares regression (including lsq curve fit function), functional and nonlinear regression (including*lsq nonlin* function), interpolation in MATLAB using spline and *pchip*

UNIT IV

Nonlinear equations-single variable, MATLAB function fzero in single variable, fixed-point iteration in single variable, Newton-Raphson in single variable, MATLAB function *fsolve* in single and multiple variables, Newton-Raphson in multiple variables.

BOOKS RECOMMENDED:

1. FausettL.V.(2007) Applied Numerical Analysis Using MATLAB,2nd Ed.,Pearson Education
2. Essential MATLAB for Engineers and Scientists,6th Edition, Brian Hahn; DanielT. Valentine, Academic Press,WebISBN-13:978-0-12-805271-6.
3. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org
4. Suggested digital platform: NPTEL/SWAYAM/MOOCs

MULTI-DISCIPLINARY COURSE
NUMERICAL METHODS

Objective: Calculation of error and approximation is necessity in all real life, industrial and scientific computing. The objective of this course is to acquaint students with various numerical methods of finding solution of different type of problems, which arises in different branches of science like locating roots of equations, finding solution of nonlinear equations, systems of linear equations, differential equations, Interpolation, differentiation, evaluating integration.

Learning Outcomes: Completing this course, a student will be able to

CO1: learn different techniques to find the zeros of algebraic and transcendental equations, numerical solutions of system of equations.
CO2: get the idea to find the numerical solutions of polynomial equations
CO3: learn to find the numerical differentiation by means of different operators.
CO4: learn to find numerical integration which will help to find the numerical solution of ODE and PDE

UNIT-I

Algorithms, convergence, Bisection method, false position method, fixed point iteration method, Newton's method, Secant method. Gauss elimination and Gauss Jordan methods, LU decomposition, Gauss-Jacobi, Gauss-Siedel.

UNIT-II

Lagrange and Newton interpolation: linear and higher order, finite difference operators.

UNIT-III

Numerical differentiation: forward difference, backward difference and central difference operators.

UNIT-IV

Integration: trapezoidal rule, Simpson's rule, Euler's method, Runge-Kutta methods of orders two and four.

BOOKS RECOMMENDED:

1. M.K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation*, 5th Ed.,

BOOKS FOR REFERENCE:

2. S.S. Sastry, Introductory method for Numerical Analysis, PHI New Delhi, 2012.
3. S.D. Conte and Carl De Boor, Elementary Numerical Analysis, Mc Graw Hill,
4. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org
5. Suggested digital platform: NPTEL/SWAYAM/MOOCs

SKILL ENHANCEMENT COURSE-I

INTRODUCTION TO PYTHON

Objective: The objective of this course is to aware the students for Python language and the programing as well as to create a learning platform to apply for slicing to access data and mathematical problems.

Learning Outcomes: After completion of this course, students will be able to:

CO1: understand why Python is a useful scripting language for applications.
CO2: learn how to use lists, tuples, and dictionaries in Python programs, learn how to write loops and decision statements in Python, learn how to use indexing and slicing to access data in Python programs.
CO3: learn how to use python for solving mathematical problems.

UNIT-I

Introduction to Python programming, installation of Python, application of Python, writing Python code, running Python programs, variables, basic input-output operations, operators.

UNIT-II

Number, string, list, tuple, set, dictionary, arrays and vectors, conditional statements (if, if-else, if-elif- else), loops (for loop, while loop).writing and calling functions, function inputs and outputs, local and global scope of variable, Lamda function , types of errors.

UNIT-III

Library for mathematics (sympy and numpy), problems on algebraic expression, ordinary and partial derivatives, integral, limit, ordinary differential equations, algebra of matrices, plotting of functions.

BOOKS RECOMMENDED:

1. Harsh Bhasin, *Python for Beginners*. New Age International; 1st Edition,2018.
2. Tim Hall and J-P Stacey, *Python 3 for Absolute Beginners*. Apress, 2009.
3. Suggestive digital platforms web links: NPTEL/SWAYAM/MOOCS.
4. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

SKILL ENHANCEMENT COURSE-2

Programing with Mathematica

Objective: The objective of this course is to aware the students for Mathematica language and the programing as well as to create a learning platform to apply for complex mathematical problems.

Learning Outcomes: After completion of this course, the students will be able to:

CO1: understand basic principles of programming language, plotting mathematical functions and solving algebraic equations.

CO2: learn the technique to find the solutions of ODE and PDE equations.

CO3: learn the numerical computation for differentiation and integration.

UNIT-I

User interface**,** mathematica language and syntax**,** functions manipulation**,** plotting mathematical functions and data. plotting 2D, 3D functions and manipulation**,** solving algebraic equation**:** root finding, transcendental equation**.**

UNIT-II

Solving ordinary differential equation (ODE)**,** solving partial differential equation (PDE)**.**

UNIT-III

Vectors and matrices**,** limits, integration and differentiation**,** numerical computation**,** symbolic manipulation.

BOOKS RECOMMENDED:

1. Stephen Wolfram ,*The Mathematica Book*, 5th Edition, Wolfram Media Inc, 2003.
2. José Guillermo Sánchez León, *Mathematica Beyond Mathematics:The Wolfram Language in the Real World*, 1st Ed., Chapman and Hall/CRC, 2017.
3. Suggestive digital platforms web links: NPTEL/SWAYAM/MOOCS.
4. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

SKILL ENHANCEMENT COURSE-3

TYPE SETTING IN LATEX (PRACTICAL)

Objective: The objective of this course is to familiarize students how to write research papers and books using the book format process of type setting by LaTex, how to prepare for document presentation

Learning Outcomes: After completion of this course, the students will be able to:

CO1: handle different types of documents, organize documents into different sections, subsections, etc., learn formatting pages (margins, header, footer, orientation).

CO2: learn formatting text and writing of complex mathematical formulae, tables and images.

CO3: learn cross-referencing, bibliography writing, indexing, read error messages as and when required, learn to create presentations using Beamer.

This is a practical paper. Students will be externally examined on their expertise on following aspects of typing as per the rules of the university/affiliated institutions:

Installation of LaTeX and different IDEs, Creating the first document using LaTeX, organizing content into sections using article and book class of LaTeX, formatting the page by setting margins, paper size, usepackage, customizing header and footer, changing the page orientation, dividing the document into multiple columns, reading different types of error messages. Formatting text (styles, size and alignment), adding colors to text and entire page, and adding bullets and numbered items, Creating basic tables, matrices and arrays, adding simple and dashed borders, merging rows and columns, and handling situations where a table exceeds the size of a page, adding an image, exploring different properties like rotate, scale, etc., writing equations in different formats, creating various form of mathematics documents, create items, add cross-referencing (refer to sections, table, images), add bibliography (references), and create back index, introduction to creating slides, adding frames, dividing the slide into multiple columns, adding different blocks, etc.

BOOK RECOMMENDED:

1. LaTeX Beginner's Guide: Create visually appealing texts, articles, and books for business and science using LaTeX, 2nd Edition , Packt Publishing, 2021.
2. Firuza Karmali Aibara : A short introduction to LaTeX: A book for beginners, Createspace Independent Publishing Platform, 2019.
3. Dilip Datta: LaTeX in 24 Hours: A Practical Guide for Scientific Writing , 1st ed., Springer, 2017.
4. Suggestive digital platforms web links: NPTEL/SWAYAM/MOOCS.
5. e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org

VALUE ADDED COURSE-1

R-PROGRAMMING (PRACTICAL)

Objectives: The objective of this course is to introduce students to R-programming language which is very useful in the field of data science.

Learning Outcomes: After completion of this course, the students will be able to:

CO1: learn a new programming language in the field of data science.

CO2: kindle the problem solving capability in statistics and statistical sciences.

List of Practicals

1. Simple Programs using Mathematical constant
2. Programs using complex functions
3. Numerical solutions of nonlinear equations and systems
4. Solving system of linear equations using Jacobi method
5. Program using Trigonometric and Hyperbolic Expressions
6. Finding Eigen values and Eigen vectors
7. Finding the volume of solid of revolution.
8. Plotting Points in the Plane and Space
9. Analyse data using Central Tendency and Measures of dispersion and distributions
10. Find the Laplace integral transforms for different functions.
11. Obtain the solution of the initial value problem in ODE and PDE

BOOK RECOMMENDED:

1. Programming with R by S.R. Mani Sekhar, T.V. Suresh Kumar, Madhavi Kasa, Sunil Kumar S. Manvi, Cengage Learning India Pvt. Ltd, 2017
2. R for Statistics by Pierre-Andre Cornillon, Arnaud Guyader, Francois Husson, Nicolas Jegou, Julie Josse, Maela Kloareg, Eric Matzner-Lober, Laurent Rouvière, Chapman and Hall, 2012
3. Statistics with R Programming by Dr. Sandip Rakshit, McGraw Hill Education (India) Pvt. Ltd, 2018.
4. Suggestive digital platforms web links: NPTEL/SWAYAM/MOOCS.

VALUE ADDED COURSE-2

MATHEMATICA (PRACTICAL)

Objectives: The objective of this course is to introduce students to mathematica language which is very useful in the simulation process dealing with mathematical modelling and also, in different branches of practical mathematics.

Learning Outcomes: After completion of this course, students will be able to:

CO1: learn a new programming language in mathematics.

CO2: increase the problem solving capability in mathematics, ploting of 2D, 3D graphs and solving LPP problems.

List of Practicals

1. Solving higher degree equations.
2. Solving system of equations by matrix method and find the eigen values and eigen vectors of a matrix of order 4 by 4 or higher order.
3. Solving system of non-linear equations.
4. Finding the differentiation of different functions of second and third derivatives.
5. Finding the Integration of different functions with limits.
6. Evaluation of double integrals and triple integrals.
7. Solving ordinary differential equations and partial differential equations with initial condition.
8. Solving system of ordinary differential equations.
9. Creating and plotting 2-D and 3-D graphs.

10. Finding the volume of solid of revolution.
11. Solving linear programming problems
12. Solving problems in numerical analysis (Finding roots, interpolations, integration)

BOOK RECOMMENDED:

1) Eugene Don, *Mathematica*, Scham's Outline Series, Mc Graw Hill Publisher, New York. (2009)
2) Pragathi Gautam and Swapnil Verma, *Practical Mathematica*, Ane Books Publisher (2019).

BOOKS FOR REFERENCE:

3) Ananta Kumar Bora, *Mathematicva: A Research Book of Mathematics*, Scholarink Publishers (2017)
4) Sal Mangano*, Mathematica Cookbook*, O'Reilly Media, Inc., 1005 Gravenstein Highway North, Sebastopol,USA (2010)\

VALUE ADDED COURSE-3

MAPLE

Objectives: The objective of this course is to introduce students how to use the Maple graphical user interface, components of a Maple worksheet and to perform basic computations.

Learning Outcomes: After completion of this course, students will be able to:

CO1: learn a new programming language in mathematics to find numerical solutions of initial value problems, nonlinear equations, Laplace transform of functions, eigenvalues and eigenvectors.

CO2: analyze data using central tendency, measure of dispersion and distributions.

List of Practicals

- Simple programs using mathematical constant
- Programs using complex functions
- Numerical solutions of nonlinear equations and systems
- Solving system of linear equations using Jacobi method
- Program using trigonometric and hyperbolic expressions
- Finding eigenvalues and eigen vectors
- Plotting points, curves, surfaces in the plane and space
- Analyze data using central tendency and measures of dispersion and distributions
- Find the Laplace integral transforms for different functions.
- Obtain the solution of the initial value problems in ODE and PDE.
- Solving problems in numerical analysis (Finding roots, interpolations, integration)

BOOK RECOMMENDED:

1. Inna Shingareva & Carlos Lizárraga-Celaya, Maple and Mathematica, A Problem Solving Approach for Mathematics *Second Edition,* Springer Wien New York.

VALUE ADDED COURSE-4

SAGEMATH

Objectives: The objective of this course is to introduce students to SageMath to use as a calculator which is very useful in solving mathematical problems of differential and integral calculus by plotting the graphs.

Learning Outcomes: After completion of this course, students will be able to:

CO1: learn to plot 2-D graphs and 3-D graphs using SageMath.
CO2: learn to implement SageMath using templates and exceptional and handling concepts, make use of theoretical concepts to solve problems and visualize the output.

List of Practicals

1. Finding all local extrema and inflection points of a function.
2. Creating and plotting 2-D graphs and 3-D graphs.
3. Finding the surface area of given surface using package.
4. Finding the approximate roots using Newton's method.

5. Plotting and finding area between curves using integrals.
6. Finding the average of a function.
7. Finding the volume of solid of revolution.
8. Finding the solution for a system of linear equations.
9. Finding the divergence and curl of vector valued functions.
10. Using differential calculus to analyze a quintic polynomials features, for finding the optimal graphing window.

BOOKS RECOMMENDED:

1. Razvan A. Mezei, An Introduction to SAGE Programming: With Applications to SAGE, Wiley, 2016.

https://doc.sagemath.org/pdf/en/tutorial/SageTutorial.pdf.

VALUE ADDED COURSE-5

SCILAB

Objectives: The objective of this course is to introduce students to SciLab language to understand the linear algebra, numerical methods and plotting of 2-D, 3-D graphs.

Learning Outcomes: After completion of this course, students will be able to:

CO1: learn to plot 2-D graphs and 3-D graphs using SciLab.

CO2: learn linear algebra and numerical methods using SciLab.

List of Practicals

1. (a) Check whether the following Boolean statements are true or false based on the values of a, b, c, x, and y given below.
   (i) a > c; (ii) a = b; (iii)$(2a+b)/x^2 < 1$; (iv)$x^2 + 2ab + b^2 \leq 23$; (v) 2ac = 2cb
   (b) Determine the result of the following calculations if a = 2.3, b = -2.3, c= π/2, x = 2/π, and y = √3:
   (i) $(a^2 + bc + x)$; (ii) sin(c) + y/c; (iii)(a+c)/(x+y); (iv)1/(cos(c) + ln(x)); (v) $(a+c)^3$ /b.
   (c) For the vectors u and v, calculate the following:
   (i) w = u+v; (ii) r = u/.v; (iii)z = v*u; (iv) t = v*.u
2. Write a program for the following operations of the matrices A, B and C :
   (i) Sum of two matrices
   (ii) Product of two matrices
   (iii) Product of Three matrices
3. Verify whether the given matrix is singular or non-singular and compute its inverse if exists.
4. Write a program for Cramer's rule to solve the simultaneous equations (maximum of three unknowns).
5. Write a program for Gauss Jacobi iteration method to solve the system of linear equations.
6. Solving the ordinary differential equations with initial condition and solving the system of ordinary differential equations.
7. Creating and plotting 2-Dgraphs.
8. Creating and plotting3-Dgraphs.
9. Finding the approximate roots using Newton's method.
10. Finding the volume of solid of revolution.

BOOKS RECOMMENDED:

1. Hema Ramachandran and Achutsankar Nair, SCILAB , S. Chand Publishers, 2011.
2. Stephen L. Campbell, Jean-Philippe Chancelier, and Ramine, Modelling and Simulation in Scilab/Scicos, 1st Edition, Springer

PROJECT / DISSERTATION

The topic of the project/dissertation be chosen in consultation with the assigned supervisor from the thrust areas given in Appendix-B.

The candidate should prepare a dissertation/ Project Report of the work done during the assigned period before appearing the final viva in the presence of external who must be an expert in that area. The examination procedure for the continuous evaluation followed by the Universities/ Affiliated Institutions for examining dissertations will be followed.

PROPOSAL FOR A REFRESHER
COURSE IN MATHEMATICS FOR NEP FOUR YEARS PROGRAM

DURATION : 18 WORKING DAYS (3 WEEKS)
(72 classes of one and half hours each as per UGC rule for Refresher classes. The idea is to have one week crash course in all the newly introduced subjects.)

1ST WEEK

DAYS/TIME	9:00 AM-10:30 AM	11:00 AM –12:30 PM	1:30 PM—3:00PM	3:30 PM—5:00 PM
MON	Real Analysis-III	Topology	Algebra III (Field theory)	MATLAB Hands On training in Lab
TUE	Real Analysis-III	Topology	Algebra III (Field theory)	MATLAB Hands On training in Lab
WED	Real Analysis-III	Topology	Algebra III (Field theory)	MATLAB Hands On training in Lab
THUR	Real Analysis-III	Topology	Algebra III (Field theory)	MATLAB Hands On training in Lab
FRI	Real Analysis-III	Topology	Algebra III (Field theory)	MATLAB Hands On training in Lab
SAT	Real Analysis-III	Topology	Algebra III (Field theory)	MATLAB Hands On training in Lab

2ND WEEK

DAYS/TIME	10:00 AM-11:00 AM	11:00 AM –12:00 PM	2:00 PM—3:00PM	3:00 PM—4:00 PM
MON	Analytic Number Theory	Complex Analysis-II	Measure theory	Python Hands on Training in Lab
TUE	Analytic Number Theory	Complex Analysis-II	Measure theory	Python Hands on Training in Lab
WED	Analytic Number Theory	Complex Analysis-II	Measure theory	Python Hands on Training in Lab
THUR	Analytic Number Theory	Complex Analysis-II	Measure theory	Python Hands on Training in Lab
FRI	Analytic Number Theory	Complex Analysis-II	Measure theory	Python Hands on Training in Lab
SAT	Analytic Number Theory	Complex Analysis-II	Measure theory	Python Hands on Training in Lab

3RD WEEK

DAYS/TIME	10:00 AM-11:00 AM	11:00 AM –12:00 PM	2:00 PM—3:00PM	3:00 PM—4:00 PM
MON	Functional Analysis	Differential Equations-III	Using Open course ware for Mathematics practicals	Mathematica Hands on training in Lab
TUE	Functional Analysis	Differential Equations-III	Using Open course ware for Mathematics practicals	Mathematica
WED	Functional Analysis	Differential Equations-III	Using Open course ware for Mathematics practicals	Hands on training in Lab
THUR	Functional Analysis	Differential Equations-III	Using Open course ware for Mathematics practicals	Mathematica
FRI	Functional Analysis	Differential Equations-III	Using Open course ware for Mathematics practicals	Hands on training in Lab
SAT	Functional Analysis	Differential Equations-III	Using Open course ware for Mathematics practicals	Mathematica

MODEL COMPUTER LAB FOR THREE/FOUR YEARS DEGREE COURSE

ITEM NUMBER	ITEM NAME	COST OF THE ITEM IN RUPEES
01	COMPUTERS – 32 (32 I5/I7 computers with more than minimum 8 GB RAM to run software properly)	32 Lacs
02	ONLINE UPS (Load of 32 Terminals)	7 lacs
03	Wi-Fi Connections	Depends on configuration inside the institution. Roughly 2 lakh
04	ACs (02 Tons x04Numbers) with installation	3Lacs
05	Computer Chairs and Tables (32+32)	2 Lacs
06	Renovation of the Lab site provided by the Institution	4 lakh
06	SOFTWARES (MATLAB +MATHEMATICA) 32 terminals	35 lakh (Depends on how many terminals to be connected for which product)
	TOTAL COST	85 lakhs

NAME OF INSTITUTIONS FOR INTERNSHIP

1. Indian Institute of Science
2. All IITs and NITs
3. Indian statistical Institutes
4. All Central Universities
5. DRDO
6. BSNL
7. SOFTWARE START UPS
8. CORPORATE Sectors like GOOGLE, AMAZON, HINDALCO, COGNIZANT, TCS, INFOSYS, ACCENTURE, MCL, NALCO, HAL, BHEL, etc.
9. Reputed Universities
10. OCAC
11. National Informatics Centre