INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAI-101 **Course Title**: Mathematics I
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Autumn **7. Subject Area:** BSC
8. **Prerequisite:** NIL
9. **Objective:** To provide the essential knowledge of basic tools of Differential Calculus, Integral Calculus, Vector Calculus and Matrix Algebra.

10. **Details of the Course**

S. No.	Contents	Contact Hours
1.	**Matrix Algebra:** Elementary operations and their use in getting the rank, inverse of a matrix and solution of linear simultaneous equations. Orthogonal, symmetric, skew-symmetric, Hermitian, skew-Hermitian, normal and unitary matrices and their elementary properties. Eigenvalues and Eigenvectors of a matrix, Cayley-Hamilton theorem, Diagonalization of a matrix.	8
2.	**Differential Calculus:** Limit, continuity and differentiability of functions of two variables, Euler's theorem for homogeneous equations, Tangent plane and normal. Change of variables, chain rule, Jacobians, Taylor's Theorem for two variables, Error approximations. Extrema of functions of two or more variables, Lagrange's method of undetermined multipliers	12
3.	**Integral Calculus:** Review of curve tracing and quadric surfaces, Double and Triple integrals, Change of order of integration. Change of variables. Gamma and Beta functions. Dirichlet's integral. Applications of Multiple integrals such as surface area, volumes, centre of gravity and moment of inertia..	12
4.	**Vector Calculus:** Differentiation of vectors, gradient, divergence, curl and their physical meaning. Identities involving gradient, divergence and curl. Line and surface integrals. Green's, Gauss and Stoke's theorem and their applications.	10
	Total	**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Kreyszig, E., "Advanced Engineering Mathematics", 10th Ed., Wiley India Pvt. Ltd	2015
2.	Jain, R. K. and Iyenger, S. R. K., "Advanced Engineering Mathematics", 5th Ed., Narosa Publishing House.	2017
3.	Thomas, G. B., Hass, J., Heil, C. and Weir M. D., "Thomas' Calculus", 14th Ed., Pearson Education	2018

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-101 **Course Title**: Computer Programming
2. **Contact Hours:** **L:** 3 **T:** 0 **P:** 2
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 10-25 **PRS:** 25 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 04 6**. Semester:** Autumn 7. **Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To provide basic knowledge of computer programming in C++.
10. **Details of the Course:**

S. No.	Contents	Contact hours
1.	**Computer Fundamentals**: Introduction to computer systems; Number system, integer, signed integer, fixed and floating point representations; IEEE standards, integer and floating point arithmetic; CPU organization, ALU, registers, memory, the idea of program execution at micro level.	7
2.	**Basic Programming in C++**: Input/output; Constants, variables, expressions and operators; Naming conventions and styles; Conditions and selection statements; Looping and control structures (while, for, do-while, break and continue); Arrays; File I/O, header files, string processing; Pre-processor directives; Compiling and linking.	10
3.	**Programming through functional decomposition**: Design of functions, void and value returning functions, parameters, scope and lifetime of variables, passing by value, passing by reference, passing arguments by constant reference, recursive functions; Function overloading and default arguments; Library functions.	10
4.	**Pointers**: Pointers; Dynamic data and pointers, dynamic arrays.	3
5.	**Object Oriented Programming Concepts**: Data hiding, abstract data types, classes, access control; Class implementation, default constructor, constructors, copy constructor, destructor, operator overloading, friend functions; Object oriented design (an alternative to functional decomposition) inheritance and composition; Dynamic binding and virtual functions; Polymorphism; Dynamic data in classes.	12
	Total	**42**

11. **List of Practicals:**

S. No.	
1.	Number systems
2.	Use of constants, variables, expressions and operators; Naming conventions and styles
3.	Conditional statements and Arrays
4.	File input and output, pre-processor directives
5.	Functional decomposition
6.	Recursive functions, overloading
7.	Pointers
8.	Object Oriented Programming: Classes and abstract data types
9.	Constructors and destructors
10.	Operator overloading
11.	Friend functions and virtual functions

12. **Suggested Books:**

S. No.	**Authors/Name of Books/Publisher**	**Year of Publication/Reprint**
1.	Stroustrup, B., "The C++ Programming Language", 4th Ed., Pearson Education India.	2022
2.	Prata, S., "C++ Primer Plus", 6th Ed., Pearson Education India.	2015
3.	Bronson G. J., "A First Book of C++", 4th Ed, Cengage India Pvt. Ltd.	2012
4.	Deitel, P. and Deitel, H., "C++ How to Program", 10th Ed., Pearson Education India.	2017
5.	Lippman, S. B., Lajoie, J. and Moo, B.E., "The C++ Primer", 5th Ed., Addison-Wesley Professional.	2012
6.	Mueller, J. P., "C++ All-in-one for Dummies", 4th Ed., Wiley.	2020

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAI-102 **Course Title**: Mathematics II
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Spring 7. **Subject Area:** BSC
8. **Prerequisite:** NIL
9. **Objective:** To introduce the basic concepts of linear algebra, probability and statistics.

10. **Details of the Course**

S. No.	Contents	Contact Hours
1.	**Vector Spaces:** Vector spaces (over the field of real numbers), subspaces, spanning set, linear independence, basis and dimension. Linear transformations, range and null space, rank-nullity theorem, matrix of a linear transformation.	8
2.	**Inner Product Spaces:** Inner-product spaces, Gram-Schmidt process, orthonormal basis; spectral theorem for real symmetric matrices, singular value decomposition; low-rank approximation.	6
3.	**Probability and distributions:** Concept of probability, random variables and their probability distributions, expectation, moments and moment generating functions, Chebyshev's inequality.	6
4.	**Special distributions:** (Discrete): Binomial, Poisson, Negative binomial, and Geometric distributions. (Continuous): Uniform, Exponential, Gamma, and Normal distributions.	5
5.	**Bivariate random variables:** Joint, marginal, and conditional distributions, statistical independence. Distributions of functions of random variables. Correlation and regression.	6
6.	**Sampling Distributions:** Random sampling and sampling distributions, law of large numbers, central limit theorem.	3
7.	**Estimation:** Point estimation, unbiased estimators, maximum likelihood estimation. Interval estimation, interval estimation of mean, variance and proportion for normal populations.	4
8.	**Testing of Hypothesis:** Simple and composite hypothesis, Type I and Type II errors, power of a test. Hypothesis testing for mean, variance and proportion for normal populations.	4
	Total	**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Axler, S., "Linear Algebra Done Right", 3rd Ed., Springer Nature.	2015
2.	Strang, G., "Linear Algebra and Its Applications" 4th Ed., Cengage India Private Limited.	2005
3.	Hogg, R. V., Mckean, J. and Craig, A. T., "Introduction to Mathematical Statistics", 8th Ed., Pearson Education India	2021
4.	Rohatgi, V. K. and Saleh, A. K. Md. E., "An Introduction to Probability and Statistics" 2nd Ed., Wiley India	2008
5.	Miller, I. and Miller, M., "John E. Freund's Mathematical Statistics with Applications", 8th Ed., Pearson Education India	2013

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-102 **Course Title**: Discrete Mathematics
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Spring 7. **Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To provide a basic knowledge of discrete mathematical structures.
10. **Details of the Course**

S. No.	Contents	Contact hours
1	Logic and Proofs: Propositional logic, propositional equivalences, predicates and quantifiers, introduction to proofs, proof methods and strategy.	5
2	Counting: The basic counting, the pigeonhole principle, permutations and combinations, binomial coefficients, generalized permutations and combinations.	4
3	Advanced Counting Techniques: Recurrence relations, solving linear recurrence relations, generating functions, inclusion-exclusion, applications of inclusion-exclusion, divide-and-conquer algorithms and recurrence relations. Growth of functions: big O, big Θ and big Ω notations.	9
4	Relations: Relations and their properties, representing relations using matrices and digraphs, closures of relations, Warshall's algorithm, equivalence relation, partial order relation, Hasse diagrams, lattices.	8
5	Boolean Algebra: Boolean functions, Boolean expressions and Boolean functions, Boolean algebra, representing Boolean functions, logic gates, minimization of circuits, Karnaugh maps.	6
6	Graphs: Graphs and graph models, basic terminology and special types of graphs, graph isomorphisms, connectivity, Euler and Hamiltonian paths and cycles, shortest-path problems, graph coloring, introduction to trees, application of trees, spanning trees, minimum spanning trees.	10
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Rosen, K. H., "Discrete Mathematics and its Applications", 8th Ed., McGraw Hill.	2019
2	Liu, C. L., "Elements of Discrete Mathematics", 4th Ed., Tata McGraw Hill.	2017
3	Deo, N., "Graph Theory with Applications to Engineering and Computer Science", Dover Publications.	2016
4	Chartrand, G. and Zhang, P., "Discrete Mathematics", Waveland Press, Inc.	2011
5	Clark, J. and Holton, D. A., "A First Look at Graph Theory", World Scientific.	1991

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-104 **Course Title**: Elementary Real Analysis
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 0
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Spring 7. **Subject Area:** PCC
8. **Pre-requisite:** NIL
9. **Objective:** To introduce the concept of convergence of sequence and series; limit, continuity, differentiability and integrability of real valued functions of a real variable.
10. **Details of the Course**

S. No.	Contents	Contact hours
1.	Real number system, ordering, bounded sets, order completeness axiom, well ordering principle; Archimedean property, complete ordered field, limit point of a set, Bolzano-Weierstrass theorem, open and closed sets, compact sets and Heine-Borel theorem. Dedekind's theorem.	8
2.	Sequences and convergence, Cauchy's first and second limit theorems, Cauchy sequences, Cauchy criterion for convergent sequences, bounded and monotonic sequences, Euler's constant, subsequences, limit superior and limit inferior. Infinite series and tests for its convergence.	8
3.	Review of limit, continuity, differentiability and Taylor's theorem for the functions of one variable. Sequential continuity, uniform continuity, Lipschitz continuity, functions of bounded variation, absolute continuity.	8
4.	Sequences and series of real valued functions, their point-wise, absolute and uniform convergence, Cauchy's general principle of uniform convergence, continuity of the limit (sum) function, differentiation and integration of the sequences and series of functions. Arzela –Ascoli Theorem.	8
5.	Definition and existence of Riemann-Stieltjes integral, Properties of integrals, Integration and differentiation, Fundamental theorem of calculus, first and second mean value theorems. Riemann integration as a particular case of RS integral.	10
	Total:	**42**

11. **Suggested Books:**

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Rudin, W., "Principles of Mathematical Analysis", 3rd Ed.**,** McGraw-Hill Education.	2017
2.	Goldberg, R. R., "Methods of Real Analysis", Oxford and IBH Publishing Company Pvt. Ltd.	2020
3.	Bartle, R. G. and Donald R. S., "Introduction to Real Analysis", 3rd Ed., John Wiley & Sons, Inc.	2010
4.	Royden H. L. and Fitzpatrick. P.M., "Real Analysis", 4th Ed., Pearson Education India	2010
5.	Apostol, T. M., "Mathematical Analysis", 2nd Ed., Narosa Publishing House.	2002
6.	Lang. S., "Real and Functional Analysis", 3rd Ed., Springer-Verlag.	1993

INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE

Name of Department: Mathematics

1. **Subject Code:** MAC-106 **Course Title:** Database Management Systems

2. **Contact Hours**: **L:** 3 **T:** 1 **P:** 0

3. **Examination Duration (Hrs.)**: **Theory:** 03 **Practical:** 00

4. **Relative Weightage: CWS:**20-35 **PRS:** 00 **MTE:** 20-30 **ETE:** 40-50 **PRE:**0

5. **Credits**: 4 6. **Semester**: Spring 7. **Subject Area**: PCC

8. **Pre-requisite**: Nil

9. **Objective**: To impart the knowledge of Database Management Systems.

10. **Details of Course**:

S. No.	Contents	Contact Hours
1	**Introduction:** Database system architecture, Data Abstraction, Data Independence, Data Definition Language (DDL), Data Manipulation Language (DML), Entity-relationship model, network model, relational and object-oriented data models, integrity constraints, data manipulation operations	7
2	**Relational database design:** The catalog types, Keys, Relational Algebra, Domain Relational Calculus, Tuple Relational Calculus, Domain and data dependency, Armstrong's axioms, Functional Dependencies, Normal forms, Dependency preservation, Lossless design	8
3	**Relational query languages:** PL/SQL basics, DDL and DML constructs, Open source and Commercial DBMS - MYSQL, ORACLE, DB2, SQL server	8
4	**Query Processing and Optimization:** Evaluation of relational algebra expressions, Query equivalence, Join strategies, Query optimization algorithms	6
5	**Transaction Concepts:** Concurrency control, ACID property, Serializability of scheduling, Locking and timestamp-based schedulers, multi-version and optimistic Concurrency Control schemes, Database recovery	7
6	**Advanced Topics:** Web databases, Distributed databases, Introduction to data warehousing and data mining, SQL language functionality to be used in python	6
	Total	**42**

11. **Suggested Books**:

S.No.	Name of Authors / Books / Publishers	Year of Publication/ Reprint
1.	Silberschatz, A., Korth, H. F., Sudharshan, S., "Database System Concepts", 7th Ed., McGraw Hill Education	2021
2.	Date, C. J., Kannan, A., Swamynathan, S., "An Introduction to Database Systems", 8th Ed., Pearson India	2003
3.	Elmasri, R. and Navathe, S. B., "Fundamentals of Database Systems", 7th Ed., Pearson Education	2015
4.	Majumdar, A. and Bhattacharya, P., "Introduction to Database Management Systems", McGraw Hill Education	2017
5.	Ramkrishnan, R. and Gehrke, J., "Database Management Systems", 3rd Ed., McGraw Hill Education	2014

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAB-103 **Course Title**: Numerical Methods

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Autumn **7. Subject Area:** BSC

8. Prerequisite: NIL

9. Objective: To introduce various numerical methods for solving linear and non-linear equations, interpolation, differentiation, integration, and differential equations.

10. Details of the Course

S. No.	Contents	Contact Hours
1.	**Error Analysis**: Exact and approximate numbers, Rounding of numbers, Significant digits, Correct digits, various types of errors encountered in computations, Propagation of errors.	3
2.	**Solutions of system of linear equations**: (i) Direct methods: Gauss elimination method without pivoting and with pivoting, LU decomposition method. (ii) Iterative methods: Jacobi and Gauss-Seidel methods.	8
3.	**Roots of non-linear equations:** Bisection method, Regula-Falsi method, Newton-Raphson method, direct iterative method with convergence criteria, Newton-Raphson method for solution of a pair of non-linear equations.	6
4.	**Eigenvalues and eigenvectors:** Dominant and smallest eigenvalues/eigenvectors by power method.	3
5.	**Interpolation:** Finite difference operator and their relationships, difference tables, Newton, Bessel and Stirling's interpolation formulae, Divided differences, Lagrange interpolation and Newton's divided difference interpolation.	6
6.	**Numerical differentiation:** First and second order derivatives by various interpolation formulae.	4
7.	**Numerical integration:** Trapezoidal, Simpsons 1/3rd and 3/8th rules with errors and their combinations, Gauss Legendre 2-points and 3-points formulae.	6
8.	**Numerical Solutions of first and second order ordinary differential equations:** Picard's method, Taylor's series method, Euler, Modified Euler, Runge-Kutta methods and Milne's method.	6
	Total	**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Gerald, C. F. and Wheatly, P. O., “Applied Numerical Analysis”, 7th Ed., Pearson Education India.	2007
2.	Jain, M. K., Iyengar, S. R. K. and Jain, R. K., “Numerical Methods for Scientific and Engineering Computation”, 8th Ed., New Age International Pvt. Ltd., New Delhi.	2022
3.	Conte, S. D. and DeBoor, C., "Elementary Numerical Analysis", McGraw- Hill Publisher.	1982
4.	Krishnamurthy, E. V. and Sen, S. K., "Applied Numerical Analysis", East-West Publication.	1998

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAB-104 **Course Title**: Mathematical Methods
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Autumn **7. Subject Area:** BSC
8. **Prerequisite:** NIL
9. **Objective:** To provide the knowledge of essential mathematical tools applied in solving ordinary and partial differential equations, and initial and boundary value problems.

10. **Details of the Course**

S. No.	Contents	Contact Hours
1.	**Ordinary Differential Equations:** Solution of linear differential equations with constant coefficients. Euler-Cauchy equations, Solution of second order differential equations by changing dependent and independent variables. Method of variation of parameters, Introduction to series solution method.	10
2.	**Partial Differential Equations:** Formation of first and second order partial differential equations. Solution of first order partial differential equations: Lagrange's equation, Four standard forms of non-linear first order equations.	6
3.	**Laplace Transform:** Laplace and inverse Laplace transform of some standard functions, Shifting theorems, Laplace transform of derivatives and integrals. Convolution theorem, Initial and final value theorem. Laplace transform of periodic functions, error functions, Heaviside unit step function and Dirac delta function. Applications of Laplace transform.	10
4.	**Z-Transform:** Z-transform and inverse Z-transform of elementary functions, Shifting theorems, Convolution theorem, Initial and final value theorem. Application of Z-transform to solve difference equations.	5
5.	**Fourier series:** Trigonometric Fourier series and its convergence. Fourier series of even and odd functions. Fourier half-range series. Parseval's identity. Complex form of Fourier series.	5
6.	**Fourier Transforms:** Fourier integrals, Fourier sine and cosine integrals. Fourier transform, Fourier sine and cosine transforms and their elementary properties. Convolution theorem. Application of Fourier transforms to BVP.	6
	Total	**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Kreyszig, E., "Advanced Engineering Mathematics", 10th Ed., Wiley India Pvt. Ltd	2015
2.	Jain, R. K. and Iyenger, S. R. K., "Advanced Engineering Mathematics", 5th Ed., Narosa Publishing House.	2017
4.	Hildebrand F. B., "Methods of Applied Mathematics", Dover Publications.	1992
6.	Sneddon, I. N., "Elements of Partial Differential Equation", Dover Publications.	2006
7.	Simmons, G. F. and Krantz, S. G., "Differential Equations:Theory, Technique and Practice", McGraw-Hill Education	2012

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-201 **Course Title**: Operations Research
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6**. Semester:** Autumn 7. **Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To acquaint the students with the basics of operations research.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1.	**Basics of LPP:** Different Types of OR Models, Convex Sets, Graphical Method, Simplex Method, Big –M Method, Two Phase Method, Revised Simplex Method.	10
2.	**Duality Theory:** Duality theory, Dual Simplex Method, Sensitivity Analysis, Parametric Linear Programming.	7
3.	**Integer Program:** Cutting Plane and, Branch and Bound Techniques for all Integer and Mixed Integer Linear Programming Problems.	5
4.	**Transportation Problems:** Balanced and unbalanced transportation problems-formulation, Dual problem, NWCM, LCEM and VAM, *u-v* method. Assignment Problems; Formulation, Hungarian method.	5
5.	**Game Theory:** Minimax (Maximin) criterion, Saddle point, Notion of dominance, Graphical and Linear Programming Methods for Rectangular Games.	4
6.	**Queuing Theory:** Steady-state solutions of Markovian Queuing Models: M/M/1, M/M/1 with limited waiting space, M/M/C, M/M/C with limited space, M/G/1.	6
7.	**Inventory Models:** Static, Dynamic and Probabilistic models.	5
	Total	**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Ravindran, A., Phillips, D.T. and Solberg, J.J., Operations Research: Principles and Practice, John Wiley and Sons, NY, Second Edition (Reprint).	2012
2.	Taha, H.A., Operations Research: An Introduction, Pearson Education Limited, NY, Tenth Edition.	2018
3.	Pant, J.C., Introduction to Optimization/ Operations Research, Jain Brothers, New Delhi, Seventh Edition.	2015
4.	Bazaraa, M.S., Jarvis, J. J. and Sherali, H. D., Linear Programming and Network Flows, John Wiley and Sons, Fourth Edition.	2013
5.	Sharma, J. K., Operations Research: Theory and Applications, Laxmi Publications Pvt. Ltd., Sixth Edition.	2016

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-202 **Course Title:** Complex Analysis

2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0

3. **Examination Duration (Hrs.)**: Theory: 3 **Practical:** 0

4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. **Credits:** 4 6. **Semester:** Spring 7. **Subject Area:** PCC

8. **Pre-requisite:** Basics of real analysis

9. **Objective:** To introduce the analytical aspects of functions of a complex variable.

10. **Details of the course:**

S. No.	Contents	Contact Hours
1.	**Introduction:** Algebra of Complex Numbers, inequalities. Stereographic Projection, Topological structure of Complex Plane, Simply connected and multiply connected domains.	**2**
2.	**Analytic Functions**: Functions of a complex variable, limits, continuity, uniform continuity, differentiability, analytic function, C-R equations, necessary and sufficient conditions, applications to the problems of potential flow, Harmonic functions, Harmonic conjugates, Milne's method. Sequences, Series, Uniform convergence, power series, elementary functions, exponential, trigonometric and hyperbolic functions and their identities in the complex plane, multiple valued functions, logarithmic functions and functions with complex exponent.	**10**
3.	**Complex Integration:** Rectifiable arcs, contours, complex line integration, Cauchy's theorem for simply and multiply connected domains, Cauchy's integral formula for the derivatives of an analytic function, Winding Numbers, Cauchy's estimate, Morera's theorem, Liouville's theorem, Fundamental theorem of Algebra. Maximum modulus principle, Schwarz Lemma, Taylor series – Laurent series – Zeros and poles of a function – Meromorphic function.	**8**
4.	**Residue Calculus:** The residue at a singularity, Residue theorem, the argument principle, Rouche's theorem, contour integration and its applications, improper integrals, evaluation of a real integral, improper integrals involving sines and cosines, definite integrals involving sines and cosines, integration through branch cut.	**6**
5.	**Conformal Mapping:** Definition, Bilinear transformation, Cross ratio, the mappings from disc to disc, disc to half plane and half plane to half plane, fixed points. Mapping of elementary transformations, the function $1/z$, z^2, $z^{1/2}$, $\exp z$, $\sin z$ and $z + 1/z$.	**7**

6.	**Applications:** Applications of conformal mapping to steady temperature, electrostatic potential, two dimensional fluid flow, stream function. Schwarz-Christoffel transformation and their applications, Poisson formula, Dirichlet problem in the unit disc, Dirichlet problem in the half plane - Neumann problem for the disc and the half plane.	**9**
	Total	**42**

11. **Suggested Books:**

S. No.	Name of Authors/ Books/Publishers	Year of Publication/Reprint
1.	L. V. Ahlfors, Complex Analysis, 3rd Edition, McGraw-Hill.	2017
2.	J. W. Churchill and R.V. Brown, Complex Analysis, McGraw-Hill.	2009
3.	J. B. Conway, Functions of one complex Variable, Vol. I, Springer Verlag, New York	1995
4.	T. W. Gamelin, Complex Analysis, Springer-Verlag	2001
5.	R. Greene and S.G. Krantz, Function Theory of One Complex Variable, 3rd Edition, GSM, Vol. 40, American Mathematical Society.	2006
6.	S. Lang, Complex Analysis, Springer – Verlag.	2003
7.	J. H. Mathews and R.W. Howell, Complex Analysis for Mathematics and Engineering, Narosa	2009
8.	E.B. Saff and A. D. Snider, Fundamentals of Complex Analysis, 3rd Edition, Pearson	2002

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAC-203 **Course Title**: Stochastic Calculus

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 0

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Autumn **7. Subject Area:** PCC

8. Pre-requisite: Basic Probability Theory.

9. Objective: To introduce the concepts of stochastic calculus.

10. Details of the Course:

S. No.	Contents	Contact hours
1.	**Basics of probability theory:** σ-field, probability measure, Borel-Cantelli lemma, random variable, Doob-Dynkin lemma, Radon-Nikodym theorem, convergence of random variables, law of large numbers, central limit theorem, Markov's inequality, Jensen's inequality.	06
2.	**Conditional expectation:** Conditioning on event, discrete random variable, arbitrary random variable and σ-field, properties.	04
3.	**Martingales in discrete and continuous time:** Filtration and adapted processes, stopping time and its properties, martingales, sub-martingales, super-martingales, martingale inequalities.	07
4.	**Brownian motion:** Definition and construction, sample path properties, reflection principle, Brownian motion with drift, Ornstein-Uhlenbeck process.	08
5.	**Itô's calculus:** Indistinguishability and modification, simple processes, Itô's integral for simple process and its properties, Itô's integral for square integrable adapted processes and its properties.	10
6.	**Stochastic differential equations:** Introduction to stochastic differential equations, notion of strong solution, Itô's lemma and Itô's product rule with their applications in solving stochastic differential equations and Itô's integrals.	07
	Total	**42**

11. Suggested Books:

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	P. Baldi, Stochastic Calculus: An Introduction Through Theory and Exercises, Springer	2017
2.	G. Kallianpur and P. Sundar, Stochastic Analysis and Diffusion Processes, Oxford University Press, Oxford.	2014
3.	R. Karandikar and B. Rao, Introduction to Stochastic Calculus, Springer.	2018
4.	I. Karatzas and S. E. Shreve, Brownian motion and stochastic calculus, 2nd Ed., Springer, New York.	1991
5.	X. Mao, Stochastic Differential Equations and Applications, 2nd Ed., Woodhead Publishing.	2007

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-291 **Course Title:** Technical Communication
2. **Contact Hours:** **L:** 2 **T:** 0 **P:** 0
3. **Examination Duration (Hrs):** Seminar mode
4. **Relative Weightage:** **CWS:** 100 **PRS:** 0 **MTE:** 0 **ETE:** 0 **PRE** 0
5. **Credits:** 2 **6. Semester:** Spring **7. Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To introduce the basics of writing and presenting the mathematical content.

10. Detail of the Course:

S.No.	Contents	Contact Hours
1.	**Technical terms:** Basic writing procedure in Mathematics, Difference between Lemma, Proposition, Theorem and Corollary. Various procedures of writing proof. Writing methods in Research Article, thesis, monograph and Book chapters.	4
2.	**Documentation:** Advantage of Latex Documentation system over WYSIWYG programs, Numbering, citation, references and Bibliography. Graphical illustration in Latex, pgf, tikz pictures and eps figures.	6
3.	**Presentation and Seminar:** Beamer presentation, Animation, Keynote and Microsoft power point presentation, hyperlink with external programs and mathematical software.	5
4.	**Software:** Exhibiting results using Mathematical software, Outline of Mathematica, Matlab and Maple Software. Numerical techniques, Graphical illustration, 3D plot, Contour Plot and Parametric plots.	7
5.	**Data simulation:** Statistical and Numerical data formulation and expression, Statistical observation through spreadsheets, Database management software, Software tools for Optimization technique.	6
Total		**28**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication/ Reprint
1.	Franco Vivaldi, Mathematical Writing, Springer	2014
2.	L. Lamport, A Document Preparation System (2^{nd} Edition), Pearson Education.	1994
3.	C. Gilderdale, Alison Kiddle, Ems Lord, Beckey Warren, Fran Watson, Approaches to learning and teaching Mathematics, Cambridge University Press, London	2017
4.	M. Abell and J. Braselton, MATHEMATICA by Example (Sixth Edition), Elsevier.	2021
5.	D. Etter, Introduction to MATLAB (Third Edition), Pearson.	2020
6.	Andy Field, Discovering statistics using R, SAGE publications	2000

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-301 **Course Title**: Basic Abstract Algebra
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Autumn 7. **Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To introduce the basic concepts of abstract algebra.
10. **Details of the Course:**

S. No.	Contents	Contact hours
2	Binary operations, groups, examples of groups: symmetric groups, dihedral groups, general linear groups; elementary properties of groups, subgroups, cosets, Lagrange's theorem, homomorphisms of groups, cyclic groups, normal subgroups, quotient groups, isomorphism theorems, correspondence theorem, automorphisms.	14
3	Group actions, Cayley's theorem, conjugacy classes, class equation, Sylow's theorems and their applications, external direct products of groups.	10
4	Definition and examples of rings, integral domains, division rings and fields, characteristic of a ring, subrings, ideals, quotient rings, homomorphism of rings, prime ideals and maximal ideals, polynomial rings, irreducibility of polynomials, factorizations of polynomials with integer coefficients.	10
5	Introduction to field extensions, algebraic extensions, ruler and compass constructions.	8
	Total	**42**

11. **Suggested Books:**

S. No.	Authors/Name of Books/Publisher	Year of Publication/Reprint
1	Gallian, J. A., "Contemporary Abstract Algebra", 9th Edition, Cengage Learning, India	2019
2	Herstein, I. N., "Topics in Algebra", 2nd Edition, John Wiley & Sons	2006
3	Fraileigh, J. B., "A First Course in Abstract Algebra", 7th Edition, Pearson Education, India	2013
4	Artin, M., "Algebra", 2nd Edition, Prentice Hall Inc.	2010

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-302 **Course Title**: Theory of Differential Equations
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Spring 7. **Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To give an introduction to the theory of ordinary and partial differential equations.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1	Existence, uniqueness and continuation of solutions of a differential equation and system of differential equations. (Grownwall inequality, fixed point methods).	**6**
2	Linear systems, properties of homogeneous and non-homogeneous systems, behavior of solutions of n^{th} order linear homogeneous equations.	**5**
3	Boundary value problems for second order differential equations, Green's function and its applications. Eigen value problems, self-adjoint form, Sturm-Liouvile problem and its applications.	**5**
4	Autonomous systems, phase plane and its phenomenon, critical points and stability for linear and nonlinear systems.	**5**
5	First Order PDE: Partial differential equations, Origins and classification of first order PDE, Initial value problem for quasi-linear first order equations: Existence and uniqueness of solution, non-existence and non-uniqueness of solutions. Surfaces orthogonal to a given system of surfaces. Nonlinear PDE of first order, Cauchy method of characteristics, Compatible systems of first order equations, Charpit's method, Solutions satisfying given conditions.	**6**
6	Second Order PDE: The origin of second order PDE. Equations with variable coefficients, Classification and canonical forms of second order equations in two variables. Classification of second order equations in 'n' variables. (Characteristic curves of second order equations in two variables.)	**3**
7	Elliptic Equations: Laplace equation in Cartesian, polar, spherical and cylindrical coordinates and its solution by Fourier series method, Poisson equation in 2D.Green's function for Laplace equation, method of images, eigenfunction methods for finding Green's function.	**6**
8	Hyperbolic Equations: One- and two-dimensional wave equation, solution by method of characteristics and Fourier series method. Parabolic Equations: Solution of homogeneous and non-homogeneous diffusion equation(1D). Duhamel's principle.	**6**
	Total	**42**

11. **Suggested Books:**

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Braun, M. "Differential Equations and Their Applications", 4th Ed., Springer.	2011
2	Deo S. G., Lakshmikanthan, V., and Raghvendra, V. "Text Book of Ordinary Differential Equations", 2nd Ed., Tata McGraw Hill.	2010
3	Simmons G. F. "Ordinary Differential Equations with Applications, Tata McGraw Hill.	2003
4	Sneddon, I. N. "Elements of Partial Differential Equations", McGrow-Hill Book Company.	1998
5	Conway J. B., A course in functional analysis, 2nd Ed., Springer.	2007
6	Laurence C. Evans., "Partial Differential Equations", American Mathematical Society.	2010
7	Tyn Myint-U., and Lokenath Debnath, Linear Partial Differential Equations for Scientists and Engineers, 4th Ed., Birkhauser.	2007
8	Strauss, W. A., Partial Differential Equations - An Introduction, John Wiley & Sons Inc; 2nd edition.	2008
9	Evans, G. , Blackledge J., an Yardley, P., "Analytic Methods for Partial Differential Equations" Springer.	2010

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAC-401 **Course Title**: Abstract Algebra

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Autumn **7. Subject Area:** PCC

8. Pre-requisite: Basic group theory and ring theory.

9. Objective: To introduce the fundamental concepts of groups, rings, modules and fields.

10. Details of the Course:

S. No.	Contents	Contact hours
1	**Groups:** Review of groups, subgroups and group homomorphism; group actions, class equation, Sylow's theorems, simplicity of alternating groups, direct product of groups, fundamental theorem of finite abelian groups.	14
2	**Rings:** Review of basic ring theory, ideals and their properties, Chinese Remainder Theorem, prime and maximal ideals, rings of fractions, factorization in integral domains, principal ideal domains, Euclidean domains, unique factorization domains, polynomial rings over unique factorization domains.	11
3	**Modules:** Basic definitions and examples, submodules and direct sums, quotient modules, homomorphism of modules and isomorphism theorems, cyclic modules, simple (irreducible) modules, free modules.	5
4	**Fields:** Field extensions, algebraic extensions, splitting fields and algebraic closures, normal and separable extensions, finite fields, automorphisms and fixed fields, Galois extensions, The Fundamental Theorem of Galois theory.	12
	Total	**42**

11.**Suggested Books:**

S. No.	Authors/Name of Books/Publisher	Year of Publication/Reprint
1	Dummit , D. S. and Foote, R. M., "Abstract Algebra", 3rd Edition, John Wiley & Sons	2003
2	Bhattacharya, P. B., Jain, S. K. and Nagpaul, S. R., "Basic Abstract Algebra", 2nd Edition, Cambridge University Press	1995
3	Artin, M., "Algebra", 2nd Edition, Prentice Hall Inc.	2010
4	Hungerford, T. W., "Algebra", Springer	1980
5	Herstein, I. N., "Topics in Algebra", 2nd Edition, John Wiley & Sons	2006
6	Jacobson, N., "Basic Algebra: Volume I", 2nd Edition, Dover Publications Inc.	1985

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAC-402 **Course Title**: Topology

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Spring **7. Subject Area:** PCC

8. Pre-requisite: Basic knowledge of real analysis.

9. Objective: To introduce the elementary properties of topological spaces and structures defined on them.

10. Details of the Course:

S.No.	Contents	Contact hours
1	**Review of set theory:** Finite, countable and uncountable sets, functions, relations, axiom of choice, Zorn's lemma.	4
2	**Topological spaces and continuous functions:** Open sets, closed sets, basis for a topology, sub basis, Hausdorff spaces, order topology, product topology, subspace topology, limit points, continuous functions, general product topology, metric spaces and their topology, quotient topology, gluing, and identification spaces.	14
3	**Connectedness and compactness:** Connected spaces, connected subspaces, path connected spaces, locally connected spaces, connected components, compact spaces, limit point compactness, local compactness, one-point compactification.	12
4	**Countability and separation axiom:** Countability axioms, separation axioms, regular and normal spaces, Urysohn's lemma, Urysohn metrization theorem, Tietze extension theorem, Tychonoff theorem.	12
Total		**42**

11.**Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Munkres, J.R., "Topology", 2nd edition, Prentice-Hall India.	2010
2.	Janich, K., "Topology", 8th edition, Springer-Verlag, UTM series.	2005
3.	Simmons, G.F., "Introduction to Topology & Modern Analysis", Krieger Publishing Company.	2003
4.	Armstrong, M. A., "Basic Topology", Springer-Verlag, UTM series.	1983
5.	Gamelin, T.W. and Greene, R.E., "Introduction to Topology", 2nd Ed., Dover Publications.	1999
6.	Min, Y., "Introduction to Topology: Theory & Applications", Higher Education Press.	2010

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAC-403 **Course Title**: Linear Algebra

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Autumn **7. Subject Area:** PCC

8. Pre-requisite: NIL

9. Objective: To introduce the fundamental concepts of linear algebra.

10. Details of the Course:

SL.NO	Contents	Contact hours
1.	**Review on vector spaces and basic of linear transformations:** matrix representation, Change of basis, algebra of linear transformations, inverse of a linear transformation, linear functionals and annihilators, dual spaces.	10
2.	**Canonical Forms:** Eigenvalues and eigenvectors, the characteristic polynomial, annihilating polynomials, the minimal polynomial, algebraic and geometric multiplicities, Cayley-Hamilton theorem, triangularization, diagonalization, invaria subspaces, invariant direct sums, primary decomposition theorem, Jordan canonica form, rational canonical form.	15
3.	**Inner Product Spaces:** Review on basic concept of inner product, orthogonal projections, positive definite, adjoint, self-adjoint, unitary and normal operators, spectral theorem for self-adjoint and normal operators on finite-dimensional vector spaces. Singular value decomposition	12
4.	**Bilinear forms**: symmetric and skew symmetric bilinear forms, real quadratic form Sylvester's law of inertia.	5
	Total	**42**

11.Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Hoffman, K. and Kunze, R.: "Linear Algebra", 2nd Ed., Pearson Education India.	2015
2.	Axler, S.: "Linear Algebra Done Right", 4th Ed. , Springer	2024
3.	Halmos, P.: "Finite Dimensional Vector Spaces", 2nd Ed., Dover Publication.	2017
4.	Lang, S.: "Linear Algebra", 3rd Ed., Springer.	2004
5.	Mirsky, L.: "An Introduction to Linear Algebra", Dover Publications, Inc., New York.	2003

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAC-404 **Course Title**: Functional Analysis

2. Contact Hours: L: 3 **T:** 1 **P:** 0

3. Examination Duration(Hrs.): Theory: 03 **Practical:** 00

4. Relative Weightage: CWS: 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 00

5. Credits: 04 **6. Semester:** Spring **7. Subject Area:** PCC

8. Pre-requisite: Basic knowledge of real analysis.

9. Objective: To introduce the concepts of Banach spaces, Hilbert spaces, linear operators and their properties.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	Normed linear spaces, convergence and absolute convergence of series in a normed linear space, Banach spaces.	7
2.	Inner product spaces, Cauchy-Schwarz inequality, Hilbert spaces, relation between Banach and Hilbert spaces.	2
3.	Convex sets, existence and uniqueness of a vector of minimum length, projection theorem. Orthogonal and orthonormal systems in Hilbert spaces with examples, Bessel's inequality, Parseval's identity, Characterization of complete orthonormal systems.	5
4.	Continuity of linear maps on normed linear spaces, four equivalent norms on the space of linear bounded operators, conjugate and dual spaces, The Riesz Representation Theorem, Compact operators, spectrum of bounded linear operators, spectral theorem on finite dimensional spaces.	8
5.	Adjoint operators, self adjoint operators, normal operators, unitary operators on Hilbert spaces and their properties, Isometric isomorphism of a Hilbert space onto itself under unitary operators, Projection operators on Banach spaces and Hilbert spaces. Orthogonal projections.	9
6.	The Closed Graph Theorem, The Uniform Boundedness Principle and its applications, The Hahn–Banach Extension and Separation theorems, Open Mapping Theorem and its applications.	11
	Total	**42**

11.**Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Bachman G. and Narici L., Functional Analysis, Dover Publications.	1998
2.	Conway J. B., A Course in Functional Analysis, 2nd Ed., Springer.	2007
3.	Debnath L. K. and Mikusinski P., Introduction to Hilbert Spaces with Applications, 3rd Ed., Academic Press.	2005
4.	Kreyszig E., Introductory Functional Analysis with Applications, Wiley.	2007
5.	Limaye B. V., Functional Analysis, Revised 3rd Ed., New Age International Publishers.	2014
6.	Nair, M. T., Functional Analysis: A First Course, PHI Pvt. Ltd.	2001
7.	Rudin W., Functional Analysis, 2nd Ed., McGraw Hill.	1991
8.	Simmons G. F., Introduction to Topology and Modern Analysis, McGraw Hill.	2017
9.	Yosida K., Functional Analysis, 6th Ed., Springer.	1995

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-405 **Course Title**: Real Analysis
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Autumn **7. Subject Area:** PCC
8. **Pre-requisite:** Elementary Real Analysis
9. **Objective:** To introduce some advanced topics in theory of real functions of several variables and metric spaces.

10. Details of the Course

S. No.	Contents	Contact hours
1	Linear transformations, Derivatives in several variable calculus, Partial and directional derivatives, The several variable calculus chain rule, Double derivatives and Clairaut's theorem, The inverse function theorem in several variable calculus, The implicit function theorem; Integration on n-dimensional Euclidean plane; Stokes' Theorem.	12
2.	Metric spaces: definition, properties and examples, Convergence of sequences, Open and closed subsets, Continuity, Cauchy sequences; completeness, Baire category theorem, contraction mapping theorem, connectedness, compactness, Heine-Borel theorem. Weierstrass approximation theorem.	12
3.	Review of the Reiman and the Riemann-Stieltjes Integrals, Fundamental theorem of calculus, first and second mean value theorems.	6
4.	Length of open sets and closed sets, Inner and outer measure, Measurable sets, Properties of measurable sets; Measurable functions. Lebesgue integration and Properties.	12
Total		**42**

11. Suggested Books:

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Rudin, W., Principles of Mathematical Analysis 3rd edition**,** McGraw-Hill Book Company.	2017
1.	Apostol, T.M., Mathematical Analysis, Narosa Publishing House.	2002
2.	Tao, T., Analysis I & I 4th edition, Texts and reading in Mathematics, Hindustan Book Agency	2022
3.	Garling, D. J. H, A Course in Mathematical Analysis: Volume 1, Foundations and Elementary Real Analysis, Cambridge.	2013
4.	Kumaresan, S., Topology of Metric Spaces , 2nd Edition, Narosa	2011

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAC-407 **Course Title**: Real and Functional Analysis
2. **Contact Hours: L:** 3 **T:** 1 **P:** 0
3. **Examination Duration(Hrs.): Theory:** 03 **Practical:** 00
4. **Relative Weightage: CWS:** 20-35 **PRS: 0 MTE:** 20-30 **ETE:** 40-50 **PRE:** 00
5. **Credits:** 04 **6. Semester:** Autumn **7. Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To provide the knowledge of Metric spaces, Banach spaces, Hilbert spaces, Linear operators and their properties.

10. Details of the Course:

S.No.	Contents	Contact hours
1	Metric spaces: Examples of metric and norms, topology of metric spaces, sequences and convergence, uniform convergence, open and closed sets, continuous maps, compactness, completeness and completions, contraction mapping theorem and applications. Weierstrass approximation theorem.	13
2	Normed spaces: Examples, including function spaces, Banach spaces and completeness (convergence and absolute convergence of series in a normed linear space), completion of normed spaces, finite and infinite dimensional normed spaces, quotient spaces of normed spaces, continuity and boundedness of linear functionals, dual spaces, continuity of linear operators and spaces of bounded linear operators, compactness in normed spaces, Weierstrass approximation theorem	12
3	Inner product spaces, Cauchy-Schwarz inequality, characterisation of inner product spaces, Hilbert spaces, relation between Banach and Hilbert spaces, orthogonality principle and orthogonal decomposition, Fourier series, Orthogonal and orthonormal systems in Hilbert spaces with examples, convergence of orthogonal series, Bessels's inequality, orthonormal bases, Parseval's identity, existence of orthonormal bases, isometry of all separate Hilbert spaces	10
4	Riesz representation theorem, Hahn-Banach theorem, reflexive spaces, the uniform boundedness principle and its applications.	7
	Total	**42**

11. Suggested Books:

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Rudin W., Principles of Mathematical Analysis, 3rd Ed. McGraw Hill Education.	2017
2	Tao T., Analysis II, 3rd Ed. Hindustan Book Agency.	2014
3	Lang S., Real and Functional Analysis, Springer-Verlag.	1993
4	Giles J. R., Introduction to the Analysis of Normed Linear Spaces, Cambridge University Press	2000
5	Conway J. B., A course in functional analysis, 2nd Ed., Springer.	2007
6	Kreyszig E., Introductory Functional Analysis with Applications, Wiley.	2007
7	Lindenstrauss J., Tzafriri L., Classical Banach spaces. I and II, Springer-Verlag	1977,1979
8	Rudin W., Functional Analysis, 2nd Ed., McGraw Hill.	1991

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-411 **Course Title**: Analytic Number Theory
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Prerequisite:** Basic knowledge of complex analysis and some background in number theory.
9. **Objective:** To give an introduction of basic concepts of analytic number theory.

10. **Details of the Course**

S.No.	Contents	Contact hours
1.	Review of complex analysis: Basic results, Fourier transform, Mellin transform. Review of Abel partial summation and the Euler-Maclaurin summation formula.	8
2.	Arithmetic functions, averages of arithmetical functions, distribution of primes, finite abelian groups and characters, Gauss sums, Dirichlet series and Euler products, Riemann Zeta function, Dirichlet L-functions, analytic proof of the prime number theorem, Dirichlet's Theorem on primes in arithmetic progression.	12
3.	Modular forms for the full modular group, Eisenstein series, cusp forms, structure of the ring of modular forms, Hecke operators and Euler product for modular forms.	12
4.	The L-function of a modular form, functional equations, modular forms and the sums of four squares.	10
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Apostol, T., "Introduction to Analytic Number Theory", Springer.	1998
2	Serre, J. P., "A Course in Arithmetic", Springer.	2012
3	Henryk, I. and Kowalski, E., "Analytic Number Theory", American Mathematical Society.	2004
4	Koblitz, N., "Introduction to Elliptic Curves and Modular Forms", Springer.	1993
5	Stein, W., "Modular Forms: A Computational Approach", American Mathematical Society.	2007

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-412 **Course Title**: Combinatorial Mathematics
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To Introduce combinatorial techniques to analyse and solve mathematical problems.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1.	Basic counting principles, permutations and combinations (with and without repetitions), binomial theorem, multinomial theorem.	3
2.	Pigeonhole principle, principle of inclusion and exclusion, derangements, inversion formulae.	4
3.	Generating functions, exponential generating functions, recurrence relations, their applications.	6
4.	Catalan numbers, difference sequences, Stirling numbers, integer partitions, systems of distinct representatives, Hall's condition.	7
5.	Polya counting, Burnside's lemma, cyclic index of a permutation group, Polya's theorems and their immediate applications.	8
6.	Latin squares, balanced incomplete block designs (BIBDs), symmetric designs, Steiner triple systems, resolvable BIBDs. Hadamard matrices and designs, *t* designs.	14
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Brualdi, R. A., "Introductory Combinatorics", 5th Ed., Pearson Education Inc,	2019
2.	Wallis, W. D. and George, J. C., "Introduction to Combinatorics", CRC Press.	2011
3.	Lint, J. H. van and Wilson, R. M., "A Course in Combinatorics", 2nd Ed., Cambridge University Press.	2001
4.	Cameron, P. J., "Combinatorics: Topics, Techniques, Algorithms", Cambridge University Press.	1995
5.	West, D. B., "Combinatorial Mathematics", Cambridge University Press.	2020
6.	Stinson, D. R., "Combinatorial Designs: Constructions and Analysis", Springer.	2004

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-413 **Course Title**: Credit Risk Modeling

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: Basic concepts of probability and statistics.

9. Objective: To introduce basic notions and fundamental models for credit risk.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	Credit risk, counterparty credit risk, credit risks of corporate bond, vulnerable claims, credit derivatives and quantitative models of credit risk, structural or firm value approach and reduced-form approach.	5
2.	Structural model for corporate debt: defaultable claim, risk neutral valuation formula, self-financing trading strategies, martingale measure; PDE approach, PDE for the value function, corporate zero-coupon bonds, corporate coupon bond; Merton's approach to corporate debt, Merton's model with deterministic and stochastic interest rates.	8
3.	First Passage Time Models: properties of first passage times; Black and Cox model, corporate zero-coupon bond, corporate coupon bond, corporate consol bond; models with stochastic interest rates	10
4.	Hazard Processes: hazard function of random time, conditional expectations w.r.t. natural filtrations, martingales associated with a continuous hazard function, martingale representation theorem, change of a probability measure, martingale characterization of the hazard function, compensator of a random time; hazard process Γ, martingale representation theorem, change of probability measure; martingale hazard process Λ, relationship between hazard processes Γ and Λ, martingale representation theorem.	11
5.	Reduced-form approach (intensity-based approach): Defaultable claim, valuation via hazard process, valuation via martingale approach, hedging of defaultable claims	8
	Total	**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Bielecki, T. R. and Rutkowski, M., "Credit Risk: Modeling, Valuation and Hedging", Springer.	2004
2.	Lando, D., "Credit Risk Modeling: Theory and Applications", Princeton University Press.	2009
3.	Ammann, M., "Credit Risk Valuation: Methods, Models, and Applications", 2nd Ed., Springer.	2001
4.	Bluhm, C., Wagner C. and Overbeck L., "An Introduction to Credit Risk Modeling", 2nd Ed., CRC Press.	2010

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-414 **Course Title**: Differential Geometry

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: Basic knowledge of differential calculus.

9. Objective: To introduce the geometric concepts of curves and surfaces.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	**Curves:** Parametrized curves in Euclidean 3-plane, length of curves, regular curves, parametrization by arc length, Frenet-Serret frame and formula, curvatures, invariance under isometry and reparametrizations, rotation number of curve, osculating circle, Hopf's Umlaufsatz theorem.	8
2.	**Surfaces:** Topological and smooth surfaces, surfaces with boundary, proper, closed, and open surfaces, implicitly defined surfaces, local parametrizations, global parametrizations. Level sets, examples of surfaces in R^3. Tangent spaces at a point.	7
3.	**Vector fields**: Smooth vector fields on an open subset of R^3, gradient vector field, vector field along a smooth curve and surfaces, integral curve of a vector field. Existence theorem of an integral curve and surface through a point, maximal integral curve. Existence of a normal vector of a connected surface. Orientation, Gauss map.	8
4.	**Geodesics:** The notion of geodesic on a surface, existence and uniqueness of geodesic on a surface through a point and with a given velocity vector field thereof. Covariant derivative of a vector field, parallel vector field along a curve. Existence and uniqueness of a parallel vector field. The Weingarten map of a surface at a point, and its self-adjoint property.	9
5.	**Curvature:** Normal curvature of a surface at a point in a given direction. Principal curvatures, first and second fundamental forms, Gauss curvature and mean curvature. Surface area and volume. Surfaces with boundary, local and global Stokes theorem. Gauss-Bonnet theorem. Triangles and hinges, local comparisons, non-positive curvature, non-negative curvature, Alexandrov's lemma.	10
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Toponogov, V., "Differential Geometry of Curves and Surfaces: A concise Guide", Birkhauser.	2006
2.	Monteil, S. and Ros, A., "Curves and Surfaces", 2nd Ed., American Mathematical Society.	2009
3.	Carmo, P. do M., "Differential Geometry of Curves and Surfaces", 2nd Ed., Dover Publications.	2016
4.	Pressley, A. N., "Elementary Differential Geometry", 2nd Ed., Springer	2009
5.	Lang, S., Fundamentals of Differential Geometry, Springer.	1999

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-415 **Course Title**: Design and Analysis of Algorithms

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PCC

8. Pre-requisite: Nil

9. Objective: To introduce various approaches for designing algorithms and how to analyze their running time-complexity.

10. Details of the Course:

S. No.	Contents	Contact Hours
1.	**Basics of Algorithms:** Notion of algorithm, pseudo code conventions, Performance analysis,Time and space complexities, loop-invariant method for correctness, Asymptotic notations: Big-oh, omega and theta notations, Average and worst case analysis, Probabilistic analysis, Amortized analysis.	6
2.	**Divide and Conquer Algorithms:** Recurrence relations, Divide and conquer relations, Solving of recurrences by iteration method and substitution method, Master theorem, Applications of Divide and Conquer designing method: Binary search algorithm, Merger sort, Quick sort, Karatsuba algorithm for fast multiplication, Strassen's matrix multiplication, and fast Fourier transform	8
3.	**Greedy Algorithms:** Huffman coding algorithm, Data structures of disjoint sets, Complexity analysis of Depth first search, Breadth first search, Prim's algorithm, Kruskal's algorithm, Dijkstra's and Bellman-Ford algorithms, Knapsack problem, Warshall's and Floyd's algorithms.	10
4.	**Dynamic Programming based Algorithms:** Principle of optimality, Optimal binary search trees, Matrix-chain multiplication, Longest common subsequence.	6
5.	**String Matching:** The naive string matching algorithm, The Rabin-Karp Algorithm, The Knuth-Morris-Pratt Algorithm, Applications	4
6.	**Computational Complexity Theory:** P, NP and NP-completeness, Reducibility, Polynomial time verification, Some examples of NP-complete problems along with reducibility.	8
	Total	42

11. Suggested References/Books:

S.No.	Name of Authors / Books / Publishers	Year of Publication/ Reprint
1.	Cormen T. H., Leiserson C. E., Rivest R. L. and Stein C., "Introduction to Algorithms", Prentice Hall India, Third Edition	2009
2.	Aho A. V., Hopcroft J. E. and Ullman J. D., "The Design and Analysis of Computer Algorithms", Pearson Education, First Edition	2002
3.	Horowitz E., Sahni S. and Rajasekaran S., "Fundamentals of Computer Algorithms", Orient Longman, Second Edition	2008
4.	Kleinberg J. and Tardos E., "Algorithm Design", Pearson Education India, First Edition	2013
5.	Levitin A., "Introduction to the Design and Analysis of Algorithm", Pearson Education, Second Edition	2014

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-416 **Course Title**: Graph Theory

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: Nil

9. Objective: To provide a basic knowledge of graph theory.

10. Details of the Course

S. No.	Contents	Contact hours
1	Introduction to Graphs: Definition of a graph, graphs as models, finite and infinite graphs, matrix representation of graphs, incidence and adjacency matrices of graphs, graph isomorphisms, types of graphs, subgraphs, walks, trails, paths, cycles, connectivity, components of a graph, bipartite graphs, vertex degrees and counting, graphic sequences.	10
2	Trees and Distance: Definition and properties of trees, rooted and binary trees, spanning trees, counting trees and spanning trees, weighted graphs, minimum spanning tree, Kruskal's Algorithm, Prim's algorithm, Dijkstra's algorithm, shortest paths.	7
3	Euler and Hamiltonian graphs: Euler tours, Fleury's algorithm, Hamiltonian cycles, Dirac's theorem, closure of a graph, Bondy and Chvatal theorem, the travelling salesman problem, algorithm to find smaller Hamiltonian cycle in complete graphs.	7
4	Planar Graphs: Planar graphs, detection of planarity, Euler's formula for planar graphs, the platonic bodies, Kuratowski's theorem.	5
5	Coloring of Graphs: Vertex coloring and upper bounds, chromatic number, Greedy algorithm, Brook's theorem, counting proper colorings, chromatic polynomial.	5
6	Directed Graphs: Types of digraphs, directed paths and connectedness, Euler digraphs, de Brujin sequences, tournaments.	4
7	Ramsey Theory: Introduction to Ramsey theory, Ramsey numbers, Ramsey theorem.	4
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	West, D. B., "Introduction to Graph Theory", 2nd Ed., Pearson Education India.	2015
2	Clark, J. and Holton, D. A., "A First Look at Graph Theory", World Scientific Publishing Co Pte Ltd.	2020
3	Deo, N., "Graph Theory with Applications to Engineering and Computer Science", Dover Publications.	2016
4	Bondy, J. A. and Murty, U. S. R., "Graph Theory", Springer	2011
5	Chartrand, G. and Zhang, P., "Introduction to Graph Theory", Tata McGraw Hill.	2007
6	Wilson, R. J., "Introduction to Graph Theory", Pearson Education.	2015

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL –417 **Course Title:** Mathematical Image Processing
2. **Contact Hours:** **L:** 3 **T:**1 **P:**0
3. **Examination Duration (Hrs):** 3 **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 4 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective**: To introduce the fundamentals of image processing and various mathematical techniques used in image analysis.
10. **Details of the Course**

S. No.	Contents	Contact hours
1.	**Spatial domain filtering:** A simple image formation model, sampling and quantization, connectivity and adjacency relationships between pixels, contrast enhancement techniques, histogram equalization and matching, smoothing and sharpening filtering in spatial domain.	6
2.	**Frequency domain filtering:** Fourier Series and Fourier transform, discrete and fast Fourier transform, sampling theorem, aliasing, filtering in frequency domain, low-pass and high-pass filters, band-reject and band-pass filters, notch filters.	6
3.	**Image restoration:** Introduction to various noise models, restoration in presence of noise only, periodic noise reduction, linear and position invariant degradation, Wiener and Least-Square filters, partial differential equations-based image restoration algorithms, calculus of variations based image restoration.	10
4.	**Wavelets and multiresolution processing:** Image pyramids, sub-band coding, multiresolution expansions, the Haar transform, wavelet transform in one and two dimensions, discrete wavelet transform for image compression and denoising.	6
5.	**Mathematical morphology:** Erosion and dilation, opening and closing, the Hit-or-Miss transformation, various morphological algorithms for binary and grayscale images, some applications in segmentation and object recognition.	6
6.	**Image analysis:** Edge detection, interest points and corners, local image features, feature matching and Hough transform, model fitting and RANSAC, scale invariant feature matching, image recognition using ML/DL models.	8
	Total	**42**

11. **Suggested Books:**

S. No.	Title/Authors/Publishers	Year of Publication/ Reprint
1.	Gonzalez, R. C. and Woods, R. E., "Digital Image Processing", 4th Ed., Pearson.	2017
2.	Jain, A. K., "Fundamentals of Digital Image Processing", Pearson Education India.	2015
3.	Aubert, G. and Kornprobst, P., "Mathematical Problems in Image Processing: Partial Differential Equations and the Calculus of Variations", 2nd Ed., Springer.	2006
4.	Burger, W. and Burge, M. J., "Principles of Digital Image Processing: Core Algorithms", Springer.	2009
5.	Scherzer, O., "Handbook of Mathematical Methods in Imaging", Springer	2011

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-418 **Course Title**: Mathematical Modeling and Simulation

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PCC

8. Pre-requisite: Nil

9. Objective: To develop skills of mathematical modeling.

10. Details of the Course:

S. No.	Contents	Contact Hours
1.	**Introduction:** History of mathematical modeling, Importance of mathematical modeling, Latest developments in mathematical modeling, Limitations of mathematical modeling, Construction of mathematical models, Mathematical models and functions, Units and Dimension, Dimensional analysis, Scaling.	9
2.	**Continuous models:** Introduction to continuous models, Steady state solutions, Linear stability analysis, Phase plane diagrams of linear systems, Carbon Dating, Drug Distribution , Growth and decay of current in a L-R Circuit, Mechanical oscillations, Dynamics of rowing model, Arms race models, Combat Models, Epidemic Models (SI, SIS, SIR, SIRS), Malthusian, Logistic and Gomperzian growth models, Predator-prey models, Competition models.	12
3.	**Discrete models:** Introduction to difference equations, Steady state solution and linear stability analysis. Introduction to discrete models, Growth and decay models, Newton's law of cooling, Bank account and mortgage model, Drug delivery model, Harrod model of economic growth, Lake pollution model, Linear predator-prey models, Density dependent growth models (including harvesting).	7
4.	**Numerical solutions:** Numerical solutions of the discrete and continuous models and its graphical representation, using mathematical software tools.	7
5.	**Computer simulations:** Modeling and simulation concepts, Discrete event simulation, Continuous simulation, Data fitting methods using mathematical software tools, Parameter estimation for discrete and continuous models, Verification and validation of simulation models.	7
	Total	**42**

11. Suggested References/Books:

S. No.	Name of Books / Authors/ Publishers	Year of Publication/ Reprint
1.	Albright, B. and Fox, W.P., "Mathematical Modeling with Excel", CRC Press, Taylor and Francis group.	2019
2.	Marotto, F. R., "Introduction to Mathematical Modeling using Discrete Dynamical Systems", Thomson Brooks/Cole.	2006
3.	Barnes, B. and Fulford, G. R., "Mathematical Modelling with Case Studies", CRC Press, Taylor and Francis Group.	2009
4.	Edsberg, L., "Introduction to Computation and Modeling for Differential Equations", John Wiley and Sons.	2008
5.	Murray, J. D., Mathematical Biology: An Introduction, Springer-Verlag New York.	2002
6.	Mityushev, V., Nawalaniec, W. and Rylko, N., "Introduction to Mathematical Modeling and Computer Simulations", CRC Press, Taylor and Francis group.	2018

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-419 **Course Title**: Number Theory
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To introduce the basic concepts of number theory.
10. **Details of the Course:**

S. No.	Contents	Contact hours
1	Divisibility, Euclidean algorithm, Linear Diophantine equations, Prime numbers, Fundamental theorem of arithmetic, Prime number theorem (statement only).	7
2	Congruences, solutions of linear congruences, Chinese Remainder Theorem, Euler's totient function, Euler-Fermat theorem, Wilson's theorem, non-linear congruences, Hensel's lemma, primitive roots and power residues	12
3	Quadratic residues, quadratic reciprocity, the Jacobi symbols.	7
4	The greatest integer function, Arithmetic functions, Mobius function and Mobius inversion formula.	6
5	Finite continued fractions, infinite continued fractions, approximation to irrational numbers.	6
6	Introduction to cryptography, public key cryptography, RSA.	4
Total		**42**

11. **Suggested Books:**

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Niven I., Zuckerman H. S., and Montgomery H. L., "An Introduction to the Theory of Numbers", John Wiley & Sons (5th Ed.)	1991
2	Burton D., M., "Elementary Number Theory", McGraw Hill (7th Ed.)	2012
3	Rosen, K. H., " Elementary Number Theory and its Applications", Addison-Wesley Publishing Company (6th Ed.).	2011
4	Koblitz N., A Course in Number Theory and Cryptography, Springer (2nd Ed.)	1994
5	Hardy, G. H. and Wright, E. M, "An Introduction to the Theory of Numbers ", Oxford University Press (6th Ed.)	2008

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-420 **Course Title**: Statistical Machine Learning

2. Contact Hours: **L:** 3 **T:** 0 **P:** 2

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 10-25 **PRS:** 25 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PCC

8. Pre-requisite: Basic knowledge of linear algebra, probability and statistics.

9. Objective: To provide knowledge about theoretical foundations and computational aspects of statistical machine learning.

10.Details of the Course:

S. No.	Contents	Contact hours
1.	**Theory of Statistical Learning:** Basics of learning theory, function estimation, understanding data, assessing model accuracy, principles of Maximum likelihood, Bayes and minimax, parametric versus nonparametric methods, Bayesian versus Classical approaches in machine learning.	6
2.	**Supervised Learning**: Linear regression (simple and multiple), confidence interval and hypothesis testing of regression coefficients, model accuracy, qualitative predictors, extension of linear models.	6
3.	**Classification Algorithms:** logistic regression, Bayesian approach for classification, linear discriminant analysis, quadratic discriminant analysis, support-vector machines, K-nearest neighbor (KNN) algorithm.	6
4.	**Resampling methods and Regularization:** Over and under sampling approaches, cross validation, linear model selection, subset selection, shrinkage methods, Ridge and Lasso methods, dimension reduction methods, Principal Component Regression (PCR) and partial least square.	7
5.	**Nonlinear models:** Polynomial regression and regression splines, generalized additive models, Tree-based methods, Random forests, Boosting algorithms.	6
6.	**Unsupervised Learning:** Principal Component Analysis, Clustering methods; k-means and hierarchical, Gaussian mixture model and expectation maximization algorithm, density estimation.	6
7.	**Deep Learning and Neural Networks:** Perceptron Model; Multilayer perceptron; Gradient Descent and Backpropagation algorithm; Convolutional Neural Networks.	5
Total		**42**

11. List of Practical:

S. No.	
1.	Hands-on with Numpy/R
2.	Hands-on with Scikit-Learn/R
3	Linear regression
4.	Logistic regression for classification
5.	Discriminant Analysis
6.	Data Resampling methods
7.	Model Selection methods
8.	Dimension reduction Approaches
9.	Nonlinear models-I
10.	Nonlinear models-II
11.	Unsupervised Learning-I
12.	Unsupervised Learning-II
13.	Neural Networks
14.	Convolutional Neural Networks

12. Suggested Books:

S. No.	**Authors/Name of Books/Publisher**	**Year of Publication/Reprint**
1.	Christopher Bishop, Pattern Recognition and Machine Learning, Springer, Information Science and Statistics Series	2006
2.	Gareth James, Daniela Witten, Trevor Hastie and Robert Tibshirani, An Introduction to Statistical Learning with Applications in R, Springer Texts in Statistics, Springer, New York	2017
3.	Trevor Hastie, Robert Tibshirani, Jerome Friedman, The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Springer Texts in Statistics, Springer Verlag, New York, Second Edition	2017
4.	Rodrigo Fernandes de Mello, Moacir Antonelli Ponti, Machine Learning: A Practical Approach on the Statistical Learning Theory, Springer Nature	2018
5.	Richard Golden, Statistical Machine Learning: A Unified Framework, Chapman & Hall/CRC Texts in Statistical Science, First Edition	2020

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-511 **Course Title**: Abstract Harmonic Analysis

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: Basic knowledge of Topology and Functional Analysis.

9. Objective: To introduce the concepts of Harmonic analysis and representation theory.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	**Banach Algebra and Spectral Theory:** Basic concepts, Gelfand theory, nonunital Banach algebras, spectral theorem, theory of representation.	9
2.	**Locally Compact Groups:** Topological groups, Haar measure, modular functions, convolutions, homogenous spaces.	8
3.	**Locally Compact Abelian Groups:** Dual group, Pontragin Duality Theorem, closed ideals, spectral synthesis, Bohr compactification, Peter-Weyl Theorem, Fourier Analysis.	8
4.	**Basic Representation Theory:** Unitary representation, representation of a Group and its group algebra, functions of positive type, induced representations, Frobenius Reciprocity Theorem, pseudo measures, imprimitivity.	9
5.	**Structures in Representation Theory:** Group C* algebra, structure of dual space, tensor products, direct integral decomposition, Planchelar Theorem.	8
Total		**42**

11.Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Folland, G. B., "A Course in Abstract Harmonic Analysis", CRC Press.	1995
2.	Fell, J. M. G. and Doran, R. S., "Representation of * - Algebras, Locally Compact Groups and Banach Algebra Bundles", Academic Press.	1988
3.	Hewitt, E. and Ross, K. A., "Abstract Harmonic Analysis", Springer.	1993
4.	Loomis, L. H., "Introduction to Abstract Harmonic Analysis", Dover Publications.	2011
5.	Rudin, W., "Fourier Analysis on Groups", Wiley-Interscience.	1990

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-513 **Course Title**: Advanced Matrix Theory
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6**. Semester:** Both **7. Subject Area:** PEC
8. **Prerequisite:** Basics of linear algebra.
9. **Objective:** To introduce the fundamental concepts of matrix theory.
10. **Details of the Course**

S.No.	Contents	Contact hours
1.	Brief review of inner product spaces and linear transformations, block matrices, determinant and inverse of block matrices, the continuity argument, commuting matrices, factorization of matrices, Schur decompositions, spectral decomposition, singular value decomposition.	7
2	Special types of matrices and their properties: idempotent, nilpotent and involutory matrices, tridiagonal matrices, circulant matrices, Vandermonde and Hadamard matrices, permutation and doubly stochastic matrices, real orthogonal matrices, contraction and unitary matrices, unitary similarity of real matrices, positive definite matrices, matrix inequalities.	10
3	Majorization and its applications in combinatorial analysis, weakly submajorized and supermajorized, relation between majorization and doubly stochastic matrices, Birkhoff's theorems, convex and monotone functions, Schur's theorem.	10
4	The minimax principle for eigenvalues, Cauchy's interlacing theorem, Poincare inequality, Weyl's inequalities, Weyl's motonocity and perturbation theorems, Lidskkii's theorems, minimax principle for singular values.	9
5	Matrix norms, Frobenius norm, spectral norm, maximum column/row sum matrix norm, unitarily invariant norms, weakly unitarily invariant norms, matrix/operator monotone, convexity and their characterizations.	6
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Zhang, F., "Matrix Theory: Basic Results and Techniques", 2nd Ed., Springer.	2011
2	Bhatia, R., "Matrix Analysis", Graduate Texts in Mathematics, Vol 169, Springer.	2011
3	Bhatia, R., "Positive Definite Matrices", Princeton University Press.	2009
4	Horn, R. A. and Johnson, C. R., "Matrix Analysis", 2nd Ed., Cambridge University Press.	2012
5	Horn, R. A. and Johnson, C. R., "Topics in Matrix Analysis", Cambridge University Press.	2011

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-514 **Course Title**: Advanced Numerical Analysis
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Basic knowledge of functional analysis and partial differential equations
9. **Objective:** To give knowledge about the mixed finite element method for Stokes and Navier-Stokes equations
10. **Details of the Course:**

S.No.	Contents	Contact hours
1	Introduction to finite element methods (FEM) for Poisson problems.	5
2	The Stokes equations, weak formulation, well-posedness, mixed FEM for Stokes equations, a priori error bounds, a posteriori error bounds, matrix properties, solution of discrete Stokes problems.	10
3	The convection-diffusion equation, weak formulation, FEM for convection-diffusion problems, a priori error bounds, a posteriori error bounds, solution of discrete convection-diffusion problems.	10
4	The Navier-Stokes equations, weak formulation and linearization, well-posedness, mixed FEM for Navier-Stokes equations, a priori error bounds, a posteriori error bounds, matrix properties, solution of discrete Navier- Stokes problems.	10
5	Solution of unsteady Navier-Stokes equations, weak formulation and implicit time stepping, well-posedness, fast iterative solver for the linearized systems.	7
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Elman, H., Silvester, D. and Wathen, A., "Finite Elements and Fast Iterative Solvers with Applications in Incompressible Fluid Dynamics", Oxford Science Publications	2014
2	Boffi, D., Brezzi, F. and Fortin, M., "Mixed Finite Element Methods and Application", Springer	2015
3	Getica, G. N., "A Simple Introduction to the Mixed Finite Element Method: Theory and Applications", Springer	2014
4	Brezzi, F. and Fortin, M., "Mixed and Hybrid Finite Element Methods", Springer	1991

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-515 **Course Title**: Advanced Operations Research

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: Basic concepts of linear programming.

9. Objective: To acquaint the students with the theory and solution techniques related with nonlinear optimization problems.

10. Details of the Course:

S. No.	Contents	Contact hours
1.	Nonlinear programming, Convex functions and their properties, differentiable convex functions, sub-gradients of convex functions, generalization of convex functions and their properties.	8
2.	The Fritz John and the Karush-Kuhn-Tucker (KKT) optimality conditions, problems with equality and inequality constraints, necessary and sufficient optimality conditions for constrained optimization problems, cone of tangents, polar cone, constraint qualifications.	9
3.	Convex quadratic programming problems, KKT conditions for quadratic programming problems, Wolfe's and Beale's methods, linear fractional programming problems, Charnes and Cooper method, separable programming, geometric programming with positive coefficients, generalized method for positive and negative coefficients.	12
4.	Dynamic programming, discrete and continuous dynamic programming, Bellman's optimality principle.	5
5.	Introduction to multiobjective programming problems, solution concepts, efficient, weak efficient and properly efficient solutions, goal programming problems, graphical method, weighted sum approach, partition approach.	8
Total		**42**

11. Suggested Books:

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Bazaraa, M. S., Jarvis, J. J. and Sherali, H. D., "Non-linear Programming: Theory and Algorithms", 4th Ed., John Wiley and Sons.	2013
2.	Pant, J. C., "Introduction to Optimization/ Operations Research", 7th Ed., Jain Brothers, New Delhi.	2015
3.	Ravindran, A., Phillips, D. T. and Solberg, J. J., "Operations Research: Principles and Practice", 2nd Ed., John Wiley and Sons, NY.	2012
4.	Taha, H.A., "Operations Research: An Introduction", 11th Ed., Pearson Education Limited, NY.	2021
5.	Mangasarian, O. L., Nonlinear Programming, McGraw Hill, New York	1969

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1.Subject Code: MAL-516 **Course Title**: Advanced Partial Differential Equations

2.Contact Hours: **L:** 3 **T:** 1 **P:** 0

3.Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4.Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5.Credits: 04 6. **Semester:** Both 7. **Subject Area:** PEC

8.Pre-requisite: Basic concepts of partial differential equations.

9.Objective: To introduce the theory of partial differential equations in higher dimensions and the concepts of distribution theory.

10. Details of the Course:

S.No.	Contents	Contact hours
1	Four important linear partial differential equations (PDE) over R^n: transport equation, Laplace equation, heat equation, wave equation; homogeneous and nonhomogeneous problem, fundamental solutions, mean value formulas, Green's function, energy methods.	12
2	Nonlinear first-order PDE, complete integrals, envelopes, characteristics, conservations laws.	10
3	Separation of variables, similarity solutions, transform methods, converting nonlinear PDE into linear PDE, asymptotics, power series.	10
4	Distribution theory, test functions, distributions, operations on distributions, convolution, fundamental solutions, Fourier transform, Schwartz space, tempered distributions.	10
Total		**42**

11.Suggested Books:

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Evans, L. C., "Partial Differential Equations," 2nd Ed., AMS.	2010
2.	Kesavan, S. "Topics in Functional Analysis and Applications", 3rd Ed., New Age International Publishers.	2019
3	Brezis, H. "Functional Analysis, Sobolev Spaces and Partial Differential Equations", Springer.	2010
4.	Mitrovic, D. and Zubrinic, D., "Fundamentals of Applied Functional Analysis", Chapman and Hall/CRC.	1997
5.	Robinson, J. C., "Infinite-Dimensional Dynamical Systems", Cambridge University Press.	2001

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-517 **Course Title**: Algebraic Number Theory
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Prerequisite:** Basic knowledge of abstract algebra.
9. **Objective:** To give an introduction to the basic concepts of algebraic number theory.

10. **Details of the Course**

S.No.	Contents	Contact hours
1	Review of field theory, Gaussian integers, integrality, integral closure, ring of integers, trace, norm, integral basis, discriminant, ideals.	10
2	Dedekind domains, unique factorisation of ideals, action of the Galois group on prime ideals, fractional ideals, decomposition group, inertia group.	10
3	Lattices, Minkowski theory, norm of an ideal, ideal class group, the class number and finiteness, Dirichlet's unit theorem.	10
4	Valuations and completions of number fields, Ostrowski`s theorem, Hensel`s lemma, unramified, totally ramified and tamely ramified extensions of p-adic fields.	12
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Janusz, G. J., "Algebraic Number Fields", 2nd Ed., American Mathematical Society.	1996
2	Neukirch, J., "Algebraic Number Theory", Springer.	1999
3	Marcus, D. A., "Number Fields", 2nd Ed., Springer	2018
4	Milne, J. S., Algebraic Number Theory, online published notes at: https://www.jmilne.org/math/CourseNotes/ant.html	2022

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-518 **Course Title**: Algebraic Topology

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: Basic knowledge of algebra and point-set topology.

9. Objective: To introduce basic concepts of algebraic topology.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	Space of maps, homotopy between maps, homotopy equivalences, contractiblity, deformation retracts, homotopy extension property, fundamental groups, necessary introduction to free product of groups, Van Kampen's theorem, examples.	8
2.	Covering spaces, lifting properties, universal cover, classification of covering spaces, Deck transformations, properly discontinuous action, covering manifolds, examples.	10
3.	Categories and functors, (co)limits of directed systems and their universal property. simplicial sets and their geometric realizations, combinatorial models of topological spaces.	7
4.	Singular homology groups, axiomatic properties, Mayer-Vietoris sequence, homology with coefficients, statement of universal coefficient theorem for homology, simple computation of homology groups. Degree theory, Euler characteristics, Lefchetz fixed point theory and its applications.	10
5.	CW-complexes and Cellular homology, simplicial complex and simplicial homology as a special case of cellular homology, relationship between fundamental group and first homology group.	7
	Total	**42**

11.Suggested Books:

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Hatcher, A., "Algebraic Topology", Cambridge University Press.	2002
2.	May, J. P. "A Concise Course in Algebraic Topology", Chicago Lectures in Mathematics Series.	1999
3.	Munkres, J. R., "Elements of Algebraic Topology", CRC Press.	1996
4.	Bredon, G., "Topology and Geometry", GTM series, Springer	1997

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-519 **Course Title**: Approximation Theory

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Prerequisite: Basic knowledge of functional analysis.

9. Objective: To introduce the concept of best approximation in normed spaces and various tools of approximation by algebraic and trigonometric polynomials.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	Review of the concepts of convexity of functions and sets. Concept of best approximation in a normed linear space, existence and uniqueness of the best approximation, approximation operators and their properties, Lebesgue constant.	10
2	Bernstein polynomials, Weierstrass theorem, Korovkin theorem, algebraic polynomials of the best approximation, Chebyshev theorems, Chebyshev polynomials.	12
3	Modulus of continuity, Lipschitz class, integral modulus of continuity and their properties, trigonometric polynomials of best approximation, Bernstein's inequality, Jackson's theorems and their converse theorems, approximation by means of Fourier series.	12
4	Positive linear operators, monotone operators, simultaneous approximation, approximation in L^p-spaces, approximation of analytic functions.	8
	Total	**42**

12. **Suggested Books:**

S. No.	Authors/Title/Publishers	Year of Publication/ Reprints
1.	Cheney, E. W., "Introduction to Approximation Theory", AMS Chelsea Publishing Co.	1981
2.	Lorentz, G. G., "Bernstein Polynomials", AMS Chelsea Publishing Co.	1986
3.	Natanson, I. P., "Constructive Function Theory Volume-I", Fredrick Ungar Publishing Co.	1964
4.	Mhaskar, H. M. and Pai, D. V., "Fundamentals of Approximation Theory", Narosa Publishing House	2000
5.	Timan, A. F., "Theory of Approximation of Functions of a Real Variable", Dover Publication Inc.	1994

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-520 **Course Title**: Coding Theory

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: Basic knowledge of abstract algebra and linear algebra.

9. Objective: To introduce the basic concepts and techniques of coding theory.

10. Details of the Course:

S. No.	Contents	Contact Hours
1.	Introduction to error-detection and error-correction, the communication channel, the coding problem, block codes, Hamming metric, nearest neighbour decoding, linear codes, generator and parity-check matrices, dual code, standard array decoding, syndrome decoding.	8
2.	Hamming codes, Golay codes, Reed-Muller codes, codes derived from Hadamard matrices.	5
3.	Bounds on codes, sphere packing bound, perfect codes, Gilbert-Varshamov bound, Singleton bound, MDS codes, Plotkin bound. Weight distributions of codes, MacWilliams identities.	8
4.	Finite fields and their structure. Cyclic codes, generator polynomial and check polynomial, defining set of a cyclic code, BCH bound, encoding and decoding of cyclic codes.	8
5.	Hamming and Golay codes as cyclic codes, BCH codes, Reed-Solomon codes, Quadratic residue codes.	7
6.	Graphical codes, convolutional codes.	6
	Total	**42**

11. **Suggested References/Books:**

S. No.	Title/Authors/Publishers	Year of Publication/Reprint
1.	Ling, S. and Xing, C., "Coding Theory: A First Course", Cambridge University Press	2004
2.	Huffman, W. C. and Pless, V., "Fundamentals of Error-Correcting Codes", Cambridge University Press	2003
3.	Roth, R. M., "Introduction to Coding Theory", Cambridge University Press	2006
4.	Pellikaan, R., Wu, X.W., Bulygin, S. and Jurrius, R., "Codes, Cryptology and Curves with Computer Algebra", Cambridge University Press	2017
5.	MacWilliams, F. J. and Sloane, N. J. A., "The Theory of Error-Correcting Codes", North Holland	1977

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-521 **Course Title**: Commutative Algebra
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic knowledge of abstract algebra
9. **Objective:** To introduce the basic concepts of commutative algebra.
10. **Details of the Course:**

S. No.	**Contents**	**Contact Hours**
1.	Commutative rings, ideals, prime and maximal ideals, the spectrum of a ring, nil radical and Jacobson radical, operations on ideals, extension and contraction of ideals, affine algebraic set, Zariski topology.	6
2.	Review of modules and submodules, operations on submodules, direct sum and product, Nakayama's lemma, exact sequences, tensor product of modules, algebras.	6
3.	Rings and modules of fractions, local properties, extended and contracted ideals in ring of fractions, primary decomposition.	5
4.	Properties of extension rings, integral extensions, going-up theorem, going-down theorem, Noether normalization theorem, Hilbert's nullstellensatz.	5
5.	Rings with chain conditions, Noetherian rings, primary decomposition in Noetherian rings, Artinian rings.	7
6.	Valuation rings, discrete valuation rings, Dedekind domains, fractional ideals, completions.	7
7.	Dimension theory, graded rings and modules, Hilbert functions, dimension theory of Noetherian local rings, regular local rings	6
Total		**42**

11. **Suggested References/Books:**

S. No.	Title/Authors/Publishers	Year of Publication/Reprint
1.	Atiyah, M. F. and Macdonald, I. G., "Introduction to Commutative Algebra", Taylor & Francis Inc.	1994
2.	Singh, B., "Basic Commutative Algebra", World Scientific Publishing Co.	2011
3.	Sharp, R. Y., "Steps in Commutative Algebra", 2nd Ed., Cambridge University Press.	2001
4.	Gopalakrishnan, N. S., "Commutative Algebra", 2nd Ed., Universities Press (India) Pvt. Ltd.	2016
5.	Dummit, D. S. and Foote, R. M., "Abstract Algebra", 3rd Ed., John Wiley & Sons.	2003
6.	Lang, S., "Algebra", 3rd Ed., Springer .	2005

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-522 **Course Title**: Computational Fluid Dynamics

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: Basic knowledge of fluid dynamics and numerical analysis.

9. Objective: To introduce the essential tools of computational fluid dynamics.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	**Review of finite difference methods for solving PDEs:** Physical and mathematical classifications, the well-posed problem; finite difference representation of PDEs, explicit and implicit approaches for finite difference solution of parabolic and elliptic PDEs; Governing equations of fluid flow and heat transfer: incompressible fluid flow and Navier–Stokes equations, energy equation, solution of heat conduction problems.	8
2.	**Grid Generation:** Physical aspects, grid generation by algebraic mapping, numerical implementation of algebraic mapping, grid generation for partial differential equation.	2
3.	**Basic CFD Techniques:** The Lax-Wendroff technique, MacCormack's technique, the relaxation technique and its use with low speed inviscid flow, vorticity-stream function approach, upwind scheme, quick scheme.	8
4.	**Incompressible Viscous Flow:** Unsteady flow: Staggered grid, MAC formulation, Implementation of boundary conditions, developments of MAC method, higher order upwind differencing scheme.	8
5.	**Finite volume method**: Basic concept of finite volume method, solution of heat conduction problem, convection-diffusion problem, artificial compressibility, auxiliary potential function, the pressure correction technique, concept of staggered grid, SIMPLE algorithm for calculation of the flow field. Upgradation of SIMPLE and introduction of SIMPLER and SIMPLEC.	12
6.	**An introduction to spectral element method**: Spectral element method and its application to some benchmark problems**.**	4
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Anderson Jr., J. D., "Computational Fluid dynamics: The Basics with Applications", Tata McGraw-Hill. Edition.	2012
2.	Patankar, S. V. , "Numerical Heat Transfer and Fluid Flow", CRC Press, Taylor and Francis Group.	2017
3.	Fletcher, C. A. J., "Computational Techniques for Fluid Dynamics: Fundamental and General Techniques", 2nd Ed., Springer-Verlag	2013
4.	Ferziger, J. H. and Peric, M., "Computational Methods for Fluid Dynamics", Springer Science & Business Media.	2012
5.	Canuto, C., Hussaine, M. Y., Quarteroni, A., and Zang, T. A., "Spectral Method in Fluid Dynamics", Springer, New York, Berlin, Heidelberg.	1988

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-523 **Course Title**: Control Theory

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: Basic concepts of matrix theory and differential equations.

9. Objective: To introduce the basic mathematical concepts of Control Theory such as controllability, observability, stability and optimal control.

10. Details of the Course:

S. No.	Contents	Contact hours
1	Mathematical models of control systems, state space representation, autonomous and non-autonomous systems, state, transition matrix, Peano series solution of linear dynamical system.	4
2	Block diagram, transfer function, realization, controllability, Kalman theorem, controllability Grammian, control computation using Grammian matrix, observability, duality theorems, discrete control systems, controllability and observability results for discrete systems.	10
3	Companion form, feedback control, state observer, realization.	6
4	Liapunov stability, stability analysis for linear systems, Liapunov theorems for stability and instability for nonlinear systems, stability analysis through linearization, Routh criterion, Nyquist criterion, stabilizability and detachability.	8
5	State feedback of multivariable system, Riccatti equation, calculus of variations, Euler-Hamiltonian equations, optimal control for nonlinear control systems, computation of optimal control for linear systems.	8
6	Control systems on Hilbert spaces, semigroup theory, mild solutions, control of a linear system.	6
Total		**42**

11. Suggested Books:

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Barnett, S. "Introduction to Mathematical Control Theory", Clarendon Press, Oxford.	1975
2	Dukkipati, R. V.,"Control Systems", Narosa Publishing House.	2005
3	Nagrath, I. J. and Gopal, M., "Control System Engineering", New Age International.	2001
4	Datta, B., "Numerical Methods for Linear Control Systems", Academic Press, Elsevier.	2005
5	Golnaraghi, F. and Kuo, B. C. "Automatic Control Systems", 10th Ed., McGraw Hill Education.	2018

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. Subject Code: MAL-524 **Course Title**: Dynamical Systems

2. Contact Hours: **L:** 3 **T:** 1 **P:** 0

3. Examination Duration (Hrs.): **Theory:** 03 **Practical:** 00

4. Relative Weightage: **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0

5. Credits: 04 **6. Semester:** Both **7. Subject Area:** PEC

8. Pre-requisite: NIL

9. Objective: To provide basic knowledge of the dynamical systems.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	**Linear Dynamical Continuous Systems:** First order equations, existence uniqueness theorems, growth equation, logistic growth, constant harvesting, Planar linear systems, equilibrium points, stability, phase space, n-dimensional linear systems, stable, unstable and center spaces	8
2.	**Nonlinear Autonomous Systems:** Motion of pendulum, local and global stability, Liapunov method, periodic solution, Bendixson's criterion, Poincare-Bendixson theorem, limit cycle, attractors, index theory, Hartman-Grobman theorem, nonhyperbolic critical points, center manifolds, normal forms, Gradient and Hamiltonian systems.	14
3.	**Local Bifurcation:** Fixed points, saddle node, pitchfork, transcritical bifurcation, Hopf bifurcation, co-dimension.	6
4.	**Discrete Systems:** Logistic maps, equilibrium points and their local stability, cycles, period doubling, chaos, tent map, horse shoe map.	6
5.	**Deterministic Chaos:** Duffing's oscillator, Lorenz System, Liapunov exponents, routes to chaos, necessary conditions for chaos.	8
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Perko L., Differential Equations and Dynamical Systems, 3rd Ed. Springer-Verlag	2010
2.	Hirsch, M.W., Smale, S., Devaney, R.L. Differential Equations, Dynamical Systems and an Introduction to Chaos, 3rd Ed., Academic Press	2013
3.	Strogatz, S. H., Nonlinear Dynamics and Chaos, 2nd Ed., CRC Press	2019
4.	Wiggins, S. Introduction to Applied Nonlinear Dynamical Systems and Chaos, 2nd Ed., Springer-Verlag	2010
5.	Lakshmanan, M, Rajasekar, S., Nonlinear Dynamics, Springer	2003
6.	Hubbard J. H., West, B. H., Differential Equations: A Dynamical Systems Approach, Springer-Verlag	2014
7.	Kaplan D., Gloss L., Understanding Nonlinear Dynamics, Springer	1995

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-525 **Course Title**: Fluid Dynamics
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To introduce the basic concepts of fluid dynamics.

10. **Details of the Course:**

S.No.	Contents	Contact hours
1.	**Basic Concepts:** A broad perspective of fluid dynamics, Definition of fluid, Distinction between solid and fluid, Concept of continuum, pressure and stress in a fluid, Fluid properties.	4
2.	**Description of Fluid Motion:** Lagrangian and Eulerian approaches, Continuity of mass flow, Circulation, Rotational and irrotational flows, Boundary surface, Streamlines, Path lines, Streak lines, Vorticity.	4
3.	**Equations of Motion and Mechanical Energy**: Inviscid case, Bernoulli's theorem, Compressible and incompressible flows, Kelvin's theorem, Constancy of circulation, Concepts of static pressure, Flow through orifices and mouthpieces.	7
4.	**Flow of Ideal Fluids**: Stream function, Complex-potential, Source, sink and doublets, Circle theorem, Method of images, Theorem of Blasius, Strokes stream function, Motion of a sphere, Helmholtz's vorticity equation, Vortex filaments, Vortex pair.	8
5.	**Incompressible Viscous Flow:** Reynolds transport theorem**,** Derivation of Navier-Stokes equations, Derivation of energy equation, Dissipation of energy, Diffusion of vorticity, Couette flow, Poiseuille flow, Hagen-Poiseuille flow, Annular flow.	14
6.	**Laminar Boundary Layers:** Dynamical similarity, Dimensional analysis, Large Reynold's numbers, Laminar boundary layer equations, Similar solutions.	5
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Batechelor, G.K., "An Introduction to Fluid Dynamics", Cambridge Press.	**2002**
2.	Schliting, H., Gersten K., "Boundary Layer Theory", Springer, 8th edition.	**2004**
3.	Rosenhead, L., "Laminar Boundary Layers", Dover Publications	**1989**
4.	Tritton, D.J., ''Physical Fluid Dynamics'', Oxford University press	**2011**
5.	Yuan, S.W., "Foundations of Fluid Mechanics", New Delhi: Prentice_Hall of India	**1988**

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-526 **Course Title**: Fourier Analysis and Applications
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Real and Complex Analysis.
9. **Objective:** To provide the analysis behind Fourier series, Fourier Transform and their applications.
10. **Details of the Course:**

S. No.	Contents	Contact Hours
1.	**Fourier Series:** The Lebesgue integral, Trigonometric series, Formulation of Fourier series and its basic properties, Uniqueness of Fourier series, Norm convergence and summability, Diverging Fourier series. Plancheral theorem, Riesz-Fischer theorem, Gibb's phenomenon	10
2.	**Applications of Fourier Series**: Sturm Liouville Problem, Bernoulli polynomials, The isoperimetric problem, Jacobi's identity for the theta function, Weierstrass approximation theorem, Wallis product formula, Weyl's equi-distribution theorem.	10
3.	**Fourier Transform:** Definition and basic properties, Fourier transform on the Schwartz space, Fourier transform on $L^1(\mathbb{R})$ and $L^2(\mathbb{R})$, Spectral analysis of the Fourier transform. Fourier transform on the Schwartz space, Abstract Fourier analysis in Hilbert spaces.	8
4.	**Applications of Fourier transform:** Solution of differential equations, Poisson summation formula, The Euler-Mac Laurin summation formula, The central limit theorem, Heisenberg's uncertainty principle, Wiener theorem.	8
5.	**Fourier transform in complex domain:** Band- and Time-limited functions, Hardy's theorem, Paley-Wiener theorem, Shannon sampling theorem. Spherical harmonics.	6
Total		**42**

11. **Suggested Books:**

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	H. Dym and H.P. McKean. Fourier Series and Integrals, Academic Press, New York and London.	1972
2.	T. W. Körner. Fourier Analysis, Cambridge University Press, Cambridge.	1989
3.	Riesz and B. Nagy, Functional Analysis, Dover Reprint	1990
4.	H. L. Montgomery, Early Fourier Analysis, American Mathematical Society	2017
5.	Mark A. Pinsky, Introduction to Fourier Analysis and Wavelets, Bob Pirtle, USA	2002
6.	Elias M. Stein and Rami Shakarchi, Fourier Analysis: An introduction, Princeton University Press, New Jersey.	2003

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-527 **Course Title**: Fuzzy Sets and Fuzzy Systems
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To introduce concepts of fuzzy set theory and its applications in some areas.
10. **Details:**

S. No.	Contents	Contact Hours
1.	**Fuzzy Sets:** Concepts of crispness and fuzziness, crisp sets and fuzzy sets, α-cuts, convex fuzzy sets, operations on fuzzy sets, Type-2 fuzzy sets, fuzzy numbers and extended operations on fuzzy numbers, LR- representations of fuzzy sets and extended operations on them, t-norms and t-conorms, increasing and decreasing generators, interval equations, fuzzy equations.	**17**
2.	**Fuzzy Relations and Fuzzy Graphs:** Fuzzy relations on fuzzy sets, composition of fuzzy relations, fuzzy graphs.	**5**
3.	**Fuzzy Analysis:** Fuzzy functions and their extrema, integration of fuzzy functions, fuzzy differentiation.	**5**
4.	**Fuzzy Logic and Approximate Reasoning:** Fuzzy measures and measures of fuzziness, linguistic variables, fuzzy logic, truth tables, approximate reasoning in support logic programming.	**5**
5.	**Expert Systems and Fuzzy Control:** Expert systems, uncertainty modeling in expert systems, fuzzy control, process of fuzzy control.	**5**
6.	**Decision Making in Fuzzy Environments:** Fuzzy decisions, fuzzy linear programming problems, fuzzy transportation and assignment problems, fuzzy dynamic programming, fuzzy multi-criteria analysis.	**5**
	Total	**42**

11. Suggested Books:

S. No.	Name of Authors/ Books/Publishers	Year of Publication/Reprint
1.	Zimmermann, H. J., "Fuzzy Set theory and its Applications", 4th Ed., Springer.	2001
2.	Klir, George J. and Folger, Tina A., "Fuzzy Sets, Uncertainty and Information", Pearson Education India.	2015
3.	Klir, George J. and Bo Yuan, "Fuzzy sets and Fuzzy Logic: Theory and Applications", Pearson Education India.	2015
4.	Ross, T. J., "Fuzzy Sets and Fuzzy Logic with Engineering Applications", 4th Ed., An Indian Adaptation	2021
5.	Lai, Y and Hwang, C., "Fuzzy Mathematical Programming", Springer-Verlag.	1992

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-528 **Course Title**: Hyperbolic Conservation Laws
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** 3 Hrs **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Basics of partial differential equations.
9. **Objective:** To provide the basic knowledge of first order scalar hyperbolic conservation laws.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1.	First order partial differential equations, methods of characteristics for linear, semi-linear, quasi-linear, and fully non-linear equations, well-posedness of Cauchy problems, non-characteristic boundary data, inverse function theorem, general method of characteristics for first order partial differential equations, local existence theorem.	10
2.	Initial value problem for first order Burger's equation, traffic flow problem, derivation of conservation laws, discontinuous or weak solutions, uniqueness, non-uniqueness, curve of discontinuity, Rankine-Hugoniot jump condition, rarefaction waves, entropy conditions, non-smooth data, shock waves, shock speed, admissible solutions, Reimann problem for convex and non-convex fluxes, long time behavior, Oleinik entropy condition, admissible entropy solution.	14
3.	Hyperbolic system of first order partial differential equations, travelling waves, plane wave solutions, domain of dependence for a symmetric hyperbolic system, uniqueness with compactly supported initial data.	8
4.	Finite difference scheme for approximation conservation laws, Lax-Wendroff scheme, Godunov scheme, Lax-Friedrichs scheme, Murman-Roe scheme, Engquist-Osher scheme.	10
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Renardy, M. and Rogers, R. C., "An Introduction to Partial Differential Equations", 2nd Ed., Springer-Verlag.	2004
2.	Evans, L. C., "Partial Differential Equations", 2nd Ed., American Mathematical Society.	2010
3.	LeVeque, R. J., "Numerical Methods for Conservation Laws", Birkhauser Verlag, Basel.	1992
4.	LeFloch, P. G., "Hyperbolic System of Conservation Laws: The Theory of Classical and Nonclassical Shock Waves", Birkhauser, Basel.	2002
5.	Smoller, J., "Shock Waves and Reaction-Diffusion Equations", Springer Verlag, New York.	1983

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-529 **Course Title**: Integral Equations and Calculus of Variations
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic concepts of differential equations.
9. **Objective:** To introduce the methods and concepts to solve integral equations, and problems through calculus of variations.

10. Details of the Course:

S. No.	Contents	Contact hours
1	Definition and classification of linear integral equations, conversion of initial and boundary value problems into integral equations, conversion of integral equations into differential equations, integro-differential equations.	4
2	Fredholm integral equations of the second kind, solution of integral equations with separable kernels, eigenvalues and eigenfunctions, solution by successive approximations, Neumann series and resolvent kernel, Adomian decomposition method, Fredholm alternative, solution of integral equations with symmetric kernels, Green's function approach, Hilbert-Schmidt theorem, Fredholm integral equations of the first kind, method of regularization and homotopy perturbation method.	8
3	Classical Fredholm theory, Fredholm method of solution and Fredholm theorems.	4
4	Volterra integral equations, successive approximations, Neumann series and resolvent kernel, equations of convolution type kernels, solution of integral equations by transform methods, singular integral equations, Abel's integral equations, Hilbert-transform, Cauchy type integral equations.	9
5	Basic concepts of the calculus of variations, functionals, extremum, variations, function spaces, the brachistochrone problem, necessary condition for an extremum, Euler-Lagrange equation with the cases of one variable and several variables, conditional extremum, variational derivative, invariance of Euler-Lagrange equations, variational problem in parametric form, applications to eigen value problems.	8
6	General variation, functionals dependent on one or two functions, derivation of basic formula, arviational problems with moving boundaries, broken extremals, Weierstrass-Erdmann conditions, second variation, weak and strong extremum.	9
Total		**42**

11. Suggested Books:

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Zemyan, S. M., "The Classical Theory of Integral Equations: A Concise Treatment", Springer.	2012
2	Wazwaz, A. M., "Linear and Nonlinear Integral Equations, Methods and Applications", Springer.	2011
3	Jerry, A. J., "Introduction to Integral Equations with Applications", 2nd Ed., Wiley–Blackwell.	1999
4	Kanwal, R. P., "Linear Integral Equations", 2nd Ed., Birkhäuser.	1997
5	Hochstadt, H., "Integral Equations", John Wiley & Sons.	1989
6	Gelfand, I. M. and Fomin, S. V., "Calculus of Variations", Dover Publications, INC.	2000
7	Weinstock, R., "Calculus of Variations with Applications to Physics and Engineering", Dover Publications, INC.	1974
8	Kot, M. "A First Course in the Calculus of Variations", American Mathematical Society.	2014

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-531 **Course Title**: Mathematical Biology
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 04 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Nil

9. Objective: To introduce the applications of mathematical modeling in the analysis of biological systems.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	An overview of mathematical biology and the modeling process.	2
2.	Continuous models: Malthus model, logistic growth, Allee effect, Gompertz growth, Michaelis-Menten Kinetics, Holling type growth, Bacterial growth in a chemostat, Harvesting model (single species), Prey predator models: Lotka-Volterra model, Modified Lotka-Volterra model, Generalized Gause predator-prey model, Leslie-Gower predator-prey model, Predator-prey model with predator dependent functional response, Lotka-Volterra competition model, Three species food chain model, Epidemic Models (SI, SIR, SIRS), Insect Outbreak Model: Spruce Budworm, Numerical solution of the models and its graphical representation.	10
3.	Qualitative analysis of continuous models: Steady state solutions, Linearization and Stability, Multiple species communities and Routh-Hurwitz Criteria, Phase plane methods and qualitative solutions, Bifurcations and limit cycles with examples in the context of biological scenario.	10
4.	Spatial Models: One species models with diffusion, Two species models with diffusion, Conditions for diffusive instability, Spreading colonies of microorganisms, Blood flow in circulatory system.	8
5.	Discrete Models: Overview of Difference equations, Steady state solution and linear stability analysis, Introduction to Discrete models: Linear Models, Growth models, Decay models, Drug delivery problem, Discrete predator-prey models, Density dependent growth models with harvesting, Discrete epidemic models, Host-Parasitoid systems (Nicholson-Bailey model), Notion of periodic point and cycle, Existence and stability conditions of two cycles, Numerical solution of the models and its graphical representation.	12
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Keshet, L. E., "Mathematical Models in Biology", SIAM.	2005
2	Murray, J. D., "Mathematical Biology: An Introduction", 3rd Ed., Springer.	2001
3	Kot, M., "Elements of Mathematical Ecology", Cambridge University Press.	2001
4	Britton, N.F., "Essential Mathematical Biology", Springer	2003
5	Bairagi, N., "Introductory Mathematical Biology", U. N. Dhur & Sons Private Ltd.	2021

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-532 **Course Title**: Mathematical Cryptography
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic knowledge of algebra, number theory and probability.
9. **Objective:** To introduce the basic concepts and techniques of mathematical cryptography.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1.	Introduction to cryptography, symmetric and asymmetric cryptosystems; Classical cryptography: substitution ciphers (shift, affine, Vigenere ciphers), Hill cipher, permutation cipher, stream ciphers; cryptanalysis of classical ciphers, DES, AES, Shannon's theory, perfect secrecy, one-time pad.	9
2.	Euclidean algorithm and the extended Euclidean algorithm, fast exponentiation, the Chinese remainder theorem, finite fields, primitive roots, computational complexity.	6
3.	Introduction to public key cryptography, the discrete logarithm problem (DLP), Diffie-Hellman key exchange, the ElGamal cryptosystem, the RSA cryptosystem.	6
4.	Primality testing, Miller-Rabin test; Factoring algorithms: Pollard's $p-1$ algorithm, smooth numbers and sieves, the quadratic sieve; Algorithms for computing discrete logarithms: Shank's algorithm, the Pohlig-Hellman algorithm.	7
5.	Cryptographic hash functions, digital signatures, RSA digital signatures, ElGamal digital signatures, the digital signature algorithm (DSA).	6
6.	Introduction to elliptic curves, elliptic curves over finite fields, the elliptic curve discrete logarithm problem (ECDLP), elliptic curve cryptography: elliptic Diffie-Hellman key exchange, elliptic El-Gamal cryptosystem, the elliptic curve DSA; Introduction to secret sharing.	8
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Hoffstein, J., Pipher, J. and Silverman, J. H., "An Introduction to Mathematical Cryptography", 2nd Ed., Springer .	2014
2.	Stinson, D. R. and Paterson, M. B., "Cryptography: Theory of Practice", 4th Ed., CRC Press.	2019
3.	Buchmann, J. A., "Introduction to Cryptography", 2nd Ed , Springer.	2004
4.	Katz, J., and Lindell, Y., "Introduction to Modern Cryptography", 2nd Ed., CRC Press.	2014
5.	Koblitz, N., "A Course in Number Theory and Cryptography", 2nd Ed., Springer.	1994

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-533 **Course Title**: Measure Theory
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic course on Real Analysis
9. **Objective:** To provide the knowledge of Lebesgue Measure and L^p spaces.
10. **Details of the Course:**

S.No.	Contents	Contact hours
6.	**Measure on the real line**: Introduction, Lebesgue outer measure, Measurable sets, Borel sets, Regular Measure, Measurable functions, Borel and Lebesgue Measurable Functions.	7
7.	**Integration of Functions of a real variable**: Integration of non-negative functions, Lebesgue Integral, Fatou's Lemma, Lebesgue Monotone Convergence theorem, The General Integral, Lebesgue dominated convergence theorem, Integration of Series, Riemann and Lebesgue Integrals.	7
8.	**Differentiation:** The four derivatives, functions of bounded variation, Lebesgue differentiation theorem, absolutely continuous functions, integrating derivatives.	5
9.	**Abstract Measure spaces**: Measures and Outer Measures, Extensions of Measure, Uniqueness of the Extension, Completion of a measure, Measure spaces, Integration with respect to a measure.	8
10.	**Inequalities and L^p spaces**: L^p spaces, Convex functions, Jensen's inequality, Inequalities of Holder and Minkowski, Convergence in Measure, Almost uniform Convergence.	6
11.	**Signed Measures and their Derivatives**: Signed Measures and the Hahn Decomposition, The Jordan decomposition, The Radon Nikodym Theorem, some applications.	5
12.	**Complex Measures**: Total variation, Absolute Continuity, Consequences of Radon Nikodym Theorem, Riesz Representation Theorem.	4
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
10.	G.D. Barra, Measure theory and Integration, 2nd Ed. Woodhead Publishing.	2013
11.	H. L. Royden, P.M. Fitzpatrick, Real Analysis, 4th Ed., Pearson India.	2015
12.	E. M. Stein, R. Shakarachi, Real Analysis, New Age International Publishers.	2010
13.	R. G. Bartle, The elements of Integration and Lebesgue Measure, Wiley Classics.	2014
14.	W. Rudin, Real and Complex Analysis, 3rd Ed., McGraw Hill.	1987
15.	P. R. Halmos, Measure Theory, Springer.	2009
16.	I. P. Natanson, E. Hewitt, L.F. Boron, Theory of Functions of a Real Variable, Dover Publications.	2016

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-534 **Course Title**: Multivariate Techniques
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic Probability and Statistics
9. **Objective:** To introduce multiple variable regression models, residual analysis and analysis of variance.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	Multivariate normal distribution: Joint and marginal densities, independence, estimation of mean vector and covariance matrix	8
2.	Causal relationships, statistical models; Two variable linear regression models: assumptions, methods for estimation of model, least square, minimum variance, best fit solutions, measure for quality of linear model, standard error.	6
3.	Estimation, confidence intervals and tests of significance and prediction of new values.	4
4.	Multiple regression analysis: Graphical procedure, assumptions, methods for estimation of model, determining best estimates.	6
5.	Test for significant overall regression, partial F and multiple F tests, partial and multiple correlation and their relationship with multivariate normal distribution.	4
6.	Confounding and interaction in regression, regression diagnostics, residual analysis, collinearity.	4
7.	Polynomial regression: second and higher order models their fitting and testing, Lack-of-fit tests, orthogonal polynomials, strategies for choosing polynomial model problems. Selecting the best regression equation.	4
8.	ANOVA: Basic concepts, Gauss Markov theorem, one-way classification, comparison of more than two means, statistical model and analysis for one-way layout, two-way classification, statistical model and analysis for two-way layout, analysis of variance using linear models.	6
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Miller, I. and Miller, M., "Freund's Mathematical Statistics with Applications", 8th Ed., Pearson Education.	2013
2.	Hogg, R. V., McKean J. W. and Craig, A., "Introduction to Mathematical Statistics", 8th edition, Pearson Education.	2019
3.	Kleinbaun, D. G., Kupper, L. L., Muller, K. E. and Nizam, A, "Applied Regression Analysis and Other Multivariable Methods", 3rd Ed., Duxbury Press CA**.**	1998
4.	Anderson, T. W. , "An Introduction to Multivariate Statistical Analysis, 3rd Ed., John Wiley & Sons.	2003
5.	Rao, C. R, "Linear Statistical Inference and Its Applications", 2nd Ed., Wiley India.	2009

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-535 **Course Title**: Numerical Linear Algebra
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Basic knowledge of linear algebra and numerical methods.
9. **Objective:** To introduce the concepts of numerical linear algebra.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1	Review of direct/ iterative methods for linear systems.	3
2	Matrix factorization (normal equations, QR and singular value decomposition) for the least squares problems, perturbation theory, rank-deficient least squares problems.	5
3	Nonsymmetric eigenvalue problems, canonical forms, perturbation theory, algorithms for the nonsymmetric eigenvalue problem (power methods, orthogonal iterations, QR iterations).	6
4	Projection methods, definitions and algorithms, one dimensional projection process, additive and multiplicative process.	3
5	Krylov subspaces, Arnoldi's method for linear systems, GMRES, the symmetric Lanczos algorithms, conjugate gradient algorithms, convergence analysis.	10
6	Methods related to normal equations: Row projection methods, conjugate-gradient and normal equation, saddle point problems.	4
7	Preconditioned iterations: Preconditioned conjugate-gradient method, preconditioned GMRES.	5
8	Preconditioning techniques: Jacobi, SOR and SSOR preconditioners, ILU factorization preconditioner, block preconditioners, preconditioners for normal equation.	6
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Saad, Y., "Iterative Methods for Sparse Linear Systems", 2nd Ed., SIAM.	2003
2	Trefthen, N., "Numerical Linear Algebra", SIAM.	1997
3	Demmel, J. W. , "Applied Numerical Algebra", SIAM.	2017
4	Dutta, B. N., "Numerical Linear Algebra and Applications", 2nd Ed., SIAM	2010

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-536 **Course Title**: Operator Theory
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Basic knowledge of functional analysis
9. **Objective:** To provide the knowledge of various operators on Hilbert spaces.
10. **Details of the Course:**

S. No.	Contents	Contact hours
1.	Review of Banach spaces, geometry of Hilbert spaces, Riesz representation theorem.	3
2.	Operators on Hilbert spaces, self-adjoint, normal and unitary operators, isometries, partial isometries, multiplication operators, positive operators, finite rank operators, compact operators and their properties.	8
3.	Eigen-spectrum, approximate eigen-spectrum, spectrum and resolvent set, numerical range, numerical radius, spectral radius, spectral mapping theorem.	6
4.	Polar decomposition theorem, spectral theorem and singular value representation of a compact self-adjoint operator, minimax principle, trace class operators, Hilbert-Schmidt operators.	7
5.	Spectral measure, spectral integrals, spectral subspaces, spectral theorem for bounded self-adjoint and normal operators.	9
6.	Reproducing kernel Hilbert spaces, Hardy space, Dirichlet space, Bergman space, Shift invariant subspaces, Beurling's theorem.	9
	Total	**42**

11. **Suggested Books:**

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Conway, J. B. , "A Course in Functional Analysis", 2nd Ed., Springer-Verlag, New York.	1990
2.	Douglas, R. G., "Banach Algebra Techniques in Operator Theory", 2nd Ed., Springer-Verlag, New York.	1998
3.	Sunder, V. S., "Operators on Hilbert Space", Hindustan Book Agency, New Delhi.	2015
4.	Paulsen, V. I. and Raghupathi, M., "An Introduction to the Theory of Reproducing Kernel Hilbert Spaces", Cambridge University Press, Cambridge.	2016
5.	Halmos, P. R. , "Introduction to Hilbert Space and the Theory of Spectral Multiplicity", Benediction Classics, India	2016
6.	Parthasarathy, K. R., "An Introduction to Quantum Stochastic Calculus", Monographs in Mathematics, 85, Birkhäuser Verlag, Basel	1992

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-537 **Course Title**: Optimal Control Theory
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Basic concepts of differential equations.
9. **Objective:** To introduce the theory of optimal control problems.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1	General optimal control problems, formulation for economic growth, resource depletion, exploited populations, advertising policies and rocket trajectories servo problems, controllability of linear equations, observability, bang-bang principle.	8
2	Variational approach, necessary conditions for optimal control, Hamiltonian, Pontryagin's principle for continuous and for bounded and discontinuous controls, state inequality constraints, switching curves, switching curves, transversality conditions, singular integrals in optimal control problems.	12
3	Dynamic programming approach, optimal control law, principle of optimality and its applications to decision making in optimal control problems, computational methods for solving optimal control problems, some real-life problems.	12
4	Differential games, penalty and barrier search techniques, sensitivity analysis in optimal control problems.	10
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Burghes, D. N. and Graham, A., "Introduction to Control Theory Including Optimal Control", John Wiley & Sons.	1980
2	Canon, M. D., Culum, C. D. and Polak, E., "Theory of Optimal Control and Mathematical Programming", McGraw Hill.	1970
3	Kirk, D. E., "Optimal Control Theory-An Introduction", Prentice Hall.	1970
4	Lee, E. G. and Markus, L., "Foundations of Optimal Control Theory", John Wiley & Sons.	1967
5	Hull, D. G., "Optimal Control Theory", Springer.	2005
6	Geering, H. P., "Optimal Control with Engineering Applications", Springer	2007
7	Evans, L. C., "An Introduction to Mathematical Optimal Control Theory", Ver 0.2, Lecture Notes. Available at: https://math.berkeley.edu/~evans/control.course.pdf	2005

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-538 **Course Title**: Orthogonal Polynomials and Special Functions
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic knowledge of Real and Complex Analysis.
9. **Objective:** To give in-depth knowledge of various special functions and the concepts of Orthogonal polynomials.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	**Gamma functions:** Beta and Gamma functions, integral representation, analytic extension to complex plane, Bohr-Mollerup theorem, Weilandts theorem, singularities, reflection formulas, Riemann zeta function, Riemann hypothesis.	6
2.	**Hypergeometric functions:** Solution of homogeneous linear differential equations of second order near an ordinary and regular singular point, their convergence and solutions for large values, differential equations with three regular singularities, hypergeometric differential equations, Gauss hypergeometric function, elementary properties, contiguous relations, integral representation, linear and quadratic transformation and summation formulae.	6
3.	**Analytic continuation:** Barnes' contour integral representation. Confluent hypergeometric function and its elementary properties.	4
4.	**Generalized hypergeometric function:** ${}_pF_q$ and its elementary properties – linear and quadratic transformations, summation formula.	4
5.	**Asymptotic series:** Definition, elementary properties, term by term differentiation, integration, theorem of uniqueness, Watson's lemma. Asymptotic expansion of 1F1 and 2F1 hypergeometric series.	6
6.	**Orthogonal polynomials:** Definition, their zeros, expansion in terms of orthogonal polynomials, three term recurrence relation, Christofel-Darboux formula, Bessel's inequality. Hermite, Laguerre and Jacobi polynomials: Definition and elementary properties.	8
7.	**Classification of orthogonal polynomials:** Classical and non-classical orthogonal polynomials, discrete orthogonal polynomials, q-analogue, Askey scheme, continued fractions, moment problems of Stieltjes, Hausdorff and Hamburger, tridiagonal matrices, spectral transformations, interlacing of zeros.	8
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Chihara, T. S., "An Introduction to Orthogonal Polynomials", Dover Publications.	2011
2.	Ismail, M. E. H., "Classical and Quantum Orthogonal Polynomials in One Variable", Cambridge University Press.	2005
3.	Marcellan, F. and Assche, W. V. (Eds.), "Orthogonal Polynomials and Special Functions: Computation and Applications", Lecture Notes in Mathematics, Springer.	2006
4.	Rainville, E. D., " Special Functions", MacMillan	1960
5.	Szego G., "Orthogonal Polynomials", Memoirs of AMS	1939

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MA-539 **Course Title**: Portfolio Optimization
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Basic concepts of probability and statistics.
9. **Objective:** To introduce modern techniques of portfolio optimization.
10. **Details of the Course**

S.No.	Contents	Contact hours
1.	Mean Variance Portfolio Theory: determining the average outcome, measure of dispersion, characteristic of portfolio in general, efficient portfolio, combination of two risky assets: short sales not allowed, shape of portfolio possibilities curve, efficient frontier with riskless lending and borrowing, techniques for calculating efficient frontier.	7
2.	Single-index model: Inputs of portfolio analysis, characteristics of single-index model, estimating beta, market model. Multi-Index model: average correlation models, mixed models, fundamental multi-index models.Techniques for determining the efficient frontier.	8
3.	Capital Asset Pricing Model (CAPM): assumptions and model, prices and CAPM, short sales disallowed, modifications of riskless lending and borrowing, personal taxes, nonmarketable assets, heterogeneous expectations, non-price taking behaviour, multi-period CAPM, multi-beta CAPM, consumption CAPM, empirical tests.	10
4.	Arbitrage Pricing Theory (APT): estimating and testing APT, APT and CAPM, recapitulation, term structure factor, credit risk factor, foreign exchange carry, value factor, size factor, momentum factor, volatility factor, liquidity factor, inflation factor, GDP factor, equity risk premium, limitations of factor investing, factor investing summary.	10
5.	Efficient Market Theory: Early development and recent theory, testing the efficient market hypothesis (EMH), tests of return predictability, tests on prices and returns, monthly pattern, announcement and price return, methodology or event studies, strong-form efficiency, market rationality.	7
	Total	**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	E. J. Elton, M. J. Gruber, S. J. Brown and W. N. Goetzmann, Modern Portfolio Theory and Investment Analysis, 9th edition, John Wiley & Sons, Inc.	2014
2.	Michael J. Best, Portfolio Optimization, Chapman & Hall/CRC	2010

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-540 **Course Title**: Regularization Theory for Inverse Problems
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** 3 Hrs **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic understanding of functional analysis and partial differential equations.
9. **Objective:** To introduce a functional analytic treatment of inverse problems in the context of operator equations with some information on numerical aspects.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1.	**A revisit of functional analysis**: Linear operators, compact linear operators, closed operators, self-adjoint operators, singular value decomposition, Moore-Penrose generalized inverse, least square solution, spectral theory, Fréchet and Gateaux differentiability, fixed point iterative methods.	7
2.	**Introduction to inverse problems:** Definition in terms of operator equation, Hadamard's criteria for well-posedness, examples, linear and nonlinear inverse problems, solutions of linear inverse problems using Moore-Penrose generalized inverse, solutions of compact linear inverse problems using self-adjoint operators.	9
3.	**Regularization theory:** Need of regularization, formal definition, parameter choice rules, order optimality, source representation for linear and compact operators, source sets, optimal algorithm and order optimal algorithm.	7
4.	**Continuous regularization methods:** Convergence and stability results, a-priori parameter choice rule for optimal order methods, saturation and converse results.	5
5.	**Tikhonov regularization:** Definition, Tikhonov functional, existence of minimizer of Tikhonov functional, convergence of Tikhonov minimizers, order optimality, relation of Tikhonov minimizer with Lagrange functional, Iterated Tikhonov regularization, convergence.	7
6.	**Iterative regularization**: Landweber iteration, convergence, discrepancy principle, finiteness of stopping index, stability results, order optimality, steepest descent method and minimal error method, Newton-type method (Levenberg-Marquardt method).	7
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Kreyszig, E., "Introductory Functional Analysis with Applications", John Wiley & Sons	1978
2.	Scherzer, O., Grasmair, M., Grossauer, H., Haltmeier, M. and Lenzen, F., "Variational Methods in Imaging", Applied Mathematical Sciences, vol 167, Springer.	2009
3.	Engl, H. W., Hanke, M., and Neubauer, A., Regularization of Inverse Problems, Springer Dordrecht.	2000
4.	Nair, M. T., "Linear Operator Equations: Approximation and Regularization", World Scientific Singapore.	2009
5.	Kaltenbacher, B., Neubauer, A., and Scherzer, O., "Iterative Regularization Methods for Nonlinear Ill-Posed Problems", Walter de Gruyter GmbH & Co. Berlin.	2008

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-541 **Course Title**: Representation Theory of Finite Groups
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Knowledge of abstract algebra.
9. **Objective:** To give an introduction to representation theory.
10. **Details of the Course**:

S.No.	Contents	Contact hours
1	Representations, subrepresentations, direct sums, tensor products, symmetric and alternating squares, Schur's lemma, complete reducibility, Maschke's theorem, group algebras, modules over group algebra, 1-dimensional representations and abelian groups.	10
2	Conjugacy classes, trace of a linear operator, character of a representation, class functions, orthogonality relations for characters.	6
3	Permutation representations, regular representation, number of irreducible representations, explicit decompositions, induced representations, irreducible representations of alternating and symmetric groups.	10
4	Integrality properties of characters, Burnside's theorem, the character of induced representation, Frobenius reciprocity theorem.	8
5	Meckey's irreducibility criterion, representation theory of GL(2,F), where F is a finite field.	8
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	James G. and Liebeck, M., "Representations and Characters of Groups", 2nd Ed., Cambridge University Press.	2012
2.	Serre, J. P. "Linear Representation of Finite Groups", Springer Verlag.	1977
3.	Steinberg, B., Representation Theory of Finite Groups, Springer.	2012
4.	Fulton, W. and Harris, J., "Representation Theory: A First Course", Springer-Verlag.	2009

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-542 **Course Title**: Semigroup Theory and Applications
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** PEC
8. **Pre-requisite:** Basics of differential equations and functional analysis.
9. **Objective:** To introduce the basic concepts of semigroup theory and its applications to partial differential equations.
10. **Details of the Course:**

S. No.	Contents	Contact hours
1	Generation and representations, uniformly continuous semigroup, C_0-semigroup, Hille-Yosida theorem, Lumer-Phillips theorem, characterization of the infinitesimal generator of C_0-semigroup, contraction semigroups on Hilbert spaces, inversion of the Laplace transform.	12
2	Abstract Cauchy problem, the homogeneous and the inhomogeneous initial value problems, regularity of mild solutions for analytic semigroups, asymptotic behavior of solutions, invariant and admissible subspaces.	10
3	Evolution equations, stable families of generators, evolution systems in hyperbolic and parabolic Cauchy problems, homogeneous and inhomogeneous equations, asymptotic behavior.	12
4	Applications to parabolic equations, L^2 and L^p theory, wave equation, Schrodinger equation.	8
Total		**42**

11. **Suggested Books:**

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Pazy, A., "Semigroups of Linear Operators and Applications to Partial Differential Equations", Springer.	1992
2.	Evans, L. C., "Partial Differential Equations", 2nd Ed., American Mathematical Society.	2010
3	Kesavan, S., "Topics in Functional Analysis and Applications", 3rd Ed., New Age International Publishers.	2019
4	Taira, K., "Analytic Semigroups and Semilinear Initial Boundary Value Problems", 2nd Ed., Cambridge University Press.	2016

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-543 **Course Title**: Sobolev Spaces and Applications
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** 3 Hrs **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC

8 Pre-requisite: Basics of functional analysis and partial differential equations.

9. **Objective:** To introduce the basic concepts of Sobolev spaces and their applications in partial differential equations.

10. Details of the Course:

S.No.	Contents	Contact hours
1.	Weak derivatives, definition and basic properties of Sobolev spaces, approximation by smooth functions, extension theorems, Poincaré's inequality, Sobolev's embedding theorems, compactness theorems, dual and fractional order spaces, trace theory, spaces involving time.	10
2.	Second order elliptic equations, variational formulation, weak solutions, Lax-Milgram theorem, regularity results, maximum principles, eigenvalues and eigenfunctions, Galerkin's approximation method.	10
3.	Second order parabolic equations, variational formulation, weak solutions, regularity results, Galerkin's approximation method, maximum principles.	10
4.	Second order hyperbolic equations, weak solutions, regularity results, propagation of disturbances.	5
5.	Nonvariational techniques, monotonicity methods, fixed point methods, nonlinear reaction-diffusion equations, nonexistence of solutions.	7
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Evans, L. C., "Partial Differential Equations," 2nd Ed., American Mathematical Society.	2010
2.	Kesavan, S., "Topics in Functional Analysis and Applications", 3rd Ed., New Age International Publishers,	2019
3	Brezis, H., "Functional Analysis, Sobolev Spaces and Partial Differential Equations", Springer.	2010
4.	Mitrovic, D. and Zubrinic, D., "Fundamentals of Applied Functional Analysis", Chapman and Hall/CRC.	1997
5.	Robinson, J. C., "Infinite-Dimensional Dynamical Systems", Cambridge University Press.	2001
6.	Adams, R. A. and Fournier, J. J. F., "Sobolev Spaces", 2nd Ed., Academic Press, Academic Press.	2003

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-544 **Course Title**: Statistical Inference
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic Probability and Statistics.
9. **Objective:** To introduce the concepts of statistical inference.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1.	**Principle of Data Reduction**: Sufficiency principle, factorization criterion, minimal sufficiency, completeness and bounded completeness, likelihood principle, equivariance principle.	8
2.	**Theory of Estimation**: Basic concepts of estimation, point estimation, method of moments, method of maximum likelihood; unbiasedness, consistency, efficiency, minimum variance estimation, Cramer – Rao bound and its generalization, Rao Blackwell theorem, existence of U.M.V.U.E estimators, interval estimation.	10
3.	**Testing of Hypothesis**: Null and alternative hypothesis, Type I and Type II errors, power function, method of finding tests, Neyman – Pearson lemma, uniformly most powerful tests, likelihood ratio principle, likelihood ratio test, sequential probability ratio test.	8
4.	**Bayesian Inference:** Loss function, risk function, admissibility, priors, Bayes risk, Bayes estimators under different loss functions, Lindley's approximation method, importance sampling method, real data analysis.	8
5.	**Nonparametric Inference:** Order statistics and their distributions, run test, sign test, Wilcoxon signed rank test, Kolmogorov-Smirnov test.	8
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Casella, G. and Berger, R. L., "Statistical Inference", 2nd Ed., Duxbury Press.	2002
2.	Thijssen, J., "A Concise Introduction to Statistical Inference", CRC Press.	2016
3.	Lehman, E.L., Romano, J. P., "Testing of Statistical Hypothesis", 3rd Ed., Springer.	2008
4.	Boos, D. D. and Stefanski, L. A., "Essential Statistical Inference: Theory and Methods", Springer.	2013
5.	Heard, N., "An Introduction to Bayesian Inference, Methods and Computation", Springer.	2021
6.	Lee, P.M., "Bayesian Statistics An Introduction", 4th Ed., John Wiley & Sons.	2012

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

1. **Subject Code:** MAL-545. **Course Title**: Stochastic Differential Equations
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic concepts of probability.
9. **Objective:** To introduce the theory of stochastic differential equations.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1	Basic notions of probability theory, Brownian motions, stochastic integrals, Itô's formula, moment inequalities, Grönwall-type inequalities.	8
2	Stochastic differential equations (SDE), existence and uniqueness of solutions, L^p-estimates, almost surely asymptotic estimates, linear stochastic differential equations, stochastic Liouville's formula, the variation of constants formula.	10
3	Relations between SDE and PDE, Feynman-Kac formula, solutions as Markov processes, generators and martingale problem.	6
4	Stability of stochastic differential equations, stability in probability, almost sure exponential stability, moment exponential stability, stochastic stabilization and destabilization.	10
5	Backward stochastic differential equations (BSDE), martingale representation theorem, equations with Lipschitz and non-Lipschitz coefficients, BSDE and quasilinear PDE.	8
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Mao, X., "Stochastic Differential Equations and Applications," 2nd Ed., Woodhead Publishing.	2007
2.	Øksendal, B., "Stochastic Differential Equations: An Introduction with Applications", 6th Ed., Springer.	2014
3	Kallianpur, G. and Sundar, P., "Stochastic Analysis and Diffusion Processes", Oxford University Press.	2014
4.	Pardoux, E. and Răscanu, A., "Stochastic Differential Equations, Backward SDEs, Partial Differential Equations", Springer.	2014
5.	Evans, L. C., "An Introduction to Stochastic Differential Equations", American Mathematical Society.	2014
6.	Karatzas, I. and Shreve, S., "Brownian Motion and Stochastic Calculus", 2nd Ed., Springer.	2004

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

1. **Subject Code:** MAL-546 **Course Title**: Stochastic Partial Differential Equations
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Basic concepts of probability and functional analysis.
9. **Objective:** To introduce the theory of stochastic partial differential equations.

10. Details of the Course:

S.No.	Contents	Contact hours
1	Hilbert space valued random variables and their integrals, conditional expectation and independence, Gaussian measures in Hilbert spaces, Kolmogorov continuity criterion, processes with filtration, martingales in Hilbert spaces.	8
2	Hilbert space valued Wiener processes, stochastic integral for generalized Wiener processes, properties of the stochastic integral, Ito's formula, stochastic Fubini's theorem, stochastic differential equations in infinite dimensions and applications to stochastic partial differential equations (SPDE).	11
3	Linear equations with additive and multiplicative noise, existence and uniqueness of solutions, continuity and regularity of solutions, stochastic parabolic and hyperbolic equations.	11
4	Existence and uniqueness for nonlinear equations, equations with Lipschitz nonlinearities, additive and multiplicative noise cases, strong, weak, martingale and mild solutions, Markov property, SPDE with locally monotone coefficients, absolute continuity and the Girsanov theorem.	12
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Da Prato, G. and Zabczyk, J., "Stochastic Equations in Infinite Dimensions," 2nd Ed., Cambridge University Press.	2014
2.	Liu, W. and Röckner, M., "Stochastic Partial Differential Equations: An Introduction", Springer.	2015
3	Gawarecki, L. and Mandrekar, V., "Stochastic Differential Equations in Infinite Dimensions", Springer.	2011
4.	Chow, P.-L., "Stochastic Partial Differential Equations", 2nd Ed., CRC Press.	2015
5.	Lototsky, S. V. and Rozovsky, B. L., "Stochastic Partial Differential Equations", Springer.	2017
6.	Prévôt C. and Röckner, M., "A Concise Course on Stochastic Partial Differential Equations", Springer.	2007

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAL-547 **Course Title**: Wavelet Analysis
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Complex Analysis and Functional Analysis.

9. Objective: To provide the theory necessary to understand and use wavelets and related constructions.

10. Details of the Course:

S. No.	Contents	Contact hours
1.	Fourier Analysis: Fourier and inverse Fourier transforms, continuous-time convolution and the delta function, Fourier transform of square integrable functions, Fourier series. Basic convergence theory and Poisson's summation formula.	10
2.	Wavelet Transforms and Basic Properties: The Gabor transform. basic properties of Gabor transforms. The integral wavelet transforms, dyadic wavelets andinversions. Basic properties of wavelet transforms.	10
3.	The discrete wavelet transforms. Orthonormal wavelets, wavelet frames and multiband, curvelets. Scaling functions and wavelets: Definition of multiresolution analysis and examples.	8
4.	Properties of scaling functions and orthonormal wavelet bases. Construction of orthonormal wavelets.	8
5.	Daubechie's wavelets and algorithms.	6
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Chui, C. K., "An Introduction to Wavelets, Academic Press", New York	1992
2.	Debnath, L., "Wavelet Transforms and Their Applications", Birkhauser, Boston, MA.	2022
3.	Daubechies, I., "Ten Lectures on Wavelets", In: CBMS-NSF Regional Conference Series in Applied Mathematics, SIAM Publication, Philadelphia, PA.	2006
4.	Hernandez, E., and Weiss, G. , "A First Course on Wavelets", CRC Press.	1999

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAT-101 **Course Title**: Numerical Optimization
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** TEB
8. **Pre-requisite:** Nil
9. **Objective:** To acquaint the students with the basics concepts of numerical optimization.
10. **Details of the Course:**

S. No.	Contents	Contact hours
1.	**Linear Programming:** Review of convex sets and various methods of linear programming.	5
2.	**Nonlinear Programming 1-D Unconstrained Minimization Methods:** *Elimination methods:* Unrestricted search, exhaustive search, dichotomous search, interval halving method, golden section, Fibonnacci search. *Interpolation methods:* Quadratic and cubic interpolation methods, Newton method, quasi-Newton method, secant method.	8
3.	**Multi-dimensional Unconstrained Minimization Methods:** *Direct search methods:* Random Search method, univariate method, pattern directions, Hooke & Jeeves methods, Powell method, Rosenbrock method, Nelder & Mead (simplex) method. *Indirect (descent) method:* Steepest descent method, conjugate gradient method, Newton method, Marquardt method, Quasi-Newton method, Dravidon-Flether-Powell (DFP) method.	10
4.	**Direct Method for Constrained Minimization:** Sequential linear programming method, Rosen's gradient projection method for linear constraints, Zoutendijk method of feasible directions for nonlinear constraints, generalized reduced gradient method for nonlinear constraints.	8
5.	**Indirect Method for Constrained Minimization:** Penalty function, interior penalty function method, exterior penalty function method, augmented Lagrange multiplier method.	6
6.	Implementation of the above methods using software.	5
	Total	**42**

11. **Suggested Books:**

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Rao, S. S., "Engineering Optimization: Theory and Practice", 5th Ed., John Wiley & Sons Inc.	2020
2.	Nocedal, J. and Wright S. J.: "Numerical Optimization", 2nd Ed., Springer Series in Operations Research, Springer-Verlag.	2006
3.	Deb, K.: "Optimization for Engineering Design Algorithms and Examples", Prentice Hall of India	1998
4.	Mohan, C. and Deep, K.: "Optimization Techniques", New Age International Pvt. Ltd.	2009
5.	Venkataraman, P., "Applied Optimization with MATLAB Programming", 2nd Ed., John Wiley & Sons, Inc.	2009
6.	Snyman, J. A., "Practical Mathematical Optimization", 2nd Ed., Springer.	2005

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAT-102 **Course Title**: Nonlinear Programming
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** TEB
8. **Pre-requisite:** Nil
9. **Objective:** To acquaint the students with the basics concepts and techniques of nonlinear programming.
10. **Details of the Course:**

S. No.	Contents	Contact hours
1.	Convex Functions, Karash Kuhn-Tucker Theory, Convex Quadratic Programming, Wolfe's, Beale and Pivot Complementary Algorithm, Separable Programming.	12
2.	Geometric Programming: Problems with positive co-efficient up-to one degree of difficulty, Generalized method for problems with positive and negative coefficients.	6
3.	Dynamic Programming: Discrete and continuous Dynamic Programming, Simple illustrations.	6
4.	Search Techniques: Direct Search and Gradient Methods, Unimodal Functions, Fibonacci Method, Golden Section Method, Method of Steepest Descent, Newton Raphson Method, Hookes and Jeeves Method, Conjugate Gradient Methods.	11
5.	Constrained optimization: Penalty function approach, Barrier Function Approach.	2
6.	Multi-objective and Goal Programming.	5
	Total	**42**

11. **Suggested Books:**

S. No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Bazaraa, M., Sherali, H. D. and Shetty, C. M., "Nonlinear Programming: Theory and Algorithms", 3rd Ed., Wiley-Interscience.	2009
2.	Taha H. A., "Operations Research: An Introduction", 10th Ed., Pearson Education, India.	2019
3.	Ravindran A, Phillips D. T., Solberg J. J., "Operations Research: Principles and Practice", John Wiley and Sons, NY, Second Edition (Reprint).	2012
4.	Pant J. C., "Introduction to Optimization/ Operations Research", 7th Ed., Jain Brothers, New Delhi.	2008
5.	Mittal K. V., Mohan, C., "Optimization Methods in System Analysis and Operations Research", 5th Ed., New Age International Pvt. Ltd., Delhi.	2020

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAT-103 **Course Title**: Numerical Analysis
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester: :** Both **7. Subject Area:** TEB
8. **Pre-requisite:** Basic course in numerical methods.
9. **Objective:** To discuss the numerical methods and their analysis for solving differential equations.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1.	**Computation of Eigenvalues of a Matrix:** Method of inflation, Jacobi, Givens and Householder methods for symmetric matrices, LR and QR methods.	5
2.	**Initial Value Problems:** Multistep methods, Error and stability analysis.	6
3	**Stiff Problems and Boundary Value Problems:** Stability of numerical methods for stiff systems, Backward differentiation methods for stiff systems, Gear's method, Boundary value problems, Shooting methods, Matrix methods for linear and non-linear boundary values problems, Collocation method.	8
4.	**Finite Differences:** Review of finite difference operators, finite difference methods, inverse interpolation- developments and applications.	2
5.	**Elliptic PDE:** Error analysis of the Poisson problem, The general diffusion equation, Boundary conditions on a curved boundary, Error analysis using a maximum principle, Asymptotic error estimates.	7
6.	**Parabolic PDE:** Concept of compatibility, convergence and stability, explicit, full implicit, Crank-Nicholson, du-Fort and Frankel scheme, ADI methods to solve two-dimensional equations with error analysis.	7
7.	**Hyperbolic PDE:** Characteristics, The CFL condition, Error analysis of the upwind scheme, Fourier analysis of the upwind scheme, The Lax–Wendroff scheme, The box scheme, The leap-frog scheme.	7
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Smith, G. D., Numerical Solution of Partial Differential Equations, Oxford University Press.	2001
2	Gerald, C. F. and Wheatly P. O., Applied Numerical Analysis, 6th Ed., Addison-Wesley Publishing.	2002
3	Froberg, C. E., Introduction to Numerical Analysis, 2nd Ed., Addison-Wesley.	2004
4	Fausett, L. V., Applied Numerical Analysis, Prentice Hall, 2nd Ed.	2007
5	Morton K. W. and Mayers D. F. Numerical Solution of Partial Differential Equations, 2nd Ed., Cambridge University Press.	2012
6	Iserles A. A first course in the numerical analysis of differential equations, 2nd Ed, Cambridge University Press.	2012

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAT-104 **Course Title**: Finite Element Methods
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** TEB
8. **Pre-requisite:** Basic knowledge of numerical methods, linear algebra and analysis
9. **Objective:** To give an introduction of the finite element method for the numerical solution of PDEs.
10. **Details of the Course:**

S.No.	Contents	Contact hours
1	Piecewise polynomial spaces in 1D, interpolation, L^2 projection, FEM for two-point boundary value problem, mathematical modeling, adaptive FEM, implementation.	8
2	Meshes, piecewise polynomial spaces in 2D, interpolation, L^2 projection, FEM for Poisson's equations, basic analysis of FEM, eigenvalue problems, adaptive FEM, implementation.	8
3	Heat equation, stability estimates, a priori estimates, a posteriori error estimates, wave equation.	8
4	Direct/iterative methods, preconditioning.	5
5	Function spaces, interpolation of functions in Hilbert spaces, abstract finite element approximation.	8
6	The non-linear Poisson equation, finite element approximation, the bistable equation, numerical approximation of the Jacobian.	5
Total		**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1	Johnson, C., "Numerical Solution of Partial Differential Equations by the Finite Element Method", Dover Publications.	2009
2	Brenner, S. and Scott, L. R., "The Mathematical Theory of Finite Element Methods", 3rd Ed., Springer-Verlag	2008
3	Braess, D., "Finite Elements: Theory, Fast Solvers and Applications in Solid Mechanics", Cambridge University Press	2007
4	Verfurth, R., "A Posteriori Error Estimation Techniques for Finite Element Methods", Oxford Science Publication	2013

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAT-105 **Course Title**: Financial Mathematics
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both **7. Subject Area:** TEB
8. **Pre-requisite:** Basic concepts of probability.
9. **Objective:** To introduce basic notions and fundamental models in financial mathematics.
10. **Details of the Course**

S.No.	Contents	Contact hours
1.	Simple market model, basic notions and assumptions, hedging, speculation, arbitrage, no-arbitrage principle, risk-free assets, time value of money, future and present values of a single amount and of an annuity, intra-year compounding and discounting, continuous compounding.	5
2.	Derivative contracts: forward, future and options, pricing of forward and future contracts, call and put options, put-call parity, European and American options, bounds on options, variables determining option prices, trading strategies.	9
3.	Cox-Ross-Rubenstein (CRR) model: numeraire, trading strategy, value process, gain process, self-financing trading strategy, arbitrage free market, equivalent martingale measure (EMM), risk neutral valuation formula, complete market, fundamental theorem of asset pricing (FTAP), One, two and three period Binomial tree model, risk neutral pricing, hedging, valuation of American and exotic options, binomial approximation.	10
4.	Black-Scholes-Merton Model: numeraire, trading strategy, value process, gain process, self-financing trading strategy, arbitrage free market, equivalent martingale measure (EMM), risk neutral valuation, complete market, fundamental theorem of asset pricing (FTAP), review of Itô's integral, Itô's lemma and geometric Brownian motion, Black-Scholes-Merton PDE, Feynman-Kac formula, martingale approach to pricing, assumptions of Black-Scholes-Merton model, implied volatility, volatility smile, volatility smirk/skew, etc., static hedging, delta hedging and Greeks.	11
5.	Extension of CRR and Black-Scholes-Merton model to dividends, currencies, consumption commodities and other non-tradeable assets, interest rate derivatives, short-rate models, Vasicek model, Cox-Ingersoll Ross (CIR) model, Ornstein-Uhlenbeck process.	7
	Total	**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Capinski, M. and Zastawniak, T., "Mathematics for Finance: An Introduction to Financial Engineering", 2nd Ed., Springer.	2010
2.	Teall, J. L. and Hasan, I., "Quantitative Methods for Finance and Investments", Blackwell Publishing.	2002
3.	Hull, J. C., "Options, Futures and Other Derivatives",10th Ed., Pearson Education.	2018
4.	Chandra, P. , "Financial Management: Theory and Practice", 10th Ed., McGraw Hill Education, India.	2019
5.	Wilmott, P., Howison S. and Dewynne, J., "The Mathematics of Financial Derivatives: A Student Introduction", Cambridge University Press.	1995
6.	Bingham, N. H. and Kiesel, R., "Risk Neutral Valuation: Pricing and Hedging of Financial Derivatives", 2nd Ed., Springer-Verlag London.	2004

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAT-106 **Course Title**: Financial Risk Management
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 04 6. **Semester:** Both 7. **Subject Area:** TEB
8. **Pre-requisite:** Basic concepts of probability and statistics.
9. **Objective:** To introduce tools of financial risk management from regularity and modelling perspectives.
10. **Details of the Course**

S.No.	Contents	Contact hours
1.	Introduction to risk management, development of financial markets, financial crisis and systemic risk, bank, insurance regulation, market regulation.	3
	Market Risk: regularity capital, coherent risk measures, value-at-risk (VaR) and expected shortfall (ES), historical, analytical and Monte Carlo methods for VaR and ES.	6
2.	Credit Risk: Overview of credit market namely loan market, bond market & credit securitization, credit default swap, basket default swap, collateral debt obligation (CDO), regularity capital, credit risk modelling, exposure at default, loss given default, probability of default, default correlation; counterparty credit risk (CCR), modelling the exposure at default, regularity capital, wrong way risk, credit valuation adjustment (CVA), debit value adjustment (DVA), bilateral CVA, regulatory capital, CVA and wrong/right way risk, collateral risk & capital allocation.	10
3.	Time series modelling: ARMA process, state space models, cointegration and error correction models, GARCH and stochastic volatility models, spectral analysis.	8
4.	Copulas and dependence modelling: Sklar's theorem, Fréchet classes, countermonotonicity, comonotonicity, dependence measure, parametric copula functions	8
5.	Extreme value theory: order statistics, univariate extreme value theory, multivariate extreme value theory	7
	Total	**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	T. Roncalli, "Handbook of Financial Risk Management", CRC Press, Taylor & Francis Group.	2020
2.	F. J. P. García, "Financial Risk Management: Identification, Measurement and Management", Springer International Publishing.	2017
3.	M. B. Miller, "Quantitative Financial Risk Management", Wiley.	2018
4.	J. Danielsson, "Financial Risk Forecasting: The Theory and Practice of Forecasting Market Risk with Implementation in R and Matlab", Wiley.	2011
5.	Y. Malevergne and D. Sornette, "Extreme Financial Risks From Dependence to Risk Management", Springer	2006
6.	A. J. McNeil, R. Frey and P. Embrechts, "Quantitative Risk Management Concepts, Techniques, and Tools", Princeton University Press.	2010
7.	R. B. Nelsen, "An Introduction to Copulas", 2nd Ed., Spinger.	2006

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

1. **Subject Code:** MAO-101 **Course Title**: Optimization Techniques
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
4. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Spring **7. Subject Area:** OEC
8. **Prerequisite:** NIL
9. **Objective:** To acquaint the students with the basic concepts of Optimization.

10. **Details of the Course**

S. No.	Contents	Contact Hours
1.	Different Types of OR Models, Case studies in Engineering applications.	2
2.	Convex Sets, Graphical Method, Simplex Method, Big – M Method, Two-Phase Method, Revised Simplex Method	10
3.	Duality Theory, Dual Simplex Method, Sensitivity Analysis.	7
4.	Cutting Plane and Branch and Bound Techniques for all Integer and Mixed Integer Programming Problems, 0-1 Integer Problems, Travelling Salesman Problem, Cargo Loading Problem.	9
5.	Transportation Problems and Assignment Problems.	4
6.	Game Theory: Rectangular Games, Minmax Theorem, Graphical solution of $2 \times n$ and $m \times 2$ games, reduction to Linear Programming Problems.	5
7.	Sequencing and Scheduling: Processing of Jobs through Machines, CPM and PERT.	5
	Total	**42**

11. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Taha, H.A., "Operations Research: An Introduction", 10th Ed., Pearson Education, India.	2019
2.	Ravindran, A., Phillips, D.T. and Solberg, J.J., "Operations Research: Principles and Practice", John Wiley and Sons, NY, Second Edition (Reprint).	2012
3.	Pant, J.C., "Introduction to Optimization", 7th Ed., Jain Brothers	2015
4.	Hillier, F. S. and Lieberman, G. J., "Introduction to Operations Research," 11th Ed., McGraw-Hill India.	2021
5.	Mittal, K.V. and Mohan, C., "Optimization Methods in System Analysis and Operations Research", New Age International Publishers.	1996

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

6. **Subject Code:** MAO-102 **Course Title**: Advanced Engineering Mathematics
7. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
8. **Examination Duration (Hrs.):** **Theory:** 03 **Practical:** 00
9. **Relative Weightage:** **CWS:** 20-35 **PRS: 0** **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
10. **Credits:** 4 **6. Semester:** Autumn **7. Subject Area:** OEC
12. **Prerequisite:** NIL
13. **Objective:** To impart the knowledge of essential mathematical tools of complex variables, partial differential equations and calculus of variations to engineering students

14. **Details of the Course**

S. No.	Contents	Contact Hours
1.	**Functions of a Complex Variable**: Analytic functions, conjugate harmonic functions, applications to the problems of potential flow.	6
2.	**Conformal Mapping:** Bilinear transformations, Schwartz-Christoffel transformations and their applications to engineering problems.	6
3.	**Complex Integration**: Line integrals, Cauchy integral theorem, Taylor's and Laurent's expansions, zeros and singularities, Cauchy residue theorem, contour integration and its applications.	10
4.	**Partial Differential Equations**: Solution of first order quasi linear equations, four standard forms of PDE, solution of first order non-linear PDE using Charpit's method, solution of linear equations with constant coefficients, classification of second order PDE, solution of one dimensional wave and diffusion equations, Laplace equation in two and three dimensions.	12
5.	**Calculus of Variations**: Functionals, Euler's equations for one and several variables, isoperimetric problems, sufficient conditions for weak and strong maxima and minima, applications.	8
	Total	**42**

15. **Suggested Books:**

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Brown, J. A. and Churchill, R. V., "Complex Variables and Applications", 9th Ed., Mc Graw Hill.	2021
2.	Jain R. K., Iyengar S. R. K., "Advanced Engineering Mathematics", 5th Ed., Narosa Publishing House, India.	2019
3.	Grewal, B. S., "Higher Engineering Mathematics", Khanna Publishers.	2020
4.	Kreyszig, E. "Advanced Engineering Mathematics", 10th Ed., John Wiley.	