UNIVERSITY OF LUCKNOW
DEPARTMENT OF MATHEMATICS AND ASTRONOMY
SYLLABUS OF M.A./M.Sc. (MATHEMATICS) TWO YEAR PROGRAMME
(SESSION 2025-26 ONWARDS)

M.A./M.Sc. SEMESTER I

Core Course 1: Topology

Credit: 4 **T:04**

Course Outcomes:

1. Define and illustrate the concept of topological spaces and continuous functions,
2. Illustrate the concept of limit point, dense sets, interior, exterior, boundary points.
3. Identify and understand bases, sub-bases and different type of spaces like Lindelof, separable, and their properties.
4. Understand the concept of compact spaces, connected spaces, locally compact spaces & locally connected spaces.

Unit I

Countable and uncountable sets, Schroeder-Bernstein theorem, Cantor's Theorem, Cantor's Sets, Cantor's continuum hypothesis, Zorn's Lemma, Well ordering principle.

Unit II

Topological spaces: Definitions and Examples, open base and open subbase for a topology, Lindelof theorem, limit points, closure, interior; Continuous functions, Homeomorphisms; relative topology, Metric Topology, Product Topology, Weak topology, The function algebras C(X,R) and C(X,C).

Unit III

Compact spaces, Heine Borel theorem, product of spaces, Tychonoff theorem, generalized Heine Borel theorem, locally compact spaces, compactness for metric spaces, Ascoli's theorem.

Unit IV

Separation Axioms: T_1 and Hausdorff spaces, completely regular and normal spaces, Urysohn's lemma; Tietze extension theorem, Urysohn's imbedding theorem; Stone Cech compactification.

Unit V

Connected spaces, the components of a space, totally disconnected space, locally connected space.

References

Text Books:

1. G.F. Simmons: Introduction to Topology and Modern Analysis, Mc-Graw Hill Book Company.
2. J.R.Munkres: Topology - A first course, Prentice Hall India Pvt. Ltd.

Suggested Readings:

1. J.L. Kelley: General Topology. Van Nostrand. Reinhold Co, New York 1995

Web References:

Digital platforms web links: NPTEL/SWAYAM/ MOOCS/Openstax.org
https://openlearninglibrary.mit/edu/courses
http://heecontent.upsdc.gov.in/SearchContent.aspx
https://www.lkouniv.ac.in/en/article/e-content-faculty-of-science

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Core Course 2: Module Theory

Credit: 4 **T:04**

Course Outcomes:

1. Identify cyclic modules, simple modules, finitely generated modules etc.
2. Find a basis of a free module.
3. Use the basis to describe module homomorphisms.
4. Describe the structure of a finitely generated module over a PID.

Unit I

Modules: definition and examples, simple modules, submodules, module homomorphisms, quotient modules, torsion free and torsion modules.

Unit II

Direct sum of modules, exact sequences, short exact sequence, split exact sequences. Five lemma.

Unit III

Free modules, modules over division rings are free modules, invariant rank property.

Unit IV

Free modules over PIDs, invariant factor theorem for submodules, finitely generated modules over PID, chain of invariant ideals, fundamental structure theorem for finitely generated module over a PID.

Unit V

Projective and injective modules, divisible groups.

References:

Text Books:

1. V.Sahai and V. Bist: Algebra, Fourth Edition, Narosa.
2. I.B.S. Passi and I.S. Luther: Algebra, Volume 3 Modules, Narosa

Suggested Readings:

1. S. Lang: Algebra, Addison Wesley.

Web References:

Digital platforms web links: NPTEL/SWAYAM/ MOOCS/Openstax.org
https://openlearninglibrary.mit/edu/courses
http://heecontent.upsdc.gov.in/SearchContent.aspx
https://www.lkouniv.ac.in/en/article/e-content-faculty-of-science

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Core Course 3: Differential Geometry of Manifolds

Credit: 4 **T:04**

Course Outcomes:
1. Elaborate the concept of differentiable manifolds and their examples.
2. Clarify the concepts of vector fields, tangent vectors & tangent spaces in a manifold.
3. Apply various concepts of differential calculus to the settings of abstract set called manifold.
4. Use Riemannian metric on a given manifold to find the various types of curvatures with emphasis on the surface/ types of manifold.
5. Bring out different connections on Riemannian manifold and its properties.
6. Calculate curvature tensor & tensors of respective connections.

Unit I
Definition and examples of differentiable manifolds, tangent vectors, tangent spaces, vector fields and their examples, Jacobian map.

Unit II
Immersions and submersions, diffeomorphism and their examples, curve in a manifold, integral curves and their examples, distributions, hypersurface of R^n, submanifolds.

Unit III
Standard connection on R^n, covariant derivative, sphere map, Weingarten map, Gauss equation, Gauss curvature equation and Coddazi-Mainardi equations.

Unit IV
Invariant viewpoint, Cartan view point, coordinate view point, difference tensor of two connections, torsion and curvature tensors.

Unit V
Riemannian manifolds, length and distance in Riemannian manifolds, Riemanian connection and curvature, curves in Riemannian manifolds, submanifolds of Riemannian manifolds.

References:
Text Books:

1. N.J. Hicks: Notes on Differential Geometry, D. Van Nostrand, 1965.
2. U. C. De, A. A. Shaikh: Differential Geometry of Manifolds, Narosa Publishing House.

Suggested Readings:

1. Y. Matsushima: Differentiable Manifolds, Marcel Dekker, Inc. New York, 1972.

Web References:

Digital platforms web links: NPTEL/SWAYAM/ MOOCS/Openstax.org
https://openlearninglibrary.mit/edu/courses
http://heecontent.upsdc.gov.in/SearchContent.aspx
https://www.lkouniv.ac.in/en/article/e-content-faculty-of-science

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Core Course 4: Fluid Mechanics

Credit: 4 **T:04**

Course Outcomes:
1. Understand the concept of fluid and their classification, models and approaches to study the fluid flow.
2. Formulate mass and momentum conservation principle and obtain solution for non viscous flow.
3. Know potential theorems, minimum energy theorem and circulation theorem.
4. Understand two dimensional motion, circle theorem and Blasius theorem.

Unit I
Types of fluids, Continuum hypothesis, Lagrangian and Eulerian method of describing fluid motion, Motion of Fluid element: Translation, Rotation and Deformation. Stream lines, Path lines and streak lines. Material derivative. Acceleration of a fluid particle in Cartesian, Cylindrical Polar and Spherical Polar Coordinates. Vorticity Vector, Vortex Lines, Rotational and Irrotational motion of fluid, Rotational velocity, Velocity Potential, Boundary surface, Boundary condition.

Unit II
Reynold transport theorem. Principle of conservation of Mass-Equation of continuity (By Lagrangian and Eulerian method). Equation of Continuity in different coordinate systems. Body force and Surface force. Euler's equation of motion-conservation of momentum, Bernoulli's Equation, Energy Equation, Impulsive effects.

Unit III
Irrotational motion in two dimensions: Stream function, Physical significance of stream function, source,sink, Doublet and vortex, their images in two dimension. Complex Velocity Potential. Milne-Thompson circle theorem .

Unit IV
Vortex, Vortex motion, Image of Vortex, Kelvin Circulation Theorem, Complex potential due to row of Vortex, Kirchhoff vortex Theorem, Blasius Theorem and Kutta-Joukowski Theorem.

Unit V
Irrotational motion produced by motion of circular cylinders in an infinite mass of liquid, Liquid Streaming past circular cylinder, Kinetic energy of liquid, Motion of sphere through a liquid at rest at infinity. Liquid streaming past a fixed sphere, Axis-Symmetric flow, Stoke's function.

References:
Text Books:

1. F. Chorlton: Text Book of Fluid Dynamics, C.B.S. Publishers, Delhi.
2. Z.U.A. Warsi: Fluid Dynamics, Theoretical and Computational Approaches, CRC Press.
3. S.W. Yuan: Foundation of Fluid Mechanics, Prentice Hall of India Pvt. Ltd. New Delhi.
4. N. Curle and H.J. Davies: Modern fluid dynamics, Van Nostrand.

Suggested Readings:

1. G. K. Bachelor: An Introduction to Fluid Dynamics. Cambridge University Press. London.
2. R.W. Fox, P.J. Pritchard and A.T. McDonald: Introduction to Fluid Mechanics, Seventh Edition, John Wiley & Sons, 2009.

Web References:

Digital platforms web links: NPTEL/SWAYAM/ MOOCS/Openstax.org
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http://heecontent.upsdc.gov.in/SearchContent.aspx
https://www.lkouniv.ac.in/en/article/e-content-faculty-of-science

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Core Course 5: Cryptography I

Credit: 2 **T:02**

Course Outcomes:
After the completion of the course, students are expected to have the ability of:
1. A broad theoretical background in cryptography.
2. Understanding of traditional ciphers and their cryptanalysis.
3. Understanding of working of modern stream and Block cipher.
4. Understanding of construction of finite fields.
5. Understanding of symmetric key cryptography.

Unit I
Definition of Cryptosystem, Symmetric cipher model, Mono and Poly alphabetic traditional Substitution ciphers e.g. Additive cipher, Ceasar cipher, Playfair cipher, Hill cipher, one time pad, Vigenere cipher.

Unit II
Transposition ciphers, cryptanalysis of these traditional ciphers, Stream and block cipher definition, linear feedback shift register (LFSR).

Unit III
Modern stream cipher based on LFSR, RC-4 stream cipher and A5/1 stream cipher.

Unit IV
Modern Block cipher, Feistel cipher, Data encryption standard (DES) block cipher, S-box design of DES.

Unit V
Construction of finite fields, modular polynomial arithmetic, advance encryption standard (AES), block cipher, S-box design of AES, cryptographic properties of Boolean functions, vectorial Boolean functions.

Books Recommended:

1. Behrouz A. Forouzan: Cryptography and network security, Tata McGraw-Hill.
2. William Stallings: Cryptography and network security Principles and practices, Pearson Education.

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Value Added Credited Course (Intradepartmental): Mathematical Biology

Credit: 2 **T:02**

Course Outcomes:
After the completion of the course, students are expected to have the ability to:

1. Identify and explain the role of mathematics in the process of modelling in the field of natural and social sciences.
2. Apply the various growth models of population
3. Explain and apply the models of harvesting and mutualism

Unit I
Continuous population model for single species, exponential population growth model, continuous population growth model: Malthus model for population growth, general population growth model.

Unit II
Qualitative analysis: equilibrium points, stability analysis, logistic population growth model and their qualitative analysis, logistic growth model for non isolated population.

Unit III
Harvesting a single natural population, constant effort harvesting, constant yield harvesting.

Unit IV
Continuous models for interacting population: Interaction between species, two species models, definition of stability, community matrix approach, Competition: Lotka-Volterra models, competition in field experiments, competition for space.

Unit V
Predator-Prey interaction, Lotka-Volterra models, dynamics of simple Lotka-Volterra models.

Books Recommended:

1. J.D.Murray: Mathematical Biology, Springer-Verlag, Berlin.
2. A. Hasting: Population Biology Concepts and Models, Springer.
3. J. Mazumdar: An introduction to Mathematical Physiology and Biology, Cambridge University Press.
4. F. Brauer, C. Castillo-Chavez: Mathematical Models in Population Biology and Epidemiology, Springer, New York.

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M.A./M.Sc. SEMESTER II

Core Course 6: Functional Analysis

Credit: 4 **T:04**

Course Outcomes:
After the completion of the course, students are expected to have the ability to :
1. Apply Holder's and Minkowski's inequalities.
2. Construct conjugate of a linear operator.
3. Basic understanding of orthogonal and orthonormal sets.
4. Construct complete orthonormal basis from a given linearly independent set.
5. Describe the spectral theorem.

Unit I
Banach Spaces: the definition and some examples, continuous linear transformations, the Hahn Banach theorem.

Unit II
The natural imbedding of N in N**, the open mapping theorem, the closed graph theorem, uniform boundedness theorem, the conjugate of an operator.

Unit III
Hilbert spaces: the definition and some simple properties, orthogonal complements, orthogonal sets, the conjugate space H*.

Unit IV
The adjoint of an operator, self adjoint operators, normal and unitary operators, projections.

Unit V
Finite dimensional spectral theory: spectrum of an operator, the spectral theorem, uniqueness of spectral decomposition.

Books Recommended :

1. G. F. Simmons: Introduction to Topology & Modern Analysis, McGraw Hill.
2. V.B. Limaye: Functional Analysis, Wiley Eastern Ltd.

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Core Course 7: Riemannian Manifolds and Bundle Theory

Credit: 4 **T:04**

Course Outcomes:

1. Use Riemannian metric for studying various types of curvatures in a manifold and to calculate Ricci tensor & Ricci curvature.
2. Recognize whether a given manifold is Einstein or not.
3. Explain Levi-Civita connection, Koszul connection and other important connections which are used in manifolds.
4. Understand the concepts of tensors and forms.
5. Understand covariant derivative and contraction in manifolds.
6. Understand Lie groups and Lie algebras with examples.
7. Explain the idea of principal fibre bundle, linear fibre bundle and the relation between them.

Unit I

Sectional curvature, Schur's theorem, Riemannian manifold, geodesic in a Riemannian manifold, projective curvature tensor, concircular curvature tensor, conformal curvature tensor, conharmonic curvature tensor, Einstein manifolds.

Unit II

Levi-Civita connection, linear connection, semi-symmetric connection, quarter symmetric connection, Koszul formula, Ricci identity.

Unit III

Tensors and forms, exterior derivative, contraction, Lie derivative, general covariant derivative.

Unit IV

Lie groups and Lie algebras with examples, homomorphism, isomorphism, one parameter subgroups and exponential map, Lie transformation group.

Unit V

Principal fibre bundle, linear frame bundle, associated bundles, tangent bundle.

Books Recommended:

1. N.J. Hicks: Notes on Differential Geometry, D. Van Nostrand, 1965.
2. B.B. Sinha: An introduction to Modern Differential Geometry, Kalyani Publishers
3. U. C. De, A. A. Shaikh: Differential Geometry of Manifolds, Narosa Publishing House.

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Core Course 8: Advanced Fluid Mechanics

Credit: 4 **T:04**

Course Outcomes:

1. Understand the concept of fluid and their classification, models and approaches to study the fluid flow.
2. Formulate mass and momentum conservation principle and obtain solution for non- viscous flow.
3. Understand two dimensional motion, circle theorem and Blasius theorem.
4. Understand the concept of stress and strain in viscous flow and to derive Navier-Stokes equations of motion and solve some exactly solvable problems.

Unit I

Newton's law of viscosity, nature of stress, stress components in real fluid, symmetry of stress tensor. Transformation of stress components. Stress invariants, Principal Stresses, Nature of Strain, Rates of strain components, transformation of rate of strain components, Rate of Strain Quadric, Relation between Stress and rate of Strain, Boundary conditions for viscous fluid.

Unit II

Navier-Stokes equation of motion-Conservation of momentum, Navier-Stokes equations in orthogonal coordinate systems (particularly in Cartesian, cylindrical and spherical coordinate systems), Energy Equation- Conservation of Energy, Energy dissipation function, Energy dissipation due to viscosity, Diffusion of vorticity.

Unit III

Plane Poiseuille and Couette flows between two parallel plates, Steady viscous flow through tubes of uniform cross-section in form of circle, ellipse and equilateral triangle under constant pressure gradient. Flow between two co-axial cylinders and concentric spheres, unsteady viscous flow over a flat plate.

Unit IV

Dynamical similarity, Reynolds number, slow viscous flow, Stoke's flow. Solution of Stokes equations, uniform flow past a sphere at low Reynolds number, torque and drag on a sphere due to a uniform flow. Flow past a circular cylinder, Stokes paradox.

Unit V:

Prandtl's boundary layer concept, boundary layer thickness- displacement, momentum of energy. momentum and energy integrals, condition for separation, boundary layer flow along a semi-infinite plate in a uniform stream, Blasius solution. Integral Theorem.

Books Recommended:

1. G. K. Batchelor: An Introduction to Fluid Dynamics, Cambridge University Press
2. F. Chorlton: Text Book of Fluid Dynamics, C.B.S. Publishers, New Delhi.
3. Z.U.A. Warsi: Fluid Dynamics, Theoretical and Computational approaches, C.R.C. Press
4. S.W. Yuan: Foundation of Fluid Mechanics, Prentice Hall of India Pvt. Ltd., New Delhi
5. L. Rosenhead: Laminar Boundary layer, Oxford Press
6. R.W. Fox, P.J. Pritchard and A.T. McDonald: Introduction to Fluid Mechanics, Seventh Edition, John Wiley & Sons, 2009
7. J. Happel and H. Brenner: Low Reynolds Number Hydrodynamics with Special Applications to Particulate Media, Prentice-Hall, Inc. 1965

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Core Course 9: Approximation Theory

Credit: 4 **T:04**

Course Outcomes:

After the completion of the course, students are expected to have the ability to:

1. Understand the concepts of interpolation processes, finite element methods etc.
2. Apply the knowledge of the theory, in research on this area.
3. Use the Weierstrass Approximation theorem, first lacunary interpolation i.e., (0, 2) interpolation and spline interpolation.

Unit I
Different types of approximations, Weierstrass approximation theorem, monotone operators, Markoff inequality, Bernstein inequality.

Unit II
Hermite and HF interpolation, Fejérs theorem for HF interpolation, Lobatto and Radau quadrature formulas, (0, 2)-interpolation on the nodes of $\pi_n(x)$, existence, uniqueness.

Unit III
Explicit representation of (0,2) interpolation, existence, uniqueness and explicit representation of Pál type (0;1) interpolation on the zeroes of $\pi_n(x)$.

Unit IV
Erdös-Túran Theorem, Jackson's theorems (I to V), Dini-Lipschitz theorem, converse of Jackson's theorem, Bernstein theorems (I, II, III), Zygmund theorem.

Unit V
Spline interpolation, existence, uniqueness, explicit representation of cubic splines, certain extremal properties and uniform approximation.

Books Recommended:

1. T.J. Rivlin: An Introduction to the Approximation of Functions, Dover Publications, NY.
2. E. W. Cheney: Introduction to Approximation Theory, McGraw-Hill Book Company.
3. A. Ralston: A First Course in Numerical Analysis, McGraw-Hill Book Company.

Core Course 10: Cryptography II

Credit: 2 **T:02**

Course Outcomes:

After the completion of the course, students are expected to have the ability of:

1. A broad theoretical background in cryptography.
2. Understanding of Public key cryptography (PKC).
3. Understanding of some methods PKC.
4. Understanding of digital signature.
5. Understanding of Elliptic curves and Elliptic curve cryptography.
6. Understanding of some modern factorization methods and discrete log finding methods.

Unit I

Public key cryptosystem (PKC) or asymmetric cryptography, design of PKC e.g one way function and trapdoor function.

Unit II

Discrete logarithm, discrete log problem (DLP), Diffie Hellman key exchange, RSA cryptosystem, Rabin cryptosystem, ElGamal encryption.

Unit III

Message integrity, Hash function, cryptographic hash function, Hash function based on block ciphers

Unit IV

Message authentication, Message authentication codes (MAC), digital signature, RSA digital signature scheme, ElGamal digital signature scheme.

Unit V

Elliptic curves, Elliptic curve arithmetic, Elliptic curve cryptography, some modern factorization techniques e.g. p-1 method, quadratic sieve, number field sieve, some techniques of finding discrete logarithm: Shanks Baby step Giant step algorithm, Pollard rho algorithm, Pohlig-Hellman algorithm.

Books Recommended:

1. Behrouz A. Forouzan: Cryptography and network security, Tata McGraw-Hill.
2. W. Stallings: Cryptography and network security Principles and practices, Pearson Education.

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Interdepartmental Course A: Astronomy & Astrophysics

Credit: 2 **T:02**

Course Outcomes:

After the completion of the course, students are expected to have the ability to:

1. Use Celestial Coordinates system to specify the positions of stars, planets, satellites, galaxies and other celestial objects in three dimensional space
2. Explore the parent star Sun and its importance for sustaining life on the earth
3. Show familiarity with techniques to explore the solar surface temperature
4. Understand the solar atmosphere and its effect on the Earth and other planets
5. Understand the origin of the solar system
6. Explore the Terrestrial, Jovian & Dwarf planets, Comets and Meteoroids.
7. Describe the formation and evolution of stars which is a key research field for all major questions in astrophysics and cosmology
8. Illustrate Hertzsprung-Russell Diagram which is a graphical tool that astronomers use to classify stars according to their luminosity, spectral type, color, temperature and evolutionary stage
9. Plot the stars on the H-R diagram according to their temperatures, spectral classes, and luminosity by which astronomers can classify stars into their different types
10. Show understanding about the Binary star systems which are very important in astrophysics because calculations of their orbits allow the masses of their component stars to be directly determined, that in turn allows other stellar parameters, such as radius and density, to be indirectly estimated
11. Describe that the Galaxies are organized clusters of billions of stars, gas, dust, and matter in all other forms, all bound by the force of gravity
12. Provide details about their Milky Way, the galaxy containing our universe

Unit I: Celestial sphere
Constellations and nomenclatures of stars, The cardinal points and circles on the celestial sphere, Coordinate system, Equatorial, Ecliptic system, Hour angle, Twilight, Spherical triangle, Polar triangle and related problems.

Unit II: The Sun and Planets
Sun: Interior structure of the Sun, atmosphere, solar activity, sunspots and magnetic field, solar wind.
Planets: Study of Terrestrial planets, Jovian planets- their surface features & atmospheres. Tidal forces, Roche limit.
Dwarf planets: Definitions and locations.
Debris of the Solar system: Comets, Asteroids, Meteoroids.

Unit III: Stellar Structure and Evolution
Stars: Magnitude scales, Colour index, Basic of star formation and evolution. Hertzsprung-Russell (HR) diagram, Spectral classification, Energy generation of stars.
Basics of degenerate remnants of stars: White dwarfs, Neutron stars, Pulsars, Black Holes, Chandrasekhar limit.

Unit IV: High Energy Astrophysics
Observational tools: Blackbody radiation, Specific intensity and flux density, Stellar parallax.
Formation & Structure of spectral lines, Radiative transfer.
Radiative processes in Astrophysics: Synchrotron emission, Energy loss and electron spectrum, Compton scattering, Bremstrahlung, Thermal bremstrahlung.
Binary stars: Classification, Accretion disks in binaries, Hulse-Taylor binary pulsar.

Unit V: The Milky way galaxy and Galaxies beyond
What are Galaxies & its types, The Milky Way Galaxy: Structure, Mass, Size. Hubble’s Classification, Formation of galaxies.

Books recommended:

1. W. M. Smart, Textbook on Spherical Astronomy, Cambridge University Press.
2. I. Todhunter, Spherical trigonometry, The Macmillan company, London.
3. B. W. Carroll and D. A. Ostlie, Modern Astrophysics, Addison-Wesley Publishing Co.
4. Eric Chaisson & Steve Macmillan, Astronomy Today, Prentice Hall, New Jersey.
5. John D Fix, Astronomy-Journey to the Cosmic Frontier, Mosby, New York.
6. B. Basu, T. Chattopadhyay & S.N. Biswas, AN Introduction to Astrophysics.
7. M. Zeilik and S. A. Gregory Introductory Astronomy & Astrophysics, 4th Edition, Saunders College Publishing.
8. T. Padmanabhan, Theoretical Astrophysics, Vol. I: Astrophysical Processes, Cambridge University Press
9. T. Padmanabhan, Theoretical Astrophysics, Vol. II: Stars and Stellar Systems, Cambridge University Press.
10. F. Shu, Mill Valley, The Physical Universe: An Introduction to Astronomy, University Science Books.
11. V. B. Bhatia, Textbook of Astronomy and Astrophysics with Elements of Cosmology, Pub-New Delhi, Narosa Publishing House.

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Interdepartmental Course B: Mathematics in Computer Design

Credit: 2 **T:02**

Course Outcomes:

After the completion of the course, students are expected to have the ability to :

1. Show familiarity with the awareness and understanding of day-to-day applications of mathematics specially in computer sciences
2. Possess insights related to computer's hardware and software design

Unit I

Preliminary concepts of mathematical functions and relations.

Unit II

Number theory and study of residues, different types of number systems: binary, octal and hexa number systems, conversions from one number system to another.

Unit III

Matrices: Solution of system of simultaneous linear equations, Eigen values and Eigen vectors.

Unit IV

Applications in computer hardware design, circuit design using universal gates.

Unit V

Elementary applications in software design, software design tools, syntax analyzers, processing of natural languages.

Books Recommended:

1. G.E. Andrews, Number Theory, Hindustan Publ. Corp., Delhi
2. M Morris Mano, Digital logic and Computer Design, Pearson.
3. F. Ayres, Matrices, Schaum Outline Series, Mc Graw Hill Book Co.
4. Introduction of Theory of Computation, Sipser, Michael, PWS Publishing
5. D. E. Knuth: The Art of Computer Programming, Addison Wesley.
6. R. P. Gabriel: Patterns of Software, Oxford University Press.

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M.A./M.Sc. Semester-III

Core Course 11: Functions of a Complex Variable

Credit: 4 **T:04**

Course Outcomes:
1. Understand the topics of Complex Analysis needed to pursue research in pure mathematics.
2. Understand the properties of maximum modulus of a Complex valued function and the results based on that property.
3. Develop manipulation skills in the use of Rouche's theorem and Argument Principle.
4. Acquire knowledge of Gamma and Zeta functions with their properties and relationships.

Unit I

Maximum modulus theorem, Schwarz's lemma, minimum modulus theorem, Hadamard's three circle theorem, automorphism of the unit disk.

Unit II

Uniform convergence of sequence and series of functions, Cauchy's criterion, Weierstrass's M-test, analytic convergence theorem, absolute and uniform convergence of power series.

Unit III

Index of a closed path, meromorphic functions, argument principle, Rouche's theorem, residue at the point at infinity, indentation around a branch point and the branch cut.

Unit IV

Function spaces: Hurwitz theorem, Infinite products, Weierstrass factorization theorem, Mittag-Leffler's theorem, Gamma functions and its properties, Riemann's Zeta function.

Unit V

Analytic continuation, uniqueness of direct analytic continuation, power series method of analytic continuation, natural boundary, Schwarz's reflection principle, Poisson formula, Jensen's formula, Poisson-Jensen's formula, order of entire functions.

References:
Text Books:

1. J. V. Deshpande: Complex Analysis, Tata McGraw-Hill Publishing Company Limited, New Delhi
2. R.V. Churchill, J.W. Brown, Complex Variables and Applications, McGraw Hill.
3. E. C. Titchmarsh: Theory of Functions, Oxford University Press

Web References:

Digital platforms web links: NPTEL/SWAYAM/ MOOCS/Openstax.org
https://openlearninglibrary.mit/edu/courses
http://heecontent.upsdc.gov.in/SearchContent.aspx
https://www.lkouniv.ac.in/en/article/e-content-faculty-of-science

Core Course 12: Advanced Linear Algebra

Credit: 4 **T:04**

Course outcome:

After the completion of the course, students are expected to have the ability to:

1. Find the minimal polynomial of an operator.
2. Compute Jordan canonical form of an operator and apply it to practical problems.
3. Demonstrate Cholesky, polar, singular value, QR and LU decompositions of a matrix.

Unit I

Review of characteristic values and characteristic vectors of linear operators, minimal polynomial, Primary decomposition theorem, Cayley Hamilton theorem.

Unit II

Diagonalisable and triangulable operators, simultaneous diagonalization and triangularization.

Unit III

Jordan canonical form, Jordan chain, Jordan block, existence of Jordan canonical form, applications of the Jordan form.

Unit IV

Unitary similarity, Schur decomposition, method of least squares, Cholesky decomposition, Hadamard inequality.

Unit V

Matrix decompositions – polar decomposition, QR decomposition, LU decomposition, singular value decomposition.

Books Recommended:

1. V. Sahai and V. Bist: Linear Algebra, Narosa
2. H. Helson: Linear Algebra, Hindustan Book Agency
3. K. Hoffman and R. Kunze: Linear Algebra, Prentice Hall

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Elective Course 13A: Almost Contact Manifolds & F-Structure Manifolds

Credit: 4 **T:04**

Course Outcomes:
After the completion of the course, students are expected to have the ability to:
1. Explain the concept of odd dimensional manifolds and their examples.
2. Understand the concepts of Lie derivative, Sasakian manifolds, K-contact Riemannian manifolds, properties of curvature on these manifolds.
3. Understand the concept of different submanifolds.
4. Apply the course knowledge in super-gravity, superstring theory and in general relativity.
5. Apply for advanced studies / research in this area.

Unit I
Almost contact manifold: elementary notions, Lie derivative, normal contact structure, affinely almost co-symplectic manifold.

Unit II
Almost Grayan manifold, almost Sasakian manifold, K-contact Riemannian manifold, properties of curvature on these manifolds, almost contact 3-structure, para contact structure.

Unit III
Sasakian manifolds, quasi-Sasakian manifold, 3-structure metric manifold, Kenmotsu manifold, trans-Sasakian manifold and their properties.

Unit IV
Co-symplectic manifolds, F-structure manifold and their properties.

Unit V
Submanifolds of almost Hermite manifolds, Kähler manifolds and almost Grayan submanifolds.

Books Recommended:

1. R. S. Mishra: Structures on a differentiable manifold and their applications, Chandrama Prakashan, Allahabad
2. U. C. De, A. A. Shaikh: Complex manifolds and contact manifolds, Narosa Publishing House

Elective Course 13B: Advanced Ordinary Differential Equations

Credit: 4 **T:04**

Course Outcomes:

After the completion of the course, students are expected to have the ability to:

1. Solve an ordinary differential equation, and characterize its solution.
2. Understand the existence, uniqueness, and other properties of a solution of differential equations.
3. Introduce the problems focusing on areas where mathematical ideas have had a major impact on human inquiry.
4. Describe a physical problems into a differential equation.
5. Show understanding of the differential equation (ordinary and partial both).
6. Analyze the structure of real-world problems and plan solutions strategies.
7. Derive the properties of solutions of differential equations.

Unit I

The fundamental existence and uniqueness theorem, dependence of solutions on initial conditions, dependence of solutions on parameters.

Unit II

General theory of linear differential equations: existence of solutions, basic theory of the homogeneous linear system, the nonhomogeneous linear system, linear independence and fundamental systems, properties of the homogeneous linear equation, reduction of order, the non homogeneous equation, the adjoint vector equation, self-adjoint vector equation.

Unit III

Matrix methods for homogeneous linear systems with constant coefficients: two equation and two functions and two unknown functions, example of the matrix methods, eigenvalue problems, Green's matrix and its properties, solutions of boundary value problem by Green's matrix.

Unit IV

Sturm-Liouville system, eigen functions, Bessel functions, singular Sturm Liouville systems, Legendre functions, boundary value problem for ordinary differential equation, solution by eigenfunction expansion, Green's functions, construction of Green's function for ordinary differential equation.

Unit V

Zeroes of solutions, Strum's separation and comparison theorems, oscillatory and nonoscillatory equations, Riccati's equation and its solution, Pruffer transformation, Lagrange's identity and Green's formula for second-order equation.

Books Recommended:

1. S.L. Ross: Differential Equations, Blaisdell Publishing Company.
2. R.H. Cole: Theory of Ordinary Differential Equations, Appleton-Century-Crofts, New York.
3. S.Ahmad, M.R.M. Rao: Theory of Ordinary Differential Equations, EWP Private Ltd.

Elective Course 13C: Advanced Algebra*

Credit: 4 **T:04**

Course Outcomes:

1. Give the structure of an abelian group of a given order.
2. Construct the splitting field extension of a given polynomial.
3. Understand the interplay of group theory and field theory.
4. Determine the minimal polynomial of an algebraic element.

Unit I

Series of groups, Schreier theorem, Jordan Holder theorem, solvable groups, nilpotent groups, insolvability of S_n for $n>5$,

Unit II

Finite abelian groups, primary decomposition theorem, basis theorem, fundamental theorem of finite abelian group, elementary divisors and invariant factors,

Unit III

Field extensions: finite extension, finitely generated extension, algebraic extension, simple extension, transcendental extension, finite field.

Unit IV

Splitting field, algebraically closed field, normal extension, separable extension, primitive element theorem.

Unit V

Galois theory- Galois group, Galois extension, Fundamental theorem of Galois theory, Artin's theorem, Fundamental theorem of algebra (algebraic proof).

Recommended Books:

1. V. Sahai & V. Bist: Algebra, Fourth Edition, Narosa.
2. J. A. Gallian, Contemporary Abstract Algebra, 4th edition, Narosa
3. DJS Robinson, An Introduction to Abstract Algebra, Hindustan Book Agency. Suggested Readings:
4. J. B. Fraleigh: A first course in Abstract algebra, Narosa
5. S. Lang: Algebra, Addison Wesley.

***To be offered to students admitted from session 2027-28 onwards.**

Elective Course 14A: Measure Theory and Integration

Credit: 4 **T:04**

Course Outcomes:

After the completion of the course, students are expected to have the ability to:
1. Display understanding of the essential foundations of important aspect of mathematical analysis.
2. Explain the measurability of a set of real numbers and measurable functions.
3. Differentiate between the Riemann integral and the Lebesgue integral.
4. Apply the measure theory and theory of the integral in other branches of pure and applied mathematics.

Unit I
Algebra of sets, countable sets, Cantor set, Borel sets, outer measure of a set and its properties. Measurable sets.

Unit II
Lebesgue measure, a non-measurable set, measurable functions and their properties, concept of almost everywhere, Littlewood's three principles.

Unit III
The Lebesgue integration of bounded function over a set of finite measure, Bounded convergence theorem, the integral of a non-negative function, Fatou's Lemma, Monotone convergence theorem, the general Lebesgue integral, Lebesgue convergence theorem.

Unit IV
Differentiation of monotone functions, Vitali's Lemma, the four derivatives, the Lebesgue differentiation theorem, functions of bounded variation, differentiation of an integral, absolute continuity.

Unit V
Inequalities and the L_p Spaces: The L_p Spaces, convex functions, Jensen's inequality, the inequalities of Holder and Minkowski, completeness of $L_p(\mu)$, convergence in measure, almost uniform convergence.

Books Recommended:
1. H.L. Royden: Real Analysis, Pearson, Prentice Hall
2. G.de Barra: Measure Theory and Integration, Wiley Eastern Ltd.
3. M.E.Taylor, Measure Theory and Integration, GSM 76, American Mathematical Society, 2006

Web References:

Digital platforms web links: NPTEL/SWAYAM/ MOOCS/Openstax.org
https://openlearninglibrary.mit/edu/courses
http://heecontent.upsdc.gov.in/SearchContent.aspx
https://www.lkouniv.ac.in/en/article/e-content-faculty-of-science

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Elective Course 14B: Linear programming and Inventory Management

Credit: 4 **T:04**

Course Outcomes:
After the completion of the course, students are expected to have the ability to:
1. Describe the basic concepts of convex analysis and explain the theoretical foundations of various issues related to linear programming modeling.
2. Formulate real-world problems as a linear programming model and describe the theoretical working of the graphical and simplex method, demonstrate the solution process by hand and solver.
3. Apply the knowledge of game theory concepts to articulate real-world decision situations for identifying, analyzing, and practicing strategic decisions to counter the consequences.
4. Demonstrate solution methods including graphs and linear programming to analyze and solve the Two-person, zero-sum games.
5. Identify the goals and objectives of inventory management and describe the importance of stocks in an organization and the reasons for holding stock.
6. Explain the various costs related to inventory system.
7. Understand the various selective inventory control techniques and its applications.

Unit I
Introduction to Linear Programming, problem formulations, methods for the solutions of a linear programming problem, slack and surplus variables, standard and matrix forms linear programming, Basic feasible solution.

Unit II
Convex sets, extreme points, hyperplanes and half spaces, polyhedral sets and cones, theoretical results based on above concepts, theory of simplex method, simplex algorithm, revised simplex method.

Unit III
Introduction to game theory, Two-person zero-sum games, Saddle points, Mixed strategies, Fundamental theorem, Computational methods using graphs and linear programming, Introduction to nonzero sum game.

Unit IV
Introduction to sequencing problem, basic terminology and assumptions, Johnson’s method, Computational methods for the solution of sequencing problem. Introduction to Inventory Systems, Analytical structure of Production and Inventory problems, Objectives of Inventory management, Factors influencing inventories, Inventory related costs.

Unit V
Properties of Inventory systems, types of inventory models, economic order quantity model with instantaneous supply, economic order quantity model with finite replenishment rate, economic order quantity models with and without shortages, Economic order quantity models with price discounts, reliability, and permissible delay in payments, selective inventory control techniques and its applications.

Books Recommended:

1. Hillier, F. S., & Lieberman, G. J. Introduction to Operations Research- Concepts and Cases (9th ed.) Tata McGraw Hill (Indian print).
2. Taha, H. A. Operations research-an introduction (8th ed.), Pearson Prentice Hall (Indian print).
3. Thie, P. R., & Keough, G. E., An introduction to linear programming and game theory (3rd ed.) New Jersey: John Wiley & Sons.
4. Ravindran, A., Phillips, D. T., & Solberg, J. J., Operations research- principles and practice (2nd ed.) New Delhi: Wiley India (P.) Ltd.
5. Axsäter, S. (2015). Inventory control (3rd ed.) Springer.
6. Silver, E. A., Pyke, D. F., & Peterson, R. (1998) Inventory management and production planning and scheduling. (3rd ed.) John Wiley New York.
7. Waters, D. (2008) Inventory control and management (2nd ed.) John Wiley & Sons.

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Elective Course 14C: Classical Mechanics

Credit: 4 **T:04**

Course Outcomes:

1. Understand the generalized coordinates, constraints, Lagrange's equations of motion and Lagrangian.
2. Understand the cyclic coordinates, generalized momentum, Hamilton's equations of motion and Hamiltonian.
3. Definition of canonical and Lagrange transformations, Poisson's brackets and their properties, different conditions for canonical transformations.
4. Understand the basic properties of rigid body motion, principle of moment of inertia, equations of motion for a rigid body.

Unit I

Generalized coordinates, types of constraints, D'Alembert's principle, Lagrange's equations of motion in presence of conservative and non-conservative forces, generalized forces, generalized potential, Lagrangian, deduction of energy equation from Lagrange's equation.

Unit II

Lagrange's equations for impulsive motion, Lagrange's multipliers method, symmetry properties and conservation laws, theory of small oscillations: Lagrange's method, normal modes, oscillation under constraints.

Unit III

Cyclic coordinates, generalized momentum, Hamilton's variational principle, principle of least action, Hamilton's equations of motion, Hamiltonian and conservation of energy.

Unit IV

Canonical transformations, Legendre transformations, generating functions, Poisson's brackets, conditions of canonical transformations, Jacobi's identity, Liouville's theorem, Hamilton-Jacobi equation.

Unit V

Generalized coordinates of rigid body, angular velocity and infinitesimal rotation, fundamental principles of rigid body, angular momentum and inertia tensor, inertial ellipsoid, principle axes- principle moments of inertia, Euler's angle, Euler's equations of motion for a rigid body, equations of impulsive motion, torque free motion of a rigid body, motion of a heavy symmetrical top.

Books Recommended:

1. E. A. Milne, Vectorial Mechanics, Methuen & Co. Ltd., London, 1965.
2. A. S. Ramsey, Dynamics, Part II, CBS Publishers & Distributors, Delhi, 1985.
3. H. Goldstein, Classical Mechanics, Addison-Wesley Publishing Company, London, 1969.
4. N. Kumar, Generalized Motion of Rigid Body, Narosa Publishing House, New Delhi, 2004.
5. J.E.Marsden, and T.S.Ratiu, Introduction to Mechanics and Symmetry, A Basic Exposition of Classical Mechanical Systems, Texts in Applied Mathematics 17, Springer-Verlag, New York, 1994.

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Elective Course 15A: Advanced Discrete Mathematics

Credit: 2 **T:02**

Course Outcomes:

After the completion of the course, students are expected to have the ability to:
1. Display familiarity with the mathematical models which are the integral part of the hardware and software of computer science.
2. Elaborate and expand their understanding of the tools helpful in the implementation of circuit design, AI algorithms and compiler constructions.

Unit I
Logic theory, logic formula, logical connectives, arguments, validity of arguments, minimal sets of logical connectives.

Unit II
Logic gates, logic circuits, logic circuits using NAND and NOR gates.

Unit III
Lattice theory: Hasse diagram, lattice isomorphism, types of lattices, direct product of lattices.

Unit IV
Automata theory, deterministic and non deterministic finite state automaton, automata machines. Regular expression and its automaton representation.

Unit V
Language theory, context free/context sensitive grammar, LR parsers, implementation of LR(0) and LR(1) parsing tables.

Books Recommended:

1. E. Mendelson, Introduction to Mathematical Logic, Chapman & Hall, 1997.
2. J. E. Hopcroft, R.Motwani, J.D. Ullman: Introduction to Automata Theory, Languages and Computation, Pearson Education, 2000.
3. B. H. Arnold, Logic and Boolean Algebra, Prentice Hall, 1962.
4. K. H. Rosen: Discrete Mathematics and its applications, MGH 1999.

Elective Course 15B: Quantum Calculus

Credit: 2 **T:02**

Course Outcomes:
After the completion of the course, students are expected to have the ability to:

1. Understand the concept of q-derivatives.
2. Derive properties of q-binomial coefficients, q-exponential functions.
3. Compute q-antiderivatives of functions and describe q-gamma and q-beta functions.
4. Start research in the field of q-special functions.

Unit I
Introduction to quantum calculus, q-derivative and h-derivative, generalised Taylor's formula for polynomials, q-analogue of $(x-a)^n$, q-derivatives of binomials, q-Taylor's formula for polynomials.

Unit II
Gauss's binomial formula and a noncommutative binomial formula, properties of q-binomial coefficients, q-Taylor's formula for formal power series and Heine's binomial formula, Euler identities and q-exponential functions.

Unit III
q-Trigonometric functions, Jacobi's triple product identity, q-Hypergeometric functions and Heine's formula, general binomial, Ramanujan product formula.

Unit IV
q-Antiderivative, Jackson integral, fundamental theorem of q-calculus, integration by parts.

Unit V
q-Gamma and q-beta functions, symmetric quantum calculus.

Books Recommended:

1. V. Kac, P. Cheung, Quantum Calculus, Universitext, Springer.
2. G.Gasper, M.Rahman, Basic Hypergeometric Series, Cambridge University Press, 2004.
3. H. Exton, q-Hypergeometric Functions and Applications, Halsted Press, 1983.

Internship/Field Work

Credit: 02

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M.A./M.Sc. Semester-IV

Core Course 16: Structures on Almost Complex Manifolds

Credit: 4 **T:04**

Course Outcomes:

After the completion of the course, students are expected to have the ability to:
1. Explain the concept of even dimensional manifolds and their examples
2. Understand the concepts of contravariant almost analytic vector fields, covariant almost analytic vector fields, killing vector fields and their applications.
3. Apply various concept of differential calculus to the settings of abstract set called manifold.
4. Show applications of Kähler manifolds in superstring theory and in general relativity

Unit I
Almost complex manifolds: Elementary notions, Nijenhuis tensor, eigenvalues of almost complex structure, contravariant and covariant almost analytic vectors, connections.

Unit II
Almost Hermite manifold: Elementary notions, almost analytic vector fields, curvature tensors, linear connections and their properties.

Unit III
Kähler manifolds, affine connections, curvature tensors, contravariant almost analytic vectors.

Unit IV
Nearly Kähler manifold, curvature identities, Curvature tensors, almost analytic vectors.

Unit V
Almost Kähler manifolds, analytic vectors, conformal transformations, curvature identities.

Books Recommended :

1. R.S. Mishra, Structures on a differentiable manifold and their applications, Chandrama Prakashan, Allahabad.
2. U. C. De, A.A. Shaikh, Complex manifolds and contact manifolds, Narosa Publishing House.

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Elective Course 17A: Wavelet Theory

Credit: 4 **T:04**

Course Outcomes:
After the completion of the course, students are expected to have the ability to:

1. Make plans for higher level research in this area and get funded by the funding agencies.
2. Learn about the mathematical analysis involved in wavelets.
3. Know the short comings in the Fourier analysis and how wavelets help in overcoming those difficulties.
4. Review Fourier transformation, continuous wavelet transform, multi-resolution analysis and algebraic constructions, included in the course.

Unit I
Fourier and inverse Fourier transforms, Convolution and delta function, Fourier transform of square integrable functions, Continuous wavelet transform: The Heisenberg uncertainty principle, the Shannon sampling theorem, Definition and examples of continuous wavelet transforms,

Unit II
A Plancherel formula, inversion formulas, the kernel functions, decay of wavelet transform, Frames: geometrical considerations, notion of frames.

Unit III
Discrete wavelet transforms, signal decomposition (analysis), relation with filter banks, signal reconstruction.

Unit IV
Multi resolution analysis, axiomatic description, the scaling function, construction of Fourier domain.

Unit V
Orthonormal wavelets with compact support: the basic idea, algebraic constructions, binary interpolation, spline wavelets.

Books Recommended:

1. C. Blatter: Wavelets, A Primer, AK Peters, 2002.
2. C.K. Chui: An Introduction to Wavelets, Academic Press.
3. I. Daubechies: Ten Lectures on Wavelets, SIAM, Philadelphia.

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Elective Course 17B: Advanced Partial Differential Equations

Credit: 4 **T:04**

Course Outcomes:

After the completion of the course, students are expected to have the ability to:

1. Describe a physical problem in the form of differential equations.
2. Solve the partial differential equation, and get characterized its solutions.
3. Analyze the structure of real-world problems and plan solution strategies.
4. Understand the properties of solutions of differential equations.
5. Understand existence, uniqueness, and other properties of a solution of differential equations.

Unit I

Introduction, basic concepts and definitions, classification of second order linear equation and method of characteristics, canonical form, equations with constant coefficients, superposition principle, method of separation of variables.

Unit II

Boundary value problems, maximum and minimum principles, uniqueness and stability theorem, Dirichlet problem for a circle, Dirichlet problem for a circular annulus, Neumann problem for a circle, Dirichlet problem for a rectangular, Dirichlet problem involving Poisson equation.

Unit III

Fourier transforms - Definition and properties, Fourier transform of some elementary functions, convolution theorem, application of Fourier transforms to solve partial differential equations. Green's functions and boundary value problems.

Unit IV

The Cauchy problem: the Cauchy problem, Cauchy-Kowalewsky Theorem, Hadmard example, Cauchy problem for homogeneous wave equations, Initial value problem, the Cauchy problem for non-homogenous wave equation, the vibration string problem, existence and uniqueness solution of the vibrating problem.

Unit V

Duhamel's Principle: Wave equations, heat conduction equations, solution of heat equation in two and three dimensions (Cartesian, polar and spherical coordinate system) in terms of Bessel's and Legendre's functions.

Books Recommended:

1. Tyn Myint-U: Partial Differential Equations of Mathematical Physics, Elsevier
2. I.N. Sneddon: Elements of Partial Differential Equations, McGraw-Hill, 1988

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Elective Course 18A: Graph Theory

Credit: 4 **T:04**

Course Outcomes:
After the completion of the course, students are expected to have the ability to:

1. Illustrate multiple applications of graphs in real life.
2. Make models that are used in designing networks of highways, railways and airways.
3. Outline data structure which are useful in computer science.

Unit I
Graph and its terminology, graph isomorphism and homomorphism, Euler's formula.

Unit II
Graph representation, statement and application of Kuratowski's theorem, coloring of graph, Four color conjecture.

Unit III
Graph connectivity, Eulerican path, Eulerian circuit, Hamiltonian path and Hamiltonian circuit, cut point, bridge and cut set.

Unit IV
Shortest path, Djikstra's algorithm, path between vertices, path matrix, Warshall's algorithm.

Unit V
Spanning tree, Kruskal's and Prim's algorithm, tree traversal, binary tree and its applications.

Books recommended:

1. F. Harary: Graph Theory, Addison Wesley 1969.
2. D. B. West: Introduction to Graph Theory, Prentice Hall 1996.
3. J. Gross and J. Yellan: Graph Theory and its Applications, CRC Press, 1998.

Elective Course 18B: Orthogonal Polynomials

Credit: 4 **T:04**

Course Outcomes:

After the completion of the course, students are expected to have the ability to:

1. Perform operations with orthogonal polynomials with their differential equations along with the corresponding recurrence relations.
2. Understand the concepts of Hermite polynomial, Laguerre polynomial, Jacobi polynomial etc with its properties.
3. Demonstrate the understanding of how physical phenomena are modeled using special functions.
4. Understand how special functions are useful in differential equations.

Unit I

Orthogonal polynomials, simple set of polynomials, orthogonality, equivalent condition for orthogonality, zeros of orthogonal polynomials, recurrence relation, Christoffel Darboux formula, generating functions.

Unit II

Definition of Hermite polynomials $H_n(x)$, differential equation and its solution, pure recurrence relations, differential recurrence relation, Rodrigues' relation, generating functions, orthogonality, integral representation of Hermite polynomial

Unit III

Laguerre polynomial $L_n(x)$, definition, differential equation and its solution, generating function, recurrence relations, Rodrigues' formula, orthogonality.

Unit IV

Jacobi's polynomial, differential equation, Bateman's generating function, Rodrigues' formula, recurrence relations, orthogonality.

Unit V

Ultraspherical Gegenbauer polynomials, Chebychev polynomials, independent solution of Chebychev polynomial, expansion of $T_n(x)$ and $U_n(x)$, generating functions, recurrence relations, orthogonality.

Books Recommended:

1. E.D. Rainville, Special Functions, Chelsea, 1960.
2. G. Szego, Orthogonal Polynomials, AMS, 1975.

Dissertation

Credit: 08