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UNIVERSITY OF CALCUTTA · CCF (NEP 2020) UG SYLLABUS

Mathematics Major (Honours) · Semester 8

Semester-wise syllabus · 4-Year Major · DSCC and SEC papers

What this file contains

- DSCC-21 and DSCC-22 (Graph Theory)
- DSCC-23.1 Mechanics-III or 23.2 Measure Theory-II
- DSCC-24.1 OR and Stochastic Process or 24.2 Differential Geometry
- DSCC-25.1 Fluid Mechanics and Computational Maths or 25.2 Functional Analysis-II and Topology-II
- Research Methodology (RM-1, RM-2)
- Internship, research project and dissertation guidelines
- Course structure page and question pattern

Source and note

The pages that follow are taken unchanged from the official University of Calcutta syllabus for Mathematics under the Curriculum and Credit Framework for Undergraduate Programmes (CCF, NEP 2020). PALMATHS has only selected the pages for this programme and semester and added this cover so students can find them quickly. Always check the University of Calcutta website (caluniv.ac.in) for later notifications, corrections or changes in paper options. PALMATHS is an independent coaching centre and is not part of, or endorsed by, the University of Calcutta.

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University of Calcutta



Syllabus for four-year (Eight Semester) B. Sc. Honours and Honours with Research Course with Mathematics Major

&

Mathematics as a Minor subject

and

Syllabus for three-year (Six Semester) Multidisciplinary Course with Mathematics

Under

Curriculum and Credit Framework (CCF)

Odd Semester : July to December

Even Semester : January to June

The syllabus for the 4 Year B.A./B.Sc. Honours and Honours with Research Course with Mathematics Major is effective from the academic year **2023-24**.

The syllabus for the 3 Year Multidisciplinary Course with Mathematics is effective from the academic year **2023-24**.

Semester	Course	Paper Code	Name of Paper	Credit	Page
SEVEN (VII)	MAJOR	MTHM-DSCC 16	Group Theory - III & Linear Algebra - II	3TH+1TU=4	41
	MAJOR	MTHM-DSCC 17	Complex Analysis - II & Measure Theory - I	3TH+1TU=4	43
	MAJOR	MTHM-DSCC 18	Generalised functions, Integral Transforms Integral Equations	3TH+1TU=4	45
	MAJOR	MTHM-DSCC 19	Topology - I	3TH+1TU=4	47
	MAJOR	MTHM-DSCC 20	Functional Analysis - I	3TH+1TU=4	49
EIGHT (VIII)		**Honours without Research**			
	MAJOR	MTHM-DSCC 21	Ordinary Differential Equation - II & Partial Differential Equation - II	3TH+1TU=4	51
	MAJOR	MTHM-DSCC 22	Graph Theory	3TH+1TU=4	53
	MAJOR	MTHM-DSCC 23.1	Mechanics - III	3TH+1TU=4	55
		or	or		
	MAJOR	MTHM-DSCC 23.2	Measure Theory - II	3TH+1TU=4	57
	MAJOR	MTHM-DSCC 24.1	Operations Research & Stochastic Process	3TH+1TU=4	59
		or	or		
	MAJOR	MTHM-DSCC 24.2	Differential Geometry	3TH+1TU=4	61
	MAJOR	MTHM-DSCC 25.1	Fluid Mechanics & Computational Mathematics	3TH+1P=4	63
		or	or		
	MAJOR	MTHM-DSCC 25.2	Functional analysis - II & Topology - II	3TH+1TU=4	66
		Honours with Research			
	MAJOR	MTHM-RM1	Research Methodology - I	3TH +1Viva =4	68
	MAJOR	MTHM-RM2	Research Methodology - II	3TH +1Viva =4	70
	MAJOR		Research Internship	4	107
	MAJOR		Dissertation/Project	8	108

Note.

1. MMTH-MN3 and MMTH-MN4 (both) shall be studied in either Semester Five or in Semester Six.
2. If Mathematics is chosen as Core Course 2 in MDC then only CC6 (Statistical & Numerical Analysis) will be taught in Semester Five and the papers CC7 (Mathematical Methods) and CC8 (Discrete Mathematics) will be taught in Semester Six.
3. **Refer to Notification No. CSR/36/2023 and Notification No. CSR/35/2024 for the Syllabus and Question Pattern for the paper "Artificial Intelligence".**
4. Marks for Tutorial will be awarded on the basis of Internal Assessment through evaluation of internal assignments for SEC papers and internal examinations for Core, Minor and IDC papers.

4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Course Structure for
4-year B.A./B.Sc. Honours & Honours with Research, with Mathematics Major

Semester	Paper Code	Name of Paper	Credit	Page No.
I	MTHM-DSCC 1	Calculus, Geometry & Vector Analysis	3TH+1TU = 4	10
	MTHM-SEC 1	C language with Mathematical Applications	3TH+1TU = 4	73
II	MTHM-DSCC 2	Basic Algebra	3TH+1TU=4	12
	MTHM-SEC 2.1 or MTHM-SEC 2.2	Python Programming & Introduction to Latex or *Artificial Intelligence	3TH+1TU=4	75
III	MTHM-DSCC 3	Real Analysis	3TH+1TU=4	14
	MTHM-DSCC 4	Ordinary Differential equations - I & Group Theory - I	3TH+1TU=4	16
	MTHM-SEC 3	Linear Programming & Rectangular Games	3TH+1TU=4	78
IV	MTHM-DSCC 5	Theory of Real Functions	3TH+1TU=4	18
	MTHM-DSCC 6	Mechanics - I	3TH+1TU=4	20
	MTHM-DSCC 7	Multivariate Calculus–I & Partial Differential Equation - I	3TH+1TU=4	22
	MTHM-DSCC 8	Group Theory - II & Ring Theory - I	3TH+1TU=4	25
V	MTHM-DSCC 9	Probability & Statistics	3TH+1TU=4	27
	MTHM-DSCC 10	Ring Theory - II & Linear Algebra - I	3TH+1TU=4	29
	MTHM-DSCC 11	Riemann Integration & Series of Functions	3TH+1TU=4	31
	MTHM-DSCC 12	Mechanics - II	3TH+1TU=4	33
VI	MTHM-DSCC 13	Metric Space & Complex Analysis-I	3TH+1TU=4	35
	MTHM-DSCC 14	Multivariate Calculus II & Applications of Calculus	3TH+1TU=4	37
	MTHM-DSCC 15	Numerical Analysis	3TH+1P=4	39
VII	MTHM-DSCC 16	Group Theory-III & Linear Algebra-II	3TH+1TU=4	41
	MTHM-DSCC 17	Complex Analysis - II & Measure Theory - I	3TH+1TU=4	43
	MTHM-DSCC 18	Generalised functions, Integral Transforms Integral Equations	3TH+1TU=4	45
	MTHM-DSCC 19	Topology - I	3TH+1TU=4	47
	MTHM-DSCC 20	Functional Analysis - I	3TH+1TU=4	49
VIII		**Honours**		
	MTHM-DSCC 21	Ordinary Differential Equation - II & Partial Differential Equation - II	3TH+1TU=4	51
	MTHM-DSCC 22	Graph Theory	3TH+1TU=4	53
	MTHM-DSCC 23.1 or MTHM-DSCC 23.2	Mechanics - III or Measure Theory - II	3TH+1TU=4 3TH+1TU=4	55 57
	MTHM-DSCC 24.1 or MTHM-DSCC 24.2	Operations Research & Stochastic Process or Differential Geometry	3TH+1TU=4 3TH+1TU=4	59 61
	MTHM-DSCC 25.1 or MTHM-DSCC 25.2	Fluid Mechanics & Computational Mathematics or Functional analysis - II & Topology - II	3TH+1P=4 3TH+1TU=4	63 66
		Honours with Research		
	MTHM-RM1	Research Methodology - I	3TH +1Viva =4	68
	MTHM-RM2	Research Methodology - II	3TH +1Viva =4	70
		Research Internship	4	107
		Dissertation/Project	8	108

***Refer to Notification No. CSR/36/2023 and Notification No. CSR/35/2024 for the Syllabus and Question Pattern for the paper "Artificial Intelligence".**

4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Ordinary Differential Equation - II & Partial Differential Equation - II

Semester : VIII	Paper Code : MTHM-DSCC 21-TH
Credit : 4	Full Marks : 100 (Theory : 75 & Tutorial : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview
Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

Group A : Ordinary Differential Equation - II [Marks: 45] [40 classes]

- **Qualitative Analysis of One-dimensional Continuous Systems :** Autonomous first order differential equations –Equilibrium points (or steady states or fixed points or stationary points), Stability and asymptotic stability of a steady state, linearization and stability analysis.
- **One-dimensional Bifurcations :** Saddle-node, Transcritical and Pitchfork bifurcations in one-dimensional case. Simple examples.
- **Systems of Differential Equations :** Types of linear systems, Differential Operators and an Operator Method, Basic Theory of Linear Systems in Normal Form: Two Equations in Two Unknown Functions, Homogeneous Linear Systems with Constant Coefficients: The Matrix Method for Homogeneous Linear Systems with Constant Coefficients: Two Equations in Two Unknown Functions, Planar linear autonomous systems: Equilibrium points, Interpretation of the phase plane and phase portraits. Planar Nonlinear systems: Equilibrium points and their stability by linearization. Simple examples.
- **Series Solution and Special Functions :** Ordinary point and singular point. Types of singularity. Series solution of a second order differential equation, Frobeneous method, Legendre equation and Legendre function, Bessel equation and Bessel functions, orthogonality conditions.
- **Sturm–Liouville Problems and Eigenfunction Expansions :** Introduction to Sturm-Liouville theory; The Sturm–Liouville problem; Inner product spaces and orthonormal systems; The basic properties of Sturm–Liouville eigenfunctions and eigenvalues; Green's function, Nonhomogeneous equations; Nonhomogeneous boundary conditions; Simple problems.

Group B : Partial Differential Equation - II [Marks : 30] [20 classes]

- Classification of second order quasi linear partial differential equations, Reduction to Canonical form and general solution, Characteristic curves of second order equation.
- **Hyperbolic Equations: The One-dimensional Wave Equation**
  Wave equation and its formulation. The Cauchy problem and d'Alembert's solution; Physical interpretation of the solution. Solution of wave equation by the method of Separation of variables in cartesian coordinates. Solution by the method of Integral transform.
- **Parabolic equations: The Heat equation**
  Heat equation and its formulation: homogeneous and nonhomogeneous boundary conditions; Solution of heat equation by the method of Separation of variables in Cartesian coordinates; Solution of Heat equation using integral transform.

- **Elliptic equations: Laplace and Poisson equations**
  Laplace and Poisson equation, Dirichlet and Neumann boundary conditions, Interior and exterior boundary value problems. Separation of variables in Cartesian and cylindrical coordinates with simple examples, Poisson's formula. Green's functions and integral representations.

References

[1] W. E. Boyce and R. C. DiPrima, Elementary Differential Equations, John Wiley & Sons, 7th Edition, 2000.

[2] E. A. Coddington and N. Levison, Theory of Ordinary Differential Equations, Tata McGraw Hill, 1955.

[3] E. L. Ince, Ordinary Differential Equations, Dover, 1956.

[4] S. L. Ross, Differential Equations, John Wiley and Sons, 3rd edition, 1984.

[5] G. Simmons, Differential Equations with Applications and Historical Notes, McGraw Hill Education, 2nd edition, 2017.

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Graph Theory

Semester : VIII	Paper Code : MTHM-DSCC 22-TH
Credit : 4	Full Marks : 100 (Theory : 75 & Tutorial : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

- Historical background of Graph Theory. Seven bridges problem. Definition of an undirected graph, degree of a vertex, degree sequences, Havel-Hakimi Theorem.
- Walks, paths, trails and cycles, subgraphs, spanning subgraphs and induced subgraphs, connected graph, disconnected graph and components, distance in a graph, complete and complete bipartite graphs, self-complementary graphs.
- Eulerian graphs, Theorems on existence of Euler paths and circuits, Hamiltonian paths and cycles, Hamiltonian graphs. Sufficient conditions of Dirac and Ore for a graph to be Hamiltonian. Applications: Traveling Salesman Problem (TSP), Route planning (planning street sweeping routes, Garbage collection routes), DNA sequencing and computational biology.
- Definition and properties of trees, minimal spanning tree in a weighted graph, Kruskal algorithm and Prim's algorithm. Binary trees and their properties, Dijkstra's algorithm to find shortest path in a graph. Applications: Network design (telephone, electrical, computer networks), Data structures (binary search trees), Hierarchical systems (organizational charts, file systems), Decision trees in artificial intelligence.
- Definition of planar graphs, Kuratowski's two graphs, the Euler polyhedron formula (Euler identity for connected planar graphs $V - E + F = 2$, where $V=$ no. of vertices, $E =$ no. of edges, $F =$ no. of faces) detection of planarity, Kuratowski's theorem (proof not required). Homeomorphic graph, Isomorphic graph, Dual of a graph. Applications: Circuit board design (VLSI design), Geographic information systems, Network visualization.
- Directed graphs (digraphs), digraphs and binary relations, strongly connected digraphs, Euler digraphs, vertex colouring of graphs, Chromatic number of graphs and its elementary properties, perfect graph, perfect matching, matrix representation of graphs, adjacency matrices of graphs and digraphs and their properties, path matrix, incidence matrices of graphs and digraphs and their properties. Applications: Map coloring problems, Four color problem.

References

[1] J. A. Bondy and U. S. R. Murty, Graph theory and related topics, Academic Press, New York, 1979.

[2] John Clark and Derek Allan Holton, A First Look at Graph Theory, World Scientific, New Jersey, 1991.

[3] N. Deo, Graph Theory with Application to Engineering and Computer Science, Prentice Hall of India, New Delhi, 1990.

[4] F. Harary, Graph Theory, Narosa Publishing House, New Delhi, 2001.

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Mechanics - III

Semester : VIII	Paper Code : MTHM-DSCC 23.1-TH
Credit : 4	Full Marks : 100 (Theory : 75 & Tutorial : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview
Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

Group A : Classical Mechanics [Marks : 60] [48 classes]

- Mechanics of a system of particles: Constraints, Degrees of freedom, reactions due to constraints. D'Alembert's principle; Lagrange's first kind equations; Generalized coordinates; Generalized forces; Lagrangian; Second kind Lagrange's equations of motion; velocity dependent potential; Principle of energy, Cyclic coordinates; Routhian formalism, Canonically conjugate coordinates and momenta.
- Action Integral; Hamilton's principle; Lagrange's equations by variational methods; Hamilton's principle for non-holonomic system; Integrals of motion, Symmetry properties and conservation laws; Statement of Noether's theorem with some illustrations; Hamiltonian and Hamiltonian equations.
- Euler-Lagrange Equation, Simple variational problems (Brachistochrone Problem, Shortest distance between two points), Hamilton's equations from variational principle; Principle of stationary action; Invariance of volume in phase space, Liouville's theorem (Statement).
- Canonical transformation; Generating function; Poisson Bracket; Equation of motion; Jacobi-Poisson equation.

Group B : Continuum Mechanics [Marks : 15] [12 classes]

- The Continuum hypothesis. Deformation and flow. Lagrangian and Eulerian descriptions. Material derivative. Deformation tensors. Finite strain tensor. Small deformation. Infinitesimal strain tensor. Principal strains. Strain invariants. Compatibility equations for linear strains. Body forces and surface forces. Stress vector. Stress components. Normal and Shear stresses. Stress deviator. Principal stresses. Invariants. Maximum shearing stress. Conservation of mass. The continuity equation. Momentum principles. Equation of motion. Energy balance. First Law of Thermodynamics. Ideal materials. Classical elasticity. Generalized Hooke's Law. Strain energy Function. Physical interpretation.

References

[1] Y. C. Fung, Foundations of Solid Mechanics, Prentice-Hall, Englewood, 1965.

[2] F. Gantmacher, Lectures in Analytical Mechanics, Mir Publ., 1975.

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[4] T. W. B. Kibble and F. H. Berkshire, Classical Mechanics, 4th ed., Addison-Wesley Longman, 1996.

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[7] N. C. Rana and P. S. Joag, Classical Mechanics, Tata McGraw Hill, New Delhi, 2002.

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[9] E.C.G. Sudarshan and N. Mukunda, Classical Dynamics: A Modern Perspectives, John Wiley & Sons, 1974.

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[13] D. S. Chandrasekharaiah and L. Debnath, Continuum Mechanics, Inc. Academic Press, Boston, 1994.

[14] T. J. Chung

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Measure Theory - II

Semester : VIII Credit : 4	Paper Code : MTHM-DSCC 23.2-TH Full Marks : 100 (Theory : 75 & Tutorial : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

- Lebesgue measurable functions and their example, characterisation of Lebesgue measurable functions, a function $f : \mathbb{R} \to \mathbb{R}$ is Lebesgue measurable if and only if $f^{-1}(U)$ is Lebesgue measurable for any open set U in the real line $\mathbb{R}$, a function $f : \mathbb{R} \to \mathbb{R}$ is Lebesgue measurable if and only if $f^{-1}(B)$ is Lebesgue measurable for any Borel set B in the real line $\mathbb{R}$, concept of almost everywhere, algebra of measurable functions, restriction of a measurable function to a measurable set is measurable, pasting lemma regarding measurable functions, Borel measurable functions and their example, if $f : \mathbb{R} \to \mathbb{R}$ is measurable and $g : \mathbb{R} \to \mathbb{R}$ is a Borel function then $g \circ f$ is measurable, limsup and liminf of a sequence of measurable functions are measurable, point-wise limit of a sequence of measurable functions is measurable, simple functions, measurable functions as point-wise limit of a sequence of simple measurable functions, approximation of Lebesgue measurable functions by continuous functions (statement only).
- **Lebesgue integral of non-negative measurable function :** Definition of the Lebesgue integral $\int_{\mathbb{R}} f(x)dx$ of a measurable function $f : \mathbb{R} \to [0, \infty]$, definition of the Lebesgue integral $\int_E f(x)dx$ as $\int_{\mathbb{R}} f\big|_E(x)dx$ for any measurable set $E \subset \mathbb{R}$, properties of Lebesgue integral of such functions : $\int_{\mathbb{R}} f(x)dx \geq 0$ for any measurable function $f : \mathbb{R} \to [0, \infty]$, if A, B be two measurable sets with $A \subseteq B$ then $\int_A f(x)dx \leq \int_B f(x)dx$ for any measurable function $f : \mathbb{R} \to [0, \infty]$, $\int_E f(x)dx = 0$ whenever E is a measurable set with $m(E) = 0$ (m being the Lebesgue measure), if $f = g$ almost everywhere on $\mathbb{R}$ then $\int_{\mathbb{R}} f(x)dx = \int_{\mathbb{R}} g(x)dx$, if $f : \mathbb{R} \to [0, \infty]$ is measurable and $\int_E f(x)dx = 0$ then $f = 0$ almost everywhere on E, Monotone Convergence Theorem (MCT), Fatou's lemma, $\int_{\mathbb{R}} (\alpha f + g)(x)dx = \alpha \int_{\mathbb{R}} f(x)dx + \int_{\mathbb{R}} g(x)dx$ for any measurable functions $f, g : \mathbb{R} \to [0, \infty]$ and $\alpha \geq 0$, some applications of MCT.
- **Lebesgue integral of a measurable function with value in $\mathbb{R}^*$:** Positive and negative parts of a measurable function $f : \mathbb{R} \to \mathbb{R}^*$, definition of $\int_{\mathbb{R}} f(x)dx$ of a measurable function $f : \mathbb{R} \to \mathbb{R}^*$, Lebesgue integrability of a measurable function $f : \mathbb{R} \to \mathbb{R}^*$, if $f : \mathbb{R} \to \mathbb{R}^*$ is Lebesgue integrable then f is real-valued almost everywhere, the set $L^1(\mathbb{R})$ of all Lebesgue integrable functions from $\mathbb{R}$ to $\mathbb{R}$ is a vector space over the field $\mathbb{R}$, linearity of Lebesgue integral for functions in $L^1(\mathbb{R})$, properties of Lebesgue integral of functions in $L^1(\mathbb{R})$: $\left|\int_{\mathbb{R}} f(x)dx\right| \leq \int_{\mathbb{R}} |f(x)|dx$, if $f \in L^1(\mathbb{R})$ and $\int_E f(x)dx = 0$ for every measurable set $E\,(\subseteq \mathbb{R})$ then $f = 0$ almost everywhere on $\mathbb{R}$, Dominated Convergence Theorem (DCT), $\int_{A \cup B} f(x)dx = \int_A f(x)dx + \int_B f(x)dx$ for any $f \in L^1(\mathbb{R})$ and any two disjoint measurable sets $A, B \subset \mathbb{R}$, relation between Lebesgue integral and Riemann integral.

References

[1] Sheldon Axler, Measure, Integration & Real Analysis; Springer Open (2020).

[2] A. Bruckner, J. Bruckner & B. Thomson, Real Analysis, Prentice Hall, 1997.

[3] G. De. Barra, Measure Theory & Integration, Wiley Eastern Limited, 1987.

[4] G. B. Folland, Real Analysis : Modern Techniques and Their Applications.

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Operations Research & Stochastic Process

Semester : VIII	Paper Code : MTHM-DSCC 24.1-TH
Credit : 4	Full Marks : 100 (Theory : 75 & Tutorial : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

Group A : Operations Research [Marks : 50] [40 classes]

- **Integer Programming:** Integer programming models; Branch-and-Bound method; Gomory's Cutting-plane method
- **Network Optimization:** Graph representations, Shortest path algorithms (Dijkstra, Bellman–Ford), Minimum spanning tree (Kruskal, Prim), Maximum flow (Ford–Fulkerson, Edmonds–Karp), Minimum cost flow problems, Network construction, Critical Path Method (CPM), Project Evaluation and Review Technique (PERT), Float time, Slack time.
- **Queuing Theory:** Poisson process and Exponential distribution, single channel exponential queuing models, steady state solutions for M/M/1/∞/FIFO model, Little's Law (Average number of items within a system equals the average arrival rate of items into and out of the system multiplied by the average amount of time an item spends in the system), Measure of effectiveness, Waiting time distributions, Finite system capacity queues Applications in communication and service systems.
- **Monte Carlo simulation:** Simulating deterministic behaviour (area under a curve, volume under a surface), generating random numbers: middle square method, linear congruence, queuing models: harbour system, morning rush hour.
- **Inventory Models:** Concept of EOQ(Economic Order Quantity) and EPQ (Economic Production Quantity), Problem of EOQ with finite rate of replenishment, Problem of EOQ with shortages, Quantity discounts, Safety stocks, Newsvendor model.

Group B : Stochastic process [Marks : 25] [20 classes]

- Stochastic Process: Basic Idea and Definition, Classification of Stochastic processes, Stationary Processes, Markov Chain-Introduction, Discrete Parameter Markov Chain, Transition Probabilities, Stochastic matrices, Examples: Random Walk with no Barrier, absorbing barrier, Reflecting Barrier, Markov chains: Definitions, Chapman-Kolmogorov equation, Equilibrium distributions, Classification of states, Long-time behaviour. Stochastic process in continuous time: Poisson process.

References

[1] Beveridge and Scheehter, Optimization Theory and Practice, McGraw Hill Kogakusha, Tokyo, 1970.

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Differential Geometry

Semester : VIII	Paper Code: MTHM-DSCC 24.2-TH
Credit : 4	Full Marks : 100 (Theory : 75 & Tutorial : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

- **Tensor :** Different transformation laws, Properties of tensors, Metric tensor, Riemannian space, Covariant Differentiation, Einstein space.
- **Theory of curves :** Curves in plane and space, Arc-length, Reparametrization, Closed curves, Level curves versus parametrized curves , curvature, torsion , Serret-Frenet formulae, Isoperimetric Inequality, Four Vertex Theorem.
- **Theory of Surfaces :** Definition of smooth parametrized surfaces in $\mathbb{R}^3$, Examples: (regular) level surfaces, quadric surfaces, ruled surfaces, surfaces of revolution, smooth functions on a surface, the tangent plane and the differential maps between regular surfaces, the first fundamental form, length of curves, isometries of surfaces, conformal mappings of surfaces, normal fields and orientability.
- **Geometry of surfaces :** Geodesics - definition and example (in particular, geodesics on a surface of revolution), second fundamental form, Gauss and Weingarten maps and their properties, normal and geodesic curvatures, Gaussian and mean curvature, principal curvatures of a surface.

References

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Fluid Mechanics & Computational Mathematics

Semester : VIII	Paper Code : MTHM-DSCC 25.1-TH&P
Credit : 4	Full Marks : 100 (Theory : 75 & Practical : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

Group A : Fluid Mechanics [Marks : 35] [28 classes]

- Introduction to material continuum; Lagrangian and Eulerian formulation; Fluid Kinematics : Path lines, stream lines; Velocity field, acceleration of a fluid particle; Material derivative; Equation of continuity (in Cartesian and cylindrical coordinates) in both forms and their equivalence
- Basic concepts of fluid at rest and fluid in motion. Viscous, non-viscous, Newtonian, perfect, compressible and incompressible fluids. Stress analysis. Stress in a fluid at rest and in motion. Transformation of stress, principal stresses, principal directions, strain analysis, rate of strain, rate of strain quadric. Constitutive equations for ideal / perfect fluid, idea of pressure at a point for perfect and viscous fluid, constitutive equation for a linearly viscous isotropic fluid.
- Conservation of momentum and derivation of equation of motion. Euler's equation for perfect fluids. Navier-Stokes equation. Equation of equilibrium for perfect fluids. Applications to hydrostatics. Bernoulli's equation. Conservative field of force. Impulsive motion. Application of Bernoulli's theorem. Equation of energy for perfect fluid.
- Irrotational motion, vorticity, flow, circulation, Kelvin's theorem. Motion of an incompressible fluid in two dimensions. Stream function, velocity potential, complex potential; Two-dimensional source, sink and doublet. Method of images. Image of a source and doublet with respect to a plane and circle. Circle theorem. Flow past a circular cylinder (with circulation). Blasius' theorem. Lift force.
- Some exact solutions of Navier-Stokes' equation. Laminar flow between parallel plates. Plane Couette flow. Plane Poiseuille flow. Flow between parallel plates. Flow in a circular pipe.

Group B : Computational Mathematics [Marks : 40] [32 classes]

- **Numerical Integration:** Gaussian quadrature, Romberg integration.
- **Numerical Solution of System of Linear Equations:** Direct methods- LU Factorisation - Crout's method. Ill-conditioned linear systems.
- **Numerical Solution of Ordinary Differential Equations (ODE):** First Order ODE (Initial value problems) – Multistep method – Adams-Moulton method, Convergence and stability of solutions. System of Equations and Higher-order Equations – Runge-Kutta method (4-th order). Fast Fourier Transform (FFT) and Spectral methods.
- **The Finite Difference Method :** Finite difference approximations - general principle, truncation errors, finite difference approximations to first order ordinary and partial derivatives, forward difference, backward difference, central difference approximations; approximations of the second order derivatives. Finite difference schemes - explicit schemes, implicit schemes, convergence and consistency of finite difference schemes, stability of finite difference schemes. The Courant-Friedrichs-Lewy (CFL) condition.

- **Numerical Solution of Boundary Value Problems for ODE:** Two-point Boundary Value Problems for ODE – Finite difference formulation for linear one-dimensional problems.
- **Numerical Solution of Partial Differential Equations (PDE):** Finite difference formultion and solutions of (i) Parabolic type equation in one dimension (Heat equation), (ii) Hyperbolic type equation in one dimension (Wave equation), (iii) Elliptic type equation (Laplace's equation in rectangles).

Practical [Marks : 25]

Use Python to solve the following problems.

(i) Finding eigenvalues and eigenvectors of a square matrix using NumPy.

(ii) Numerical integration using SciPy. Numerical integration using three point Gaussian quadrature.

(iii) Solution of equations using bisection method, Newton-Raphson method. Solution of equations using SciPy.

(iv) Numerical solution of a system of linear equations using Matrix inversion method and LU factorisation method (using NumPy and SciPy).

(v) Numerical solution of initial value problems using NumPy and SciPy. Pictorial representations of solutions.

(vi) Numerical solution of boundary value problems (for ODE) using NumPy and SciPy. Pictorial representations of solutions.

(vii) Numerical solution of Heat equation and Wave equation using NumPy and SciPy. Pictorial representations of solutions.

(viii) In irrotational, inviscid flow, the velocity potential ϕ satisfies $\nabla^2\phi = 0$. Solve $\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} = 0$ on a 2D grid with a "step" or "hump" at the bottom using the Gauss-Seidel iterative method.

(ix) Consider the interference of two waves of the same amplitude of $A_0 = 1m$. The resultant wave can be described by $A(x,t) = A_0\left\{\sin\left(2\pi\left(\frac{x}{\lambda_1} - \frac{t}{T_1}\right)\right) + \sin\left(2\pi\left(\frac{x}{\lambda_2} - \frac{t}{T_2}\right)\right)\right\}$.

(x) Using Python, produce animations for different interference scenarios with varying periods T_1, T_2 and wavelengths λ_1, λ_2.

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Functional Analysis - II & Topology - II

Semester : VIII	Paper Code : MTHM-DSCC 25.2-TH
Credit : 4	Full Marks : 100 (Theory : 75 & Tutorial : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview
Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

Group A : Functional Analysis - II [Marks : 40] [32 classes]

- Open mapping theorem, closed graph theorem and uniform boundedness principle, some applications of these theorems.
- Inner product space, Hilbert space, example of Hilbert space : $\mathbb{R}^n$, $\mathbb{C}^n$, ℓ^2 etc., orthonormality, orthogonal complement, orthonormal basis, separable Hilbert space, a Hilbert space is separable if and only if it has a countable orthonormal basis, Bessel's inequality for separable Hilbert space, Parseval's equation for separable Hilbert space, Gram-Schmidt orthonomalisation process, Riesz representation theorem, reflexivity of Hilbert space (statement only).

Group B : Topology - II [Marks : 35] [28 classes]

- **Connectedness :** Connected sets and their characterizations, components, Union of connected sets, Closure of a connected set is connected. Continuous image of a connected set is connected, generalized intermediate value theorem for topological spaces, Finite product of connected spaces is connected, for any countable subset S of $\mathbb{R}^2$, $\mathbb{R}^2 \setminus S$ is connected. Locally connected spaces and its properties.

  Path connectedness, an open subset of $\mathbb{R}^n$ is connected iff it is path connected, path component.
- **Quotient spaces :** Definition and examples of Quotient topology, quotient map. Definition of a quotient space of a topological space X determined by an equivalence relation on X and associated theorems. Formation of quotient spaces, such as, circle, cylinder, Möbius strip, torus, etc.
- **Nets and Filters**: Definitions and examples, subnets, ultrafilters; Convergence and cluster points of nets and filters; Hausdorffness, continuity, limit point of sets and compactness in terms of nets and filters; canonical way of converting nets to filters and vice-versa.

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Research Methodology I

Semester : VIII	Paper Code : MTHM-RM1-TH
Credit : 4	Full Marks : 100 (Theory : 75 & Viva-Voce : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

Group A : Foundations of Research [Marks : 15] [10 classes]

- **Introduction to Research :** Meaning and objectives of research; Types and significance of research; Research process and scientific methods.
- **Research in Mathematics :** How to identify a research topic; Literature survey.
- **Research Problem :** Definition and necessity; Techniques of defining a research problem; Formulation and objectives of research problem.
- **Principles of mathematical writing :** Clarity and elimination of ambiguity; Logical structure and coherence; Proper definitions and assumptions; Rigor in proofs; Consistency of notation; Integration of symbols and words; Citation and acknowledgment; Reproducibility; Avoiding errors.

Group B : Web Resources & Research Ethics [Marks : 15] [10 classes]

- **Professional Organizations and Web Resources :** American Mathematical Society (AMS), Mathematical Association of America (MAA), Society for Industrial and Applied Mathematics (SIAM), arXiv, ResearchGate.
- **Journal Metrics :** Impact Factor (JCR), MCQ, SNIP, SJR, h-index, CiteScore, Google Scholar Metrics, Limitations and challenges of journal metrics.
- **Databases and Indexing Services :** MathSciNet, zbMath, Web of Science, Scopus.
- **Research Ethics :** Ethics in scientific research, Plagiarism and academic integrity, Use of plagiarism detection software (URKUND / Ouriginal / Turnitin).

Group C : Mathematical Modelling Tool [Marks : 45] [40 classes]

- **Partial Differential Equation (PDE) :** Classification of second order quasi-linear PDE, Reduction to Canonical form and general solution, Characteristic curves of second order equation.
- **Hyperbolic Equation:** One-dimensional Wave Equation and itormulation. The Cauchy problem and d'Alembert's solution; Physical interpretation of the solution. Solution of wave equation - method of Separation of variables in Cartesian coordinates using Integral transform.
- **Parabolic equations:** Heat equation and its formulation, homogeneous and nonhomogeneous boundary conditions, Solution of heat equation - method of Separation of variables in Cartesian coordinates, using integral transform.

- **Elliptic equations:** Laplace and Poisson equations, Dirichlet and Neumann boundary conditions, Interior and exterior boundary value problems, Separation of variables in Cartesian coordinates with simple examples, Poisson's formula. Green's function and integral representations.
- **Numerical Solution of PDE :** Explicit and implicit types of finite difference methods. Numerical solutions of Heat equation, Wave equation, Laplace's equation in rectangles.

References

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

Research Methodology II

Semester : VIII	Paper Code : MTHM-RM2-TH
Credit : 4	Full Marks : 100 (Theory : 75 & Viva-Voce : 25)
Minimum number of classes required : 60	

4-yr Credit Distribution | MDC Credit Distribution | Course Overview
Major | Minor | MDC | Question Pattern

Course Outcome

CO1 :

Group A : Scientific Communication & Publishing : [Marks : 10] [8 classes]

- **Structure of a research paper :** Title and running title, Authorship (single and multiple), Writing abstract and introduction, Problem formulation and analytical proofs, Results and discussion, Figures, tables, graphs (design principles), Acknowledgements, Conflict of interest, References and citation styles, Selection of keywords, AMS subject classification.
- **Communication and Publishing :** Manuscript submission and communication with editor; Handling referees' comments and galley proofs, transferring copyright, open access publishing.
- Basic idea of how to write review articles.

Group B : Thesis writing & Presentation Tools [Marks : 15] [10 classes]

- **Fundamentals of Thesis and Project Report Writing :** Format of the Thesis/ Project report, Review of Literature, Writing methods and results, Preparation of tables and figures, Discussion and Conclusion, Summary and Synopsis, Bibliography and citation, Avoiding Plagiarism and self-plagiarism.
- **Latex for Typesetting and Slide preparation :** Knowledge on preamble, Input file structure and commands. Documentclasses and formatting - article, amsart, report, book, beamer. Mathematical equations and symbols, commutative diagrams, arrays, tables and figures, Bibliography and indexing. Slide preparation using beamer class. Output formats, DVI, PS, PDF.

Group C : [Marks : 50] [42 classes]

(Either Unit - I or Unit - II will be offered)

Unit - I : Machine Learning in Mathematical Research

- **Introduction to Graph Theory:** What is a graph? Simple graphs, Vertices (nodes), Edges (lines), Degrees of vertices, Connected graphs, Konigsberg bridges problem, Adjacency matrix, Incidence matrix, Complete graphs, Regular graphs, Bipartite graphs, Walk, Path, Cut Sets, Cut vertices, Eulerian graphs and Euler's theorem,- Hamiltonian graphs, Weighted graph, Digraphs, The travelling salesman problem, Tree, Spanning tree, Counting labeled trees, Cayley's theorem (statement only).
- **Graph algorithms:** Breadth-first search and Depth-first search algorithms, Kruskal's and Prim's algorithms, Dijkstra's algorithm.

- **Introduction to Machine learning (ML):** Definition and scope of Machine Learning, Types of Machine learning - Supervised Learning, Unsupervised Learning, Reinforcement Learning; Applications of ML in Science, Business and Technology.
- **Supervised Learning :** Linear Regression (model idea and cost function); Logistic Regression (basic idea); K-nearest neighbour (KNN) algorithm; The Bootstrap; Model selection, Model evaluation -accuracy, confusion matrix; Overfitting and Underfitting.
- **Unsupervised Learning :** Clustering concept, K-Means Algorithm (basic steps & objective function), Principal Component Analysis (PCA) – geometric interpretation.
- **Tree-based Methods :** Decision Trees (concept & splitting criteria), Overfitting in trees; Ensemble methods (basic idea)- Random Forest, Boosting (introductory idea).
- **Support Vector Machines :** The Maximal Margin Classifier, Construction of the Maximal Margin Classifier, Support Vector Classifiers, The Support Vector Machine (SVM); Relationship to Logistic Regression.

Laboratory Practice Assignments

- **Machine Learning with Python :** Introduction to Python, Use of libraries NumPy, SciPy, Scikit, Simple linear regression, Logistic Regression, K-Nearest Neighbors, The Bootstrap, Random Forests, Boosting, Support Vector Machine, Principal Components Analysis, K-Means Clustering.

Unit - II : Graph Theory in Mathematical Research

- Historical background of Graph Theory. Seven bridges problem. Definition of an undirected graph, degree of a vertex, degree sequences, Havel-Hakimi Theorem.
- Walks, paths, trails and cycles, subgraphs, spanning subgraphs and induced subgraphs, connected graph, disconnected graph and components, distance in a graph, complete and complete bipartite graphs, self-complementary graphs.
- Eulerian graphs, Theorems on existence of Euler paths and circuits, Hamiltonian paths and cycles, Hamiltonian graphs. Sufficient conditions of Dirac and Ore for a graph to be Hamiltonian.
- Definition and properties of trees, minimal spanning tree in a weighted graph, Kruskal algorithm and Prim's algorithm. Binary trees and their properties, Dijkstra's algorithm to find shortest path in a graph.
- Definition of planar graphs, Kuratowski's two graphs, the Euler polyhedron formula (Euler identity for connected planar graphs $V - E + F = 2$, where V= no. of vertices, E = no. of edges, F = no. of faces) detection of planarity, Kuratowski's theorem (proof not required). Homeomorphic graph, Isomorphic graph, Dual of a graph.
- Directed graphs (digraphs), digraphs and binary relations, strongly connected digraphs, Euler digraphs, vertex colouring of graphs, Chromatic number of graphs and its elementary properties, perfect graph, perfect matching, matrix representation of graphs, adjacency matrices of graphs and digraphs and their properties, path matrix, incidence matrices of graphs and digraphs and their properties.

References

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4-yr Credit Distribution | MDC Credit Distribution | Course Overview

Major | Minor | MDC | Question Pattern

MTHM-DSCC 20-TH	**Functional Analysis I**
(Marks : 75)	(a) 7 questions are to be attempted out of 10 questions each carrying 5 marks. Each question may have multiple parts. (b) 5 questions are to be attempted out of 8 questions each carrying 8 marks Each question may have multiple parts.
MTHM-DSCC 21-TH	**Ordinary Differential Equations-II & Partial Differential Equations-II**
Group A: Ordinary Differential Equations (Marks: 45)	(a) 5 questions are to be attempted out of 8 questions each carrying 5 marks. These questions will be set from the topics Qualitative Analysis of One-dimensional Continuous Systems, One-dimensional Bifurcations and Systems of Differential Equations. Each question may have multiple parts. (b) 2 questions are to be attempted out of 4 questions each carrying 10 marks These questions will be set from the topics Series Solution and Special Functions and Sturm–Liouville Problems and Eigen function Expansions. Each question may have further parts.
Group-B : Partial Differential Equations (Marks : 30)	5 questions are to be attempted out of 8 questions each carrying 6 marks. Each question may have further parts.
MTHM-DSCC 22-TH	**Graph Theory**
(Marks : 75)	(a) 7 questions are to be attempted out of 10 questions each carrying 5 marks. Each question may have multiple parts. (b) 5 questions are to be attempted out of 8 questions each carrying 8 marks. Each question may have multiple parts.
MTHM-DSCC 23.1-TH	**Mechanics-III**
Group A: Classical Mechanics (Marks : 60)	(a) 5 questions are to be attempted out of 8 questions each carrying 6 marks. These will be set from the topics mentioned in the syllabus starting from 'Mechanics of a system of particles...' to '...Statement of Noether's theorem with some illustrations' (b) 5 questions are to be attempted out of 8 questions each carrying 6 marks. These will be set from the topics mentioned in the syllabus istarting from 'Hamiltonian and Hamiltonian equations...' to '...Generating function; Poisson Bracket; Equations of motion'. Each question may have further parts.
Group B: Continuum Mechanics (Marks : 15)	3 questions are to be attempted out of 6 questions each carrying 5 marks. Each question may have further parts.
MTHM-DSCC 23.2-TH	**Measure Theory-II**
(Marks : 75)	(a) 7 questions are to be attempted out of 10 questions each carrying 5 marks . Each question may have multiple parts. (b) 5 questions are to be attempted out of 8 questions each carrying 8 marks. Each question may have multiple parts.

MTHM-DSCC 24.1-TH	**Operations Research & Stochastic process**
Group A: **Operations Research** (Marks : 50)	(a) 5 questions are to be attempted out of 8 questions each carrying 7 marks. These will be set from the topics Integer Programming, Network Optimization and Queuing Theory. Each question may have further parts. (b) 3 questions are to be attempted out of 5 questions each carrying 5 marks. These will be set from the topics Monte Carlo simulation and Inventory Models. Each question may have further parts.
Group B : **Stochastic process** (Marks : 25)	5 questions are to be attempted out of 8 questions each carrying 5 marks. Each question may have further parts.
MTHM-DSCC 24.2-TH	**Differential Geometry**
(Marks : 75)	(a) Short answer type questions: 5 questions are to be attempted out of 8 questions each carrying 2 marks. (b) Long answer type questions: 11 questions are to be attempted out of 8 questions each carrying 5 marks. Each question may have multiple parts.
MTHM-DSCC 25.1-TH	**Fluid Mechanics & Computational Mathematics**
Group A: **Fluid Mechanics** (Marks : 35)	5 questions are to be attempted out of 8 questions each carrying 7 marks. Each question may have further parts.
Group B : Computational Mathematics (Marks : 40)	8 questions are to be attempted out of 12 questions each carrying 5 marks. Each question may have further parts.
MTHM-DSCC 25.2-TH	**Functional Analysis - II and Topology - II**
Group A : **Functional Analysis-II** (Marks : 40)	5 questions are to be attempted out of 8 questions each carrying 8 marks. Each question may have multiple parts.
Group B : Topology-II (Marks : 35)	5 questions are to be attempted out of 8 questions each carrying 7 marks. Each question may have multiple parts.

4-yr Credit Distribution | MDC Credit Distribution | Course Overview
Major | Minor | MDC | Question Pattern

Guidelines for Research Internship in Mathematics for Semester VIII (Honours with Research)

1. Every Undergraduate student enrolled in Four year B.Sc. in Mathematics Honours with Research (under CCF) must complete one Research Internship carrying 4 credits in Semester VIII. This internship is a mandatory academic requirement for the completion of the programme.

2. The duration of the internship shall be 6–8 weeks. The internship must be completed before the End-Semester Examination, at least 30 days prior to the commencement of the semester-end examination.

3. The internship should involve academic or research-oriented work in Mathematics. The following types of activities may be considered appropriate:

   - A mini research project in mathematics.
   - Mathematical modelling or computational work.
   - A study project under the supervision of a college faculty member.
   - Internship at research institutes or recognized academic organizations.

4. The internship may include activities such as:

   - Reading and understanding mathematical research papers or books.
   - Learning and using mathematical or computational software.
   - Solving mathematical problems or preparing a survey/study report.
   - Maintaining and submitting a project notebook documenting the work.

5. At the completion of the internship, each student must submit a Project Notebook / Internship Report and appear for a Viva-Voce Examination. The total marks (100) has the following distribution :

   - Project Notebook / Internship Report - 60
   - Viva-Voce Examination - 40

   Students must obtain a minimum of 40% of the total marks (i.e., 40 out of 100) to successfully complete the internship.

6. The evaluation of the Research Internship will be conducted by the Mathematics Department of the College (the student's mother institution). The evaluation committee will consist of the Head of the Department of the concerned college, the Supervisor(s), and an External Expert. The name of the External Expert will be proposed by the college and approved by the University.
   The committee will assess the Project Notebook / Internship Report submitted by the student as well as the knowledge and understanding acquired during the internship, through the viva-voce examination.

7. The Internship Report should be prepared following the structure/design provided below.

4-yr Credit Distribution | MDC Credit Distribution | Course Overview
Major | Minor | MDC | Question Pattern

Guidelines for Dissertation/Project in Mathematics for Semester VIII (Honours with Research)

1. The Project Dissertation is intended to introduce students to independent learning, mathematical investigation, and academic writing. It provides an opportunity for students to explore in depth a specific topic in mathematics under the guidance of a supervisor.

2. The Head of the department of Mathematics of the student's own college will assign a supervisor from the faculty members of his/her department. The supervisor will help the student in selecting a topic, identifying appropriate references, understanding mathematical concepts and structuring the dissertation. This process may be initiated at the beginning of Semester VII, so that students have sufficient time for topic selection and preliminary study before formally undertaking the Project Dissertation in semester VIII.

3. The Dissertation will be evaluated by a Committee consisting of at least the Supervisor and an External Expert. The name of the External Expert will be proposed by the college and approved by the University. The evaluation will include assessment of the written dissertation, oral presentation of his/her work and a viva-voce examination to judge the student's understanding of the work.

4. The total marks (200) will be distributed as follows:

   - Dissertation - 100
   - Oral Presentation - 50
   - Viva-Voce Examination - 50.

   Students must obtain a minimum of 40% of the total marks (i.e., 80 out of 200) for successful completion of this 8 credit course.

5. Dissertation should be prepared following the structure provided below.

4-yr Credit Distribution | MDC Credit Distribution | Course Overview
Major | Minor | MDC | Question Pattern

Structure of Project Notebook /Internship Report and Dissertation in Mathematics

1. The title Page should include the following items:
   - Title of the Project
   - Name of the student
   - University Roll number and Registration number
   - Course : 4 Year B. Sc. Honours with Research with Mathematics Major
   - Semester VIII
   - College Name, University name
   - Name of Supervisor(s)
   - Year of submission
2. Certificate from the supervisor confirming that the work is done under his/her guidance and that the work is free from plagiarism.
3. Acknowledgement
4. Abstract (i.e., A summary of the work in 150-250 words.)
5. A brief introduction which will include the objective and the background of the topic under consideration.
6. Literature Review.
7. Main part : Definitions, Results/Theorems/Computations, examples, etc.
8. Outcome of the entire work and Conclusion.
9. References (List should not exceed 2 pages)