Post-Graduate Department of Mathematics

NAAC Accredited Grade "A+"

UNIVERSITY OF KASHMIR, SRINAGAR.

NOTES :

Minutes of the PGBOS Meeting

No: F(PGBOS-NEP)20

Dated 16.05.2025

Date: April 21, 2025

Time: 11:00 a.m to 4.00 p.m.

Venue: Meeting Hall (Smart)

A meeting of the Postgraduate Board of Studies (PGBOS) in Mathematics was held on April 21, 2025, under the chairmanship of Prof. Mukhtar Ahmad Khanday, Head, Department of Mathematics, University of Kashmir.

Agenda:

To discuss and finalize the draft structure and syllabus for the proposed Two-Year and One-Year Master's Programme in Mathematics under NEP-2020 scheme to be effective from 2025 onwards.

Members Present:

1. Prof. M.A. Khanday HOD, Mathematics University of Kashmir	Chairman/Convener
2. Prof. S. Pirzada Department of Mathematics, University of Kashmir	Member
3. Prof. M.A. Mir Department of Mathematics, University of Kashmir	Member
4. Prof. N.A. Rather Department of Mathematics, University of Kashmir	Member
5. Prof. K.S. Charak Department of Mathematics, University of Jammu	External Member (Attended Online)
6. Prof. K.R. Kazmi Department of Mathematics, Aligarh Muslim University (Attended Online)	External Member
7. Prof. M. Iqbal Bhat Department of Mathematics, South Campus Anantnag	Member
8. Dr. Aftab Hussain Shah Department of Mathematics, Central University of Kashmir, Ganderbal	Member
9. Prof. Aijaz A. Bhat Islamia College for Science and Commerce, Srinagar	Member
10. Dr. M. Ibrahim Mir Department of Mathematics, South Campus Anantnag	Member
11. Prof. Basharat A. Want Department of Physics, University of Kashmir	Member
12. Prof. M.S. Pukhta Division of Statistics, SKUAST, Shalimar, Srinagar	Member
13. Dr. M. Saleem Lone Department of Mathematics, University of Kashmir	Member
14. Dr. Tawseef Rashid Department of Mathematics, University of Kashmir	Member

Proceedings and Resolutions:

1. **Welcome Address:** The Chairperson welcomed all the members of the PGBOS and briefed them about the agenda of the meeting, specifically focusing on the need for restructuring the Master's Programme in line with the latest academic developments and national frameworks (NEP-2020).
2. **Presentation of Draft Structure:** The draft structure and syllabus for the 2-Year and 1-Year Master's Programme in Mathematics were presented before the board for consideration. The proposed changes are aimed at aligning the curriculum with NEP-2020 guidelines, and contemporary research trends in Mathematics.

NOTES :

No: No. F(PGBIS-NEP)/2025

Dated 16.05-2025

3. **Deliberations:** Members thoroughly discussed the structure, course content, credit distribution, and evaluation scheme. Constructive suggestions were made to enhance the interdisciplinary relevance and research orientation of the curriculum.

4. **Recommendations:**
   - Minor modifications were suggested in a few course titles and contents and the same were incorporated in the structure and design.
   - Based on the valuable discussion made by the members, the course design and structure has been finalized in order to strengthen academic and professional competencies of students in the subject at National/International level [see **Annexure-I**].
   - The revised draft structure has been recommended by the board for approval.

5. **Resolution:** The PGBOS unanimously resolved to forward the recommended syllabus and structure of the 2-Year and 1-Year Master's Programme in Mathematics under NEP-2020 scheme to the concerned statutory bodies for approval (Batches 2025 and onwards).

The meeting concluded with a vote of thanks to the Chair.

Signatures of the Members

Prof. M.A. Khanday — Prof. S. Pirzada

Prof. M.A. Mir — Prof. N.A. Rather

Prof. K.S. Charak — Prof. K.R. Kazmi

Prof. M. Iqbal Bhat — Dr. Aftab Hussain Shah

Dr. Aijaz A. Bhat — Dr. M. Ibrahim Mir

Prof. Basharat A. Want — Prof. M.S. Pukhta — Mr. Tanveer-AH Sr. Scholar

Dr. M. Saleem Lone — Dr. Tawseef Rashid — Mr. Wasim Ah. Sr. Scholar

Prof. M.A. Sidiqi
Chief Coordinator
NEP Cell

Prof. M. Ashraf
NEP Cell.

16/5/2025
Chairman

DEPARTMENT OF MATHEMATICS
UNIVERSITY OF KASHMIR, SRINAGAR-190006
Jammu and Kashmir, India
(NAAC Accredited Grade A⁺ University)

Structure & Syllabus for 2-Year/1-Year Master's Program in Mathematics (CW+CW and CW+R Schemes)

NCrf Credit Level	Semester	Core Papers (Core Course/ Elective) Course Name and Code	Course Level	Credits	Total Credits	Max. Marks Internal	Max. Marks End Sem	Max. Marks Total	Contact Hours
6	I	Abstract Algebra (MMTHCAA125)	400	4 (Core)	20	28	72	100	For each credit: Theory (15h) and Practicals (30 h)
		Real Analysis (MMTHCRA125)	400	4 (Core)		28	72	100	
		Metric and Topological Spaces (MMTHCTS125)	400	4 (Core)		28	72	100	
		Topics in Number Theory (MMTHDNT125)	400	4 (DCE)		28	72	100	
		Computational Mathematics (MMTHDCM125)	400	4 (DCE)		28	72	100	
		Mathematical Statistics (MMTHDMS125)	400	4 (DCE)		28	72	100	
		Numerical Analysis (MMTHDNA125)	400	4 (DCE)		28	72	100	
	II	Complex Analysis (MMTHCCA225)	400	4 (Core)	20	28	72	100	For each credit: Theory (15h) and Practicals (30 h)
		Ordinary and Partial Differential Equations (MMTHCDE225)	400	4 (Core)		28	72	100	
		Linear Algebra (MMTHCLA225)	400	4 (Core)		28	72	100	
		Research Methodology (MMTHDRM225)	500	4 (DCE)		28	72	100	
		Integral Equations and Calculus of Variations (MMTHDIE225)	400	4 (DCE)		28	72	100	
		Algebraic Topology (MMTHDAT225)	400	4 (DCE)		28	72	100	
		Operations Research (MMTHDOR225)	400	4 (DCE)		28	72	100	
		Total Credit (First Year)				**40**			
1-Year Masters Program in Mathematics or 3rd / 4th Semester of 2-year Program						**Lateral Entry**			
6.5	III	Functional Analysis (MMTHCFA325)	500	4 (Core)	20	28	72	100	For each credit: Theory (15h) and Practicals (30 h)
		Differential Geometry (MMTHCDG325)	500	4 (Core)		28	72	100	
		Measure Theory (MMTHCMT325)	500	4 (Core)		28	72	100	
		Advanced Complex Analysis (MMTHDCA325)	500	4 (DCE)		28	72	100	

	Advanced Graph Theory (MMTHDGT325)	500	4 (DCE)		28	72	100	
	Mathematical Biology (MMTHDMB325)	500	4 (DCE)		28	72	100	
	Fourier and Wavelet Analysis (MMTHDFW325)	500	4 (DCE)		28	72	100	
IV (CW+CW and CW+R Schemes)	Fields and Galois Theory (MMTHCFG425)	500	4 (Core)	20	28	72	100	For each credit: Theory (15h) and Practicals (30 h)
	Research Project (MMTHPDI425)	500	12 (DCE)			300		
	Internship (MMTHISO425)	500	4(DCE)		28	72	100	
	Riemannian Geometry (MMTHDRG425)	500	4 (DCE)		28	72	100	
	Advanced Functional Analysis (MMTHDFA425)	500	4 (DCE)		28	72	100	
	Advanced Measure Theory (MMTHDMT425)	500	4 (DCE)		28	72	100	
	Homological Algebra (MMTHDHA425)	500	4 (DCE)		28	72	100	
	Non-Linear Functional Analysis (MMTHDNL425)	500	4 (DCE)		28	72	100	
	Total Credits (Aggregate)					80		

Members of Board of Studies

Prof. M A.Khanday HOD Mathematics (Chairman)	**Prof. S. Pirzada** (Member) University of Kashmir	**Prof. M. Abdullah Mir** (Member) University of Kashmir		**Prof. N. A. Rather** (Member), Ex. Professor University of Kashmir	
Prof. K. S. Charak (External Member) Jammu University	**Prof. K. R. Kazmi** (External Member) Aligarh Muslim Univ.	**Prof. M Iqbal Bhat** (Member, South Campus) University of Kashmir		**Dr. Afrab H. Shah** (Member) Central Univ. of Kashmir	
Dr. Aijaz A. Bhat (Member) Islamia College Hawal	**Dr. M. Ibrahim Mir** (Member, S. Campus) University of Kashmir	**Prof. Basharat A Want** (Member, Physics Dept) University of Kashmir		**Prof. M. S. Pukhta** (Member) SKUAST-K	
Prof. M. Ashraf Shah (Co-Opted Member) NEP-Cell University of Kashmir	**Prof. M. A. Sidiqi** (Co-Opted Member) NEP-Cell University of Kashmir	**Dr. M. S. Lone** (Co-Opted Member)	**Dr. T. Rashid** (Co-Opted Member)	**Mr. Tanveer A Bhat** Sr. Research	**Mr. Wasim Thoker** Sr. Research Scholar

Chairman 16/5/2025

Program Execution and Evaluation

The M.A/M.Sc Mathematics program in the department shall be governed by the University approved statutes, however the department specific regulations are as under.

Regulations for 2-Year & 1-Year Masters program in Mathematics (NEP-2020)

1. Credit Requirements

1. **Total Program Credits**: Minimum of 80 credits (20 per semester across 4 semesters).
2. **Core Paper Requirement**: At least **50%** of the total credits must be from core courses.
3. **Credit Definition**:
   a. **1 Credit (Theory)** = 15 hours of lectures/tutorials
   b. **1 Credit (Practical)** = 30 hours

2. Assessment Structure

- **Two Internal Assessments**:
  - **1st**: After Units I & II
  - **2nd**: After Units III & IV
- **Passing Internal Assessments**: Mandatory to appear for End Term Exams.
- **Support Systems**:
  - **Remedial classes** for underperforming students.
  - **Counseling/Recommendations** and other opportunities for high performers at national/international levels.

3. Attendance & Evaluation Criteria

- **Minimum Attendance**: 75%
- **Minimum Marks for Passing**: 40%
- **Moral Conduct**: Must be satisfactory for final evaluation.

4. Semester-wise Academic Structure

Semesters I–III:

1. **Core Papers**: 12 credits
2. **Electives (DCE)**: Minimum 8 credits
3. **Total per semester**: Minimum 20 credits, Maximum 24 credits.

Semester IV: Choice Between Two Academic Models

CW+CW Model (Coursework + Coursework)

1. **Core Papers**: 4 credits
2. **Discipline Centric Electives (DCE)**: *Minimum* 16 credits (based on Departmental offerings)
3. **Total**: Minimum of 20 credits

CW+Research Model (Coursework + Research Project)

1. **Core Papers**: 4 credits
2. **Research Project**: 12 credits
   I. **Dissertation**: 8 credits → **200 marks total**, evaluated as:
      i. 50 marks by the **Project Mentor**
      ii. 100 marks for the **written dissertation** (by external members)

iii. 50 marks for **Final Viva-Voce**, jointly conducted by a panel:
    1. Head of Department (HoD)
    2. External Examiner (nominated by the University)
    3. Project Mentor
    4. Senior Faculty Member (if HoD is a Mentor).

II. **Theory Paper**: 4 credits titled **"Recent Advances in the Relevant Research Topic"**
   i. **100 marks** (20 internal and 80 external marks)
   ii. The course contents for this theory paper shall be designed by the concerned project mentor.

3. **Additional Requirement**:
   I. One **DCE course or Internship** (4 credits)
   II. This ensures completion of the minimum of **80-credits** in the whole program.

5. Exit Option after Semester II

1. Award: **Postgraduate Diploma (PG Diploma)**
2. Condition: Completion of a **4-credit internship**, as per UGC norms.

6. Lateral Entry (from 2026 onwards).

- The students who have completed 4-year UG (Honors/Research mode) from the recognized institutions shall be eligible.
- Intake as a lateral entry into Semester III, as per university policy to be devised in due course of time.

7. Internship Structure

- **Credits**: 4 (DCE category)
- **Duration**: 60 hours (~1 month, 12–15 hrs/week)
- **Location**: At National level Institutions/Schools in Jammu & Kashmir
- **Timing**: After final exams (full weeks, not just weekends)
- **Purpose**: Enhance Research/Teaching skills and align with NEP goals
- Students shall be given an opportunity to work as interns with Mathematicians /Scientists working in various Institutions of repute.
- 20 Marks shall be awarded by the concerned local mentor and 80 Marks by the external mentor. The evaluation of external 80 marks shall be done on the basis of the following points:

  a. Research Aptitude (10 marks)
  b. Domain/Subject knowledge (15 marks)
  c. Independent working skills (5 marks)
  d. Communication and Presentation Skills (8 marks)
  e. Problem Solving Skills (10 marks)
  f. Innovative and creative mindset (7 marks)
  g. Attendance and Punctuality (5 marks)
  h. Summary of the Internship report (20 marks)

- The school internship modalities shall be executed as per already approved university guidelines.

Program Learning Outcomes (PLO's):

Upon completion of the PG program in Mathematics, the students will be able:

PLO1. To develop a strong foundation in pure and applied mathematics, enabling students to analyze, formulate, and solve complex mathematical problems.

PLO2. To enhance students' ability to think logically and critically, with an emphasis on rigorous reasoning, proof techniques, and mathematical modeling.

PLO3. To equip students with research-oriented skills through exposure to mathematical theories, computational tools, and independent project work.

PLO4. To instill values of academic integrity, collaborative learning, and a commitment to continuous professional development in mathematical sciences.

PLO5. To inculcate knowledge of Complex Polynomial Theory, Graph Theory, Mathematical Biology, Fixed Point Theory and Differential Geometry.

PLO6. Apply mathematical tools, numerical techniques, and software packages to model real-world problems.

PLO7. Gain hands-on experience through internships, enabling them to apply theoretical knowledge in academic, societial, or research settings.

PLO8. Prepare for research projects, doctoral programs, or careers requiring analytical and abstract reasoning in mathematics and allied fields.

Course Learning Outcomes (CLOs) Mapping with Program Learning Outcomes (PLOs)

The **Course Learning Outcomes (CLOs)** are carefully mapped to the **Program Learning Outcomes (PLOs)** to ensure that the objectives of each course contribute meaningfully to the overall aims of the M.Sc. Mathematics program. This mapping process helps to maintain consistency between course-level learning and program-level expectations. Each **CLO** is analyzed in relation to the relevant **PLO** to determine the level of contribution it makes toward achieving the broader educational goals. This systematic mapping enables clear tracking of how effectively the courses contribute to the program's mission. It also helps in the continuous improvement of both course design and program structure based on the outcome attainments. Thus, the **CLO-PLO** mapping forms an integral part of academic planning and quality assurance in the department.
The correlation levels used in the mapping are defined as follows:

The various correlation levels are

Number	Meaning	Description
3	**High Correlation**	The Course Outcome is strongly contributing to the Program Outcome. There is a direct and significant relationship.
2	**Moderate Correlation**	The Course Outcome is moderately contributing to the Program Outcome. There is a partial but important relationship.
1	**Low Correlation**	The Course Outcome is minimally contributing to the Program Outcome. The connection is weak but present.
0	**No Correlation**	The Course Outcome does not contribute to the Program Outcome at all.

2-Year Master's Program in Mathematics (NEP-2020)

ABSTRACT ALGEBRA

MA/M.Sc. Mathematics (1st Semester) Total Credits: **04**

Course Code: **MMTHCAA125 (15 hours per credit)** Total Marks: **100**

Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): After the completion of this course students shall be able to:

- **CLO1.** Apply the structure theorems for cyclic groups and finite abelian groups.
- **CLO2.** Analyze group homomorphisms, automorphisms, and group actions.
- **CLO3.** Explore group classifications using Sylow theorems and composition series.
- **CLO4.** Gain a working knowledge of polynomial rings and factorization in rings.

UNIT-I

Semigroups and criterion for a semigroup to be a group, Cyclic groups and their generators (finite and infinite), Structure theorem for cyclic groups, Endomorphisms, automorphisms, inner and outer automorphisms, Cauchy's and Sylow's theorems for abelian groups, Groups of symmetries, alternating groups, simple groups, Classification and properties of groups of order six, Simplicity of the alternating group A_n.

UNIT-II

Finite Groups and Group Actions: Conjugacy classes and class equations for groups of orders $p, 2p, p^2, p^3$. Applications of class equations, Sylow theorems for finite groups. Direct product of groups and finite abelian group classification, Normal and subnormal series, Composition series and the Jordan-Hölder theorem, Zassenhaus lemma and Schreier's refinement theorem, Solvable groups: examples and related theorems.

UNIT-III

Rings and Integral Domains: Review of rings and basic definitions, Field of quotients for an integral domain, Embedding of integral domains, Euclidean rings with examples such as $Z[\sqrt{-1}], Z[\sqrt{2}]$, Principal Ideal Rings (PIRs), Unique Factorization Domains (UFDs), Euclidean Domains (EDs), GCD and LCM in rings, Factorization theorem and relationships among EDs, UFDs, and PIRs.

UNIT-IV

Polynomial Rings and Factorization: Polynomial rings and the division algorithm, Irreducible polynomials and primitive polynomials, Rational field and integer monic polynomials, Gauss's Lemma and Eisenstein's Irreducibility Criterion, Cyclotomic polynomials, Contraction of polynomials, Polynomial rings and some basic results of commutative ring theory.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHCAA125 .1	3	2	1	3	3	1	1	3	**2.12**
MMTHCAA125 .2	3	3	2	2	2	3	2	2	**2.37**
MMTHCAA125 .3	3	2	2	3	3	2	3	2	**2.5**
MMTHCAA125 .4	3	2	2	2	1	3	1	3	**2.12**
Average PLO	**3**	**2.25**	**1.75**	**2.5**	**2.25**	**2.25**	**1.75**	**2.5**	**2.28**

Recommended Books

1. J. A. Gallian, Contemporary Abstract Algebra, Cengage Learning, USA, 9th Edition, 2015.
2. I.N. Heristein, Topics in Algebra, John Wiley & Sons, 2nd Edition, 1975.
3. P. B. Bhatacharaya and S.K. Jain, Basic Abstract Algebra, Cambridge University Press, 4th Edition, Reprint 2009.
4. J. B. Fragleigh, A First Course in Abstract Algebra, Pearson New International, 2014.
5. K. S. Miller, Elements of Modern Abstract Algebra, Krieger Publishing, 1975.
6. Surjeet Singh and Qazi Zameer-ud-Din, Modern Algebra, Vikas Pub Hou. Pvt Ltd, 8th Edition, 2006.

2-Year Master's Program in Mathematics (NEP-2020)
Real Analysis

MA/M.Sc. Mathematics (1st Semester) Total Credits: **04**
Course Code: **MMTHCRA125 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): After completion of this course, students shall be able to:

CLO1. Understand the concepts of Riemann–Stieltjes integration, including conditions of integrability and applications of the fundamental theorem of calculus.
CLO2. Analyze the convergence of improper integrals and apply classical inequalities in mathematical proofs.
CLO3. Examine uniform convergence of sequences and series of functions, and apply related theorems like Weierstrass M-test and approximation theorem.
CLO4. Analyze the convergence of sequence of functions and series.

UNIT-I

Integration: Definition and existence of Riemann–Stieltje's integral, behavior of upper and lower sums under refinement, necessary and sufficient conditions for RS-integrability of continuous and monotonic functions, reduction of an RS-integral to a Riemann integral, basic properties of RS-integrals, differentiability of an indefinite integral of continuous functions, the fundamental theorem of calculus for Riemann integrals.

UNIT-II

Improper integrals: integration of unbounded functions with finite limit of integration, comparison tests for convergence, Cauchy's test, infinite range of integration, absolute convergence, integrand as a product of functions, Abel's and Dirichlet's test.
Inequalities: arithmetic-geometric means equality, inequalities of; Cauchy-Schwartz, Jensen, Holder & Minkowski, inequality on the product of arithmetic means of two sets of positive numbers.

UNIT-III

Infinite series: Carleman's theorem, conditional and absolute convergence, multiplication of series, Merten's theorem, Dirichlet's theorem, Riemann's rearrangement theorem. Young's form of Taylor's theorem, generalized second derivative, Bernstein's theorem and Abel's limit theorem.

UNIT-IV

Sequences and series of functions: Point wise and uniform convergence, Cauchy criterion for uniform convergence, Mn-test, Weierstrass M-test, Abel's and Dirichlet's test of uniform convergence, uniform convergence and continuity, Riemann integration and differentiation, Weierstrass approximation theorem, examples of continuous nowhere differentiable functions.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHCRA125.1	3	3	1	1	3	1	1	3	**2**
MMTHCRA125.2	3	2	2	2	2	3	2	2	**2.25**
MMTHCRA125.3	3	3	2	2	2	2	3	3	**2.5**
MMTHCRA125.4	3	1	2	2	3	3	1	2	**2.12**
Average PLO	**3**	**2.25**	**1.75**	**1.75**	**2.5**	**2.25**	**1.75**	**2.5**	**2.22**

Recommended Books:

1. S.C.Malik and S. Arora, Mathematical Analysis, New Age International, Pvt. Ltd, 7th Edition, 2024.
2. W. Rudin, Principles of Mathematical Analysis, McGraw Hill Edu, 3rd Edition, 2017.
3. T. M. Apostol, Mathematical Analysis, Narosa Publishers, 2002.
4. A. J.White, Real Analysis: An Introduction, Addison-Wesley; First Edition, 1968.
5. R. Goldberg, Methods of Real Analysis, Oxyford and IBH Publishing, 2020.

2-Year Master's Program in Mathematics (NEP-2020)
Metric and Topological Spaces

MA/M.Sc. Mathematics (1st Semester) Total Credits: **04**
Course Code: **MMTHCTS125 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 Time Duration: 2½ hrs

Course Learning Outcomes(CLO's): After completion of this course, students shall be able to:

- **CLO1.** Understand core concepts of metric and topological spaces.
- **CLO2.** Analyze continuity, compactness, and connectedness in various spaces.
- **CLO3.** Apply key theorems like Baire's, Heine-Borel, and Urysohn's.
- **CLO4.** Use topological ideas to study function behavior and structure of spaces.

UNIT - I

Review of countable and uncountable sets, Schroeder-Bernstein theorem, axiom of choice and its various equivalent forms, definition and examples of metric spaces, open and closed sets, completeness in metric spaces, Baire's category theorem, and applications to the (1) non-existence of a function which is continuous precisely at irrationals (ii) impossibility of approximating the characteristic of rationals on [0, 1] by a sequence of continuous functions.

UNIT - II

Completion of a metric space, Cantor's intersection theorem with examples to demonstrate that each of the conditions in the theorem is essential, uniformly continuous mappings with examples and counter examples, extending uniformity continuous maps, Banach's contraction principle with applications to the inverse function theorem in R.

UNIT - III

Topological spaces; definition and examples, elementary properties, Kuratowski's axioms, continuous mappings and their characterizations, pasting lemma, convergence of nets and continuity in terms of nets, bases and sub bases for a topology, lower limit topology, concepts of first countability, second countability, separability and their relationships, counter examples and behavior under subspaces, product topology and weak topology, compactness and its various characterizations.

UNIT - IV

Heine-Borel theorem, Compactness, Tychnoff's theorem, sequential compactness and total boundedness in metric spaces, Lebesgue's covering lemma, continuous maps on compact spaces, separation axioms and their permanence properties, connectedness and local connectedness, their relationship and basic properties, connected sets in ℝ, Uryson's lemma, Uryson's metrication lemma, Tietize's extension theorem, one point compactification.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLOs
MMTHCTS125.1	3	3	2	2	3	2	3	3	**2.62**
MMTHCTS125.2	3	2	2	3	2	3	3	2	**2.5**
MMTHCTS125.3	3	3	2	2	3	2	3	3	**2.62**
MMTHCTS125.4	3	3	2	3	3	3	3	1	**2.62**
Average PLOs	**3**	**2.75**	**2**	**2.5**	**2.75**	**2.5**	**3**	**2.25**	**2.59**

Recommended Books:

1. G.F.Simmons, Introduction to Topology and Modern Analysis, McGraw Hill Education, 2004.
2. J. R. Munkres, Topology, PHI Learning Limited, Second Edition, 2011.
3. K.D. Joshi, Introduction to General Topology, New age International Publishers, Second Edition 2006.

2-Year Master's Program in Mathematics (NEP-2020)
Topics in Number Theory

MA/M.Sc. Mathematics (1st Semester) Total Credits: **04**
Course Code: **MMTHDNT125 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): After the completion of this course, students shall be able to:

- **CLO1.** Apply concepts of modular arithmetic, primitive roots, and the λ-function to solve classical number theoretic problems.
- **CLO2.** Analyze and interpret quadratic residues using Euler's criterion, Legendre and Jacobi symbols, and quadratic reciprocity.
- **CLO3.** Evaluate number theoretic functions, use Möbius inversion and investigate perfect numbers and rational approximations.
- **CLO4.** Utilize continued fractions and L-functions to explore connections between rational approximations and prime distribution.

UNIT -I

Integers belonging to a given exponent (mod *p*) and related results, converse of Fermat's theorem; If d|p-1, then congruence $x^d \equiv 1 (mod p)$ has exactly d-solutions; If any integer belongs to $t(mod p)$, then exactly $\phi(t)$ incongruent numbers belong to $t(mod p)$, primitive roots, there are $\phi(p-1)$ primitive roots of an odd prime p, any power of an odd prime has a primitive root, the function λ (m) and its properties, $a^{\lambda(m)} \equiv 1 (mod m)$, where $(a, m)=1$. There is always an integer which belongs to λ(m) (mod m), primitive λ -roots of m, the numbers having primitive roots are $1,2,4, p^{\alpha}, 2p^{\alpha}$ where p is an odd prime.

UNIT -II

Quadratic residues, Euler criterion, the Legendre symbol and its properties, Lemma of Gauss, the law of a quadratic reciprocity, characterization of primes of which 2,-2, 3,-3, 5, 6 and 10 are quadratic residues or non residues, Jacobi symbol and its properties, the reciprocity law for Jacobi symbol.

UNIT -III

Number theoretic functions, some simple properties of $\tau(n), \sigma(n), \phi(n)$ and $\mu(n)$. Mobius inversion formula. Perfect numbers. Necessary and sufficient condition for an even number to be perfect, the function $[x]$ and its properties, average order of magnitudes of $\tau(n), \sigma(n), \phi(n)$, Farey fractions, rational approximations.

UNIT -IV

Simple continued fractions, application of the theory of infinite continued fractions to the approximation of irrationals by rationals, Hurwitz theorem, Relation between Riemann Zeta function and the set of primes, characters, the *L*-Function $L(S, \chi)$ and its properties, Dirichlet's theorem on infinity of primes in an arithmetic progression.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLOs
MMTHDNT125.1	3	3	2	3	2	3	3	3	**2.75**
MMTHDNT125.2	3	2	3	2	2	2	2	3	**2.37**
MMTHDNT125.3	3	1	3	1	1	2	2	3	**2**
MMTHDNT125.4	3	2	2	2	3	2	1	3	**2.25**
Average PLOs	**3**	**2**	**2.5**	**2**	**2**	**2.25**	**2**	**3**	**2.34**

Recommended Books

1. Ivan Niven, Herbert S. Zuckerman, and Hugh L. Montgomery, An Introduction to the Theory of Numbers,John Wiley & Sons, 6th edition, 1991.
2. W. J. LeVeque, Topics in Number Theory, Vol. I & II, Addison-Wesley 1956.
3. T. M. Apostol, Introduction to Analytic Number Theory,Springer International, 1976.
4. G.H. Hardy and E.M. Wright, An Introduction to the Theory of Numbers,Oxford University Press, 6th edition, 2008.

2-Year Master's Program in Mathematics (NEP-2020)
COMPUTATIONAL MATHEMATICS

MA/M.Sc. Mathematics (1^{st} Semester) Total Credits: **04**
Course Code: **MMTHDCM125 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: **Marks 28,** Theory: **Marks 72** Time Duration: **2½ hrs**

Course Learning Outcomes(CLO's): After the completion of this course, students shall be able to:

- **CLO1.** Apply basic Python programming constructs such as variables, loops, conditionals, functions, and libraries to solve mathematical problems.
- **CLO2.** Use Python libraries (such as NumPy, SymPy, and Matplotlib) to perform symbolic and numerical computation in calculus and visualize mathematical functions.
- **CLO3.** Implement numerical methods and solution for linear algebra problems such as root-finding, numerical integration, and numerical linear algebra using Python-based tools and libraries.
- **CLO4.** Formulate and solve ordinary and partial differential equations using Python libraries and numerical techniques, and interpret the solutions graphically and analytically.

Unit I:

Python Essentials for Mathematical Thinking**:** Variables, data types, control flow (conditionals, loops), Functions, scope, and exceptions, Using Jupyter Notebook / Google Colab, Introduction to the math and numpy libraries, Basic vector and matrix operations, Plotting with matplotlib.
Key Activities: Write functions to compute quadratic roots, factorials, etc. Perform vector arithmetic and matrix multiplication in numpy, Plot polynomials, trigonometric, and exponential functions

Unit II:

Calculus and Symbolic Math with Python: Symbolic computation with sympy: expressions, limits, derivatives, integrals, Partial derivatives and gradient vectors, Numerical differentiation and integration with scipy.integrate, Overlay plots of functions, their derivatives, and integrals.
Key Activities: Symbolically derive and plot f(x)f(x)f(x), f′(x)f'(x)f′(x), and ∫f(x) dx\int f(x)\,dx∫f(x)dx ,Compute definite integrals both symbolically and numerically; compare results, Use gradients to analyze functions of two variables

Unit III:

Linear Algebra & Numerical Methods: Matrix operations in numpy.linalg: inverse, determinant, transpose, Solving Ax=bA\mathbf{x}=\mathbf{b}Ax=b and interpreting solutions, Eigenvalues, eigenvectors, and diagonalization, LU and QR factorizations (scipy.linalg), Root finding: bisection, Newton–Raphson, and secant methods
Key Activities: Solve circuit-modeled linear systems and interpret physical meaning, Implement and compare convergence of Newton's method vs. bisection, Decompose matrices and visualize the effect on linear transformations

Unit IV:

Modeling & Differential Equations: Formulating first and second order ODEs (e.g., logistic growth, pendulum), Solving ODEs numerically with scipy.integrate.odeint and solve_ivp, Introduction to finite-difference schemes for PDEs, Simulating heat and wave equations on simple domains.
Key Activities: Code and visualize ODE solutions; compare to analytical forms, Build a finite-difference solver for the 1D heat equation, Animate solutions over time and interpret behaviour.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ **PLO** →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	**Average CLO**
MMTHDCM125.1	3	3	2	2	3	3	2	2	**2.5**
MMTHDCM125.2	3	2	1	1	2	3	2	3	**2.13**
MMTHDCM125.3	3	2	2	3	1	3	2	3	**2.38**
MMTHDCM125.4	3	2	3	2	3	3	2	3	**2.63**
Average PLO	**3**	**2.25**	**2**	**2**	**2.25**	**3**	**2**	**2.75**	**2.41**

Recommended Books:

1. Christian Hill, Learning Scientific Programming with Python, Cambridge University Press, 2nd Edition, 2020.
2. Jaan Kiusalaas, Numerical Methods in Engineering with Python 3, Cambridge University Press, 3rd Edition, 2013.
3. Svein Linge & Hans Petter Langtangen, Programming for Computations – A Gentle Introduction to Numerical Simulations with Python, Springer, 2nd Edition, 2020.
4. Gilbert Strang, Linear Algebra and Learning from Data, Wellesley-Cambridge Press, 1st Edition, 2019.

2-Year Master's Program in Mathematics (NEP-2020)
MATHEMATICAL STATISTICS

MA/M.Sc. Mathematics (1st Semester) Total Credits: **04**
Course Code: **MMTHDMS125 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: **Marks 28,** Theory: **Marks 72** Time Duration: **2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of the course, students will be able to:

CLO1. Analyze and model random experiments using probability theory.
CLO2. Apply various probability distributions to real-world scenarios.
CLO3. Understand and apply concepts of estimation and hypothesis testing.
CLO4. Utilize statistical methods for making sound predictions and decisions.

Unit-I

Probability set function, Random variables: discrete and continuous, Probability density function (pdf), cumulative distribution function (cdf)–properties and applications. Conditional probability and Bayes theorem. Mathematical expectation, variance, and higher moments, Moment generating functions and characteristic functions, Inequalities: Markov, Chebyshev, Jensen, Joint, marginal, and conditional distributions, Covariance, correlation, and stochastic independence.

Unit-II:

Standard Probability Distributions: Discrete distributions: Bernoulli, Binomial, Negative Binomial, Geometric, Trinomial, Poisson, Continuous distributions: Uniform, Exponential, Gamma, Chi-square, Beta, Normal, Bivariate Normal distribution and their properties. Problems and Applications.

Unit-III:

Limit Theorems and Parameter Estimation: Law of large numbers and Central Limit Theorem and its applications. Point estimation: properties of estimators (bias, consistency, efficiency). Methods of estimation: Method of Moments, Maximum Likelihood Estimation (MLE), Interval estimation: confidence intervals for means, variances in normal distributions, Unbiased and minimum variance unbiased estimators (MVUE), Rao-Blackwell theorem. Sufficiency: Factorization Theorem and the Fisher-Neyman.

Unit-IV:

Inference and Hypothesis Testing: Exponential family of distributions and completeness, Complete and sufficient statistics, Rao-Cramer inequality and its implications. Hypothesis testing framework: Null and alternative hypotheses, Type I and Type II errors, power of a test, Most powerful (MP) tests and Neyman-Pearson Lemma.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO 6	PLO7	PLO8	Average CLO
MMTHDMS125.1	3	3	2	1	2	3	2	3	**2.38**
MMTHDMS125.2	3	3	2	2	3	2	2	2	**2.38**
MMTHDMS125.3	3	3	3	3	1	3	2	3	**2.63**
MMTHDMS125.4	2	2	2	2	2	2	1	1	**1.75**
Average PLO	**2.75**	**2.75**	**2.5**	**2**	**2**	**2.5**	**1.75**	**2.25**	**2.29**

Recommended Books:

1. Sheldon Ross, A First Course in Probability, Pearson Education, 10th Edition, 2018
2. Robert V. Hogg, Joseph W. McKean, Allen T. Craig, Introduction to Mathematical Statistics, Pearson Education, 8th Edition, 2018.
3. Morris H. DeGroot, Mark J. Schervish, Probability and Statistics, Pearson Education, 4th Edition, 2011.
4. George Casella, Roger L. Berger, Statistical Inference, Cengage Learning, 2nd Edition, 2001.

2-Year Master's Program in Mathematics (NEP-2020)

NUMERICAL ANALYSIS

MA/M.Sc. Mathematics (1st Semester) Total Credits: **04**
Course Code: **MMTHDNA125 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: **Marks 28,** Theory: **Marks 72** Time Duration: **2½ hrs**

Course Learning Outcomes(CLO's):

CLO1. Analyze and implement matrix factorization techniques and iterative solvers for large systems of linear equations.
CLO2. Develop and apply numerical methods for solving boundary and initial value problems in differential equations.
CLO3. Employ numerical strategies for solving eigenvalue problems and partial differential equations.
CLO4. Evaluate the stability, accuracy, and efficiency of numerical algorithms using real-world data and simulations.

Unit-I
Review of Numerical Methods, Numerical Linear algebra: LU Decomposition, Cholesky's Method, Singular Value Decomposition, Iterative methods: Jacobi, Gauss-Seidel, Solution of Tri-diagonal system. Least squares curve fitting, Spline functions: Basic concepts of Linear, Quadratic, and Cubic splines.

Unit-II
Numerical Methods for Ordinary Differential Equations (ODE's): Modified Euler's method, Runge-Kutta methods (up to 4th order): derivation and implementation, Predictor corrector methods: Adams-Moulton, Milne's method, Boundary value problems: Finite difference method, cubic spline method, Galerkin's method.

Unit-III
Numerical Methods for Partial Differential Equations (PDE's): Finite Difference Methods (FDM): Elliptic, Parabolic, and Hyperbolic equations, Consistency, Stability, and convergence of difference schemes, Solution of heat equation: Crank-Nicolson method, Bender Schmidt recurrence method, Solution of Laplace equation: Alternating Direction Implicit (ADI) methods.

Unit-IV
Numerical Eigenvalue Problems and Optimization: Power Method, Inverse Iteration, Eigen values of symmetric Tri-diagonal matrix, QR Algorithm, Rayleigh Quotient Iteration, Numerical optimization: Gradient Descent, Newton's Method in optimization, Constrained optimization: Lagrange multipliers, penalty methods. 3

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO 5	PLO6	PLO7	PLO8	Average CLO
MMTHDNA125.1	3	3	2	2	2	3	2	2	**2.37**
MMTHDNA125.2	3	1	2	1	2	3	3	2	**2.13**
MMTHDNA125.3	3	2	2	3	2	3	2	3	**2.5**
MMTHDNA125.4	3	1	2	1	2	3	3	2	**2.13**
Average PLO	**3**	**1.75**	**2**	**1.75**	**2**	**3**	**2.5**	**2.25**	**2.28**

Recommended Books:

1. S.S. Sastry, Introductory Methods of Numerical Analysis, PHI Publications, Fifth Edition 2012.
2. Yousef Saad, Iterative Methods for Sparse Linear Systems, 2nd Edition, SIAM, 2003.
3. Kendall Atkinson and Weimin Han, Elementary Numerical Analysis, 3rd Ed., Wiley, 2004.
4. C.F. Gerald and P.O. Wheatley, Applied Numerical Analysis, 7th Edition, Pearson, 2004.
5. Richard L. Burden and J. Douglas Faires, Numerical Analysis, 10th Edition, Brooks/Cole, Cengage Learning, 2015.

2-Year Master's Program in Mathematics (NEP-2020)
Complex Analysis

MA/M.Sc. Mathematics (2^{nd} Semester) Total Credits: **04**
Course Code: **MMTHCCA225 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): After completion of this course, students shall be able to:

CLO1. Understand the concepts of analyticity, Cauchy-Riemann equations, and complex integration.

CLO2. Apply the fundamental theorems of complex analysis like Cauchy's, Liouville's, and Rouche's theorems.

CLO3. Classify singularities and analyze the behavior of complex functions using Laurent series and infinite products.

CLO4. Explore and apply conformal mappings and Möbius transformations in geometric function theory.

UNIT -I

Continuity and differentiability of complex functions, C-R equations and analytic functions, necessary and sufficient condition for a function to be analytic, complex integration, Cauchy Goursat theorem, Cauchy's integral formula, higher order derivatives, Morera's theorem, Cauchy's inequality.

UNIT -II

Liouville's Theorem and its generalization, fundamental theorem of algebra, Taylor's theorem, Maximum/Minimum modulus theorem, Schwarz lemma and its generalizations, zeros of an analytic function and their isolated character, identity theorem, Argument principle , Rouche's theorem and its applications.

UNIT -III

Laurant's theorem, classification of singularities, removable singularity, Riemann's theorem, poles and behaviour of a function at a pole, essential singularity, Casorati-Weiersstras theorem on essential singularity. Infinite products, convergence and divergence of infinite product, absolute convergence, necessary and sufficient conditions for convergence and absolute convergence.

UNIT -IV

Mobius transformation: Definition, examples, properties and classification, fixed points, cross ratio, inverse points and critical points, conformal mapping, linear transformations carry circles to circles and inverse points to inverse points, mappings of (i) upper half plane on to the unit disc, (ii) unit disc on to the unit disc, (iii) left half plane on to the unit disc and (iv) circle on to a circle. The transformation $w=z^2$ and w = 1/2(z + 1/z).

CLO-PLO Mapping Matrix (Strength version)

CLO ↓	PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHCCA225.1		3	2	3	2	3	2	3	3	**2.63**
MMTHCCA225.2		3	3	3	3	3	3	2	3	**2.87**
MMTHCCA225.3		3	1	3	2	3	3	2	3	**2.5**
MMTHCCA225.4		3	3	3	2	3	3	3	3	**2.87**
Average PLO		**3**	**2.25**	**3**	**2.25**	**3**	**2.75**	**2.5**	**3**	**2.72**

Recommended Books:

1. L. V. Ahlfors, Complex Analysis (3rd Edition), McGraw-Hill Education, 1979.
2. S. Ponnusamy, Foundations of Complex Analysis (2nd Edition), Narosa Publishing House, 2005.
3. Zeev Nehari, Conformal Mapping, Dover Publications, 2012.
4. Richard A. Silverman, Complex Analysis with Applications, Dover Publications, 1984.
5. John B. Conway, Functions of One Complex Variable I (2nd Edition), Graduate Texts in Mathematics, Vol. 11, Springer, 1978.

2-Year Master's Program in Mathematics (NEP-2020)
Ordinary and Partial Differential Equations

MA/M.Sc. Mathematics (2nd Semester) Total Credits: **04**
Course Code: **MMTHCDE225 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): After the completion of this course, students shall be able to:

CLO1. Understand and apply fundamental theorems related to the existence, uniqueness, and continuation of solutions to ordinary differential equations.

CLO2. Analyze linear systems of differential equations using fundamental matrices, variation of parameters, and apply Sturm-Liouville theory.

CLO3. Solve and classify second-order partial differential equations using canonical forms, Laplace and Fourier transforms.

CLO4. Apply separation of variables and eigenfunction methods to solve boundary value problems and wave equations in various coordinate systems.

UNIT -I

Existence of solutions, initial value problem, Arzela-Ascoli lemma, Cauchy Piano existence theorem, uniqueness of solutions with examples, Lipchitz condition and Gronwall inequality, method of successive approximation, Picard-Lindlof theorem, continuation of solutions, system of differential equations, dependence of solutions on initial conditions and parameters. Maximal and minimal solutions of the system of ordinary differential equations, Caratheodary theorem.

UNIT -II

Linear differential equations, linear homogeneous equations, linear system with constant coefficients, linear systems with periodic coefficients, fundamental matrix and its properties, non-homogeneous linear systems, variation of constant formula. Sturm-Liouville theory and Green function method with applications.

UNIT -III

Origin of second order partial differential equations, linear partial differential equations with constant coefficients, methods for solution of second order partial differential equations, classification of second order partial differential equations, canonical forms, Monge's method for the solution of non-linear partial differential equations. Laplace and Fourier transforms and their applications to partial differential equations.

UNIT -IV

Boundary value problems, Drichlet's and Neumann problems for a circle and sphere; solutions by separation of variables method, cylindrical coordinates and spherical polar coordinate system, maximum-minimum principle, uniqueness theorem, Derivation of wave equation, D' Alembert's solution of one dimensional wave equation, separation of variables method, periodic solutions; method of eigen-functions, Duhamel's principle for wave equation.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHCDE225.1	3	3	3	2	3	2	2	3	**2.62**
MMTHCDE225.2	3	3	2	3	3	3	2	2	**2.62**
MMTHCDE225.3	3	3	2	3	3	3	2	3	**2.75**
MMTHCDE225.4	3	3	3	3	3	3	2	2	**3**
Average PLO	**3**	**3**	**2.5**	**2.75**	**3**	**2.75**	**2**	**2.5**	**2.75**

Recommended Books:

1. D. Somasundaram, Ordinary Differential Equations, Narosa Publishers, New Delhi.
2. W.T.Reid, Ordinary Differential Equations.
3. E.A.Coddington and N.Levinson, Theory of Ordinary Differential Equations.
4. K. Sankara Rao, Introduction to Partial Differential Equations, PHI, 3rd Ed. 2011.
5. Robert C. Mc Owen, Partial Differential Equations-Methods and Applications, Pearson Education, Delhi, 2004.
6. L. C. Evans, Partial Differential Equations, GTM, AMS, 1998
7. H.T.H. Piaggio, Differential Equations, CBS Publishers and Distributors, New Delhi.
8. F. John, Partial Differential Equations, 3rd ed., Narosa Publ. Co., New Delhi,1979.

2-Year Master's Program in Mathematics (NEP-2020)
LINEAR ALGEBRA

MA/M.Sc. Mathematics (2nd Semester) Total Credits: **04**
Course Code: **MMTHCLA225 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 Time Duration: 2½ hrs

Course Learning Outcomes(CLO's): After the completion of this course, students are expected to

CLO1. Understand vector spaces, subspaces, and linear transformations including their properties such as rank, nullity, and isomorphism.

CLO2. Analyze linear operators through matrix representations, eigenvalues, minimal and characteristic polynomials, and diagonalizability.

CLO3. Apply concepts of inner product spaces, orthogonal projections, and spectral theorems to solve problems in orthogonality and operator theory.

CLO4. Interpret and compute canonical forms including Jordan and rational canonical forms, and study bilinear and quadratic forms.

Unit-I
Vector spaces, algebra of subspaces, quotient and product spaces, linear dependence and independence of vectors, bases and dimension of vector spaces. Linear transformations, null space and range, rank and nullity of a linear transformation. Isomorphism theorems, Sylvester's theorem.

Unit-II
Matrix representation of a linear transformation, algebra of linear transformations, change of coordinate matrix. Dual spaces, dual basis, annihilators. Similarity and invertibility of linear transformations. Examples and applications of characteristic polynomials, minimal polynomials. Eigen values and eigenspaces, diagonalizability.

Unit-III
Inner product spaces, orthonormal bases and orthogonal projections, Gram- Schmidt orthogonalization, orthogonal complements. Normal and self-adjoint operators. The spectral theorems. generalized eigen vectors and eigen spaces. Jordan decomposition.

Unit-IV
Canonical forms: triangular form, invariance, invariant direct sum decomposition, primary decomposition, nilpotent operators, Jordon canonical form, cyclic subspaces, rational canonical form, quotient spaces, bilinear forms, alternating bilinear forms, symmetric bilinear forms, quadratic forms.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHCLA225.1	3	3	2	3	3	3	2	3	**2.75**
MMTHCLA225.2	3	2	2	2	3	3	2	3	**2.5**
MMTHCLA225.3	3	2	2	2	3	3	2	3	**2.5**
MMTHCLA225.4	3	2	2	2	3	3	3	3	**2.63**
Average PLO	**3**	**2.25**	**2**	**2.25**	**3**	**3**	**2.25**	**3**	**2.59**

Recommended books:

1. Robort A. Beezer, A first course in linear algebra, Organge Grove Books, 2009.
2. John B. Fraleigh and Raymond, Linear Algebra, Pearson Publishers, 3rd Edition, 1995.
3. A. K. Sharma, Linear Algebra, Discovery Edition, 1st Edition, 2016.
4. K. Hoffman and R. Kunze, Linear Algebra, Pearson Education, 2018.
5. S. Lipschutz & M. Lipson, Linear Algebra, Schaum's outline series, Tata McGraw-Hill, 4th Edition 2009.

2-Year Master's Program in Mathematics (NEP-2020)
RESEARCH METHODOLOGY

MA/M.Sc. Mathematics (2nd Semester) Total Credits: **04**
Course Code: **MMTHDRM225 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: **Marks 28,** Theory: **Marks 72** Time Duration: **2½ hrs**

Course Learning Outcomes(CLO's): After completion of this course, students shall have accquired

- **CLO1.** The basic concepts of research methods & methodology
- **CLO2.** The awareness about research ethics.
- **CLO3.** The knowledge of research database and scientific documentation LaTex.
- **CLO4.** The basics of mathematical software MATLAB.

UNIT-I

Meaning of research, objectives of research, motivation in research, types of research, identification of a research problem, research Methods vs Methodology. Scientific conduct: Intellectual honesty and research integrity, Plagiarism, conflicts of interest, violation of publication ethics, predatory publishers and journals.

UNIT-II

Research design and drafting of research plan for funding and research programe. Paper writing skills. Indexing database: citation databases, web of science, scopus, Mathscinet, SCI, ESCI etc, Impact factor, H-index, Google scholar. Use of plagiarism software's like Turnitin, Urkund and other open source software tools.

Unit III

Basics of MATLAB, Overview of features and workspace, Data types, Arrays: Initialization and definition, Array, functions, 2---D Arrays, Multidimensional Arrays, Processing Array elements, Array sorting, Matrices: Matrix Operations & Functions, Special Matrices. Decision Making using If---Else and Switch, Function definitions, Function arguments, Function returns, Embedded Functions, Files and I/O, Reading from a file, Writing to a file, Formatting output, For Loops, Do While Loop, Plots and Graphs, Plot Types, Plot Formatting, Multiple Plots, Plot Fits.

Unit IV

Installation of Kile and MikTeX, Simple typesetting, Spaces, Quotes, Dashes, Accents, Special symbols, Text positioning; Fonts: Type Style, Type Size, The Document: Document class, Font and Paper size, Page formats; Page style: Heading declarations, Page numbering, Formatting Lengths, Understanding Latex compilation Basic Syntax, Writing equations, Matrix, Tables, Page Layout – Titles, Abstract Chapters, Sections, References, Equation references, citation. List making environments Table of contents, Generating new commands, Figure handling numbering, List of figures, List of tables, Generating index, Packages: Geometry, Hyperref, amsmath, amssymb, algorithms, algorithmic graphic, color, tiles listing. Classes: article, book, report, beamer, slides.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDRM225.1	3	3	3	3	3	3	3	3	**3**
MMTHDRM225.2	3	3	3	3	2	3	3	3	**2.87**
MMTHDRM225.3	3	1	3	1	1	1	2	3	**1.88**
MMTHDRM225.4	3	2	3	1	2	3	1	3	**2.25**
Average PLO	**3**	**2.25**	**3**	**2**	**2**	**2.5**	**2.25**	**3**	**2.5**

Recommended Books

1. P. Chaddah (2018) Ethics in Competitive Research: Do not forget scooped; do not get plagiarized, ISMB: 978-9387480865.
2. Indian National Science Academy (INSA), Ethics in Science Education, Research and Governance (2019), ISBN: 978-939482-1-7.
3. Research Methodology: Methods and Techniques, Kothari, C.R., New Age Inter., 4th Ed. 2019.
4. E. Krishnan. LATEX Tutorials A PRIMER.Indian TEX Users Group, Trivandrum, India, 2003
5. William J. Palm III, Introduction to MATLAB for Engineers, McGraw-Hill Education, 3rd Edition, 2011
6. Lawerence F. Shampine, Solving Odes with MATLAB, McGraw-Hill Education, 1st Edition, 2003.

2-Year Master's Program in Mathematics (NEP-2020)

INTEGRAL EQUATIONS & CALCULUS OF VARIATIONS

MA/M.Sc. Mathematics (2nd Semester) Total Credits: **04**
Course Code: **MMTHDIE225 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of this course, the student will be able to:

CLO1. Understand and solve linear integral equations of Volterra and Fredholm types using methods like successive approximations and Neumann series.
CLO2. Apply Fredholm theory, symmetric kernel techniques, and Hilbert-Schmidt theory to analyze and solve integral equations.
CLO3. Formulate and solve variational problems using Euler-Lagrange equations and related necessary and sufficient conditions.
CLO4. Employ direct methods such as Rayleigh-Ritz and Galerkin's to solve variational problems in ordinary and partial differential equations.

UNIT -I

Linear integral equations of the first and second kinds, Volterra and Fredholm integral equations, relations between differential and integral equations, solution of Volterra and Fredholm integral equations by the methods of successive substitutions and successive approximations, iterated and resolvent kernels, Neumann series, reciprocal functions, Volterra's solutions of Fredholm equations.

UNIT -II

Fredholm associated equation, solution of integral equations using Fredholm's determinant and minor, homogeneous integral equations, integral equations with separable kernels, the Fredholm alternatives, symmetric kernels, Hilbert Schmidt theory for symmetric kernels, applications of integral equations to differential equations, initial value problem, boundary value problem, Dirac-Delta function, Green's function approach.

UNIT -III

Functionals, The concept of variation and its properties, Variational problems with fixed and moving boundaries, The Euler-Lagrange equation, Variational problems in parametric form. Reflection and refraction extremals. Necessary and Sufficient conditions for an extremum, Canonical equations and variational principles, Complementary variational principles.

UNIT -IV

Isoperimetric problem, The Hamilton-Jacobi equation, Direct methods for variational problem: Rayleigh-Ritz method, Galerkin's method, Variational methods for boundary value problems in ordinary and partial differential equations.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDIE225.1	3	3	3	2	2	3	2	2	**2.5**
MMTHDIE225.2	3	3	1	3	2	1	3	3	**2.38**
MMTHDIE225.3	3	3	2	1	2	3	2	3	**2.38**
MMTHDIE225.4	3	3	2	2	2	2	3	3	**2.5**
Average PLO	**3**	**3**	**2**	**2**	**2**	**2.25**	**2.5**	**2.75**	**2.44**

Books Recommended:

1. R. P. Kanwal, Linear Integral Equations (Theory and Technique), Academic Press Birkhauser-1997.
2. W. V. Lovitt, Linear Integral Equations, Dover Publications, Inc. New York, 1950.
3. K. F. Riley, M.P. Hobson and S.T. Bence, Mathematical Methods for Physics and Engineering Cambridge University Press, U.K., 1997.
4. M. D. Raisinghania, Integral Equations and Boundary Value Problems, S.C. Chand India, 2007.
5. Shanti Swarup, Integral Equations (&Boundary Value Problems), Krishna Prakashan Media (P) Ltd. Meerut, India, 2014.
6. A. S. Gupta, Calculus of Variation with Applications, Prentice-Hall, India, 1997.
7. G. M. Ewing, Calculus of Variations with Applications, Dover, 1985.
8. Sagan, An Introduction to the Calculus of Variations, Dover Publications, 1967.
9. J.N. Reddy, Finite Element Method, McGraw Hills, Third Edition, 2005.

2-Year Master's Program in Mathematics (NEP-2020)
Algebraic Topology

MA/M.Sc. Mathematics (2nd Semester) Total Credits: **04**
Course Code: **MMTHDAT225 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): After successful completion of the course, the students will be able to:

CLO1. Understand concepts of path homotopy, deformation retracts, and basic topological constructions.
CLO2. Compute fundamental groups and apply them to classical theorems in topology and algebra.
CLO3. Analyze covering spaces and apply lifting theorems in topological contexts.
CLO4. Develop an understanding of simplicial complexes and compute simplicial homology using Mayer-Vietoris sequences.

Unit-I
Introduction to Homotopy, Paths and path homotopy, homotopy equivalence, contractibility, deformation retracts. Basic constructions: cones, mapping cones, mapping cylinders, suspension.

Unit-II
Fundamental groups: construction of fundamental groups, fundamental group of circle. Application to Fundamental Theorem of Algebra, Brouwer's Fixed Point Theorem and the Borsuk-Ulam Theorem.

Unit-III
Covering spaces: covering spaces of $S^1$and $S^1 S^1$. Lifting: path and homotopy lifting, lifting properties, Lifiting Criterion, regular covering spaces.

Unit-IV
Cell complexes, subcomplexes with examples. Simplicial complexes, barycentric subdivision, stars and links. Simplicial Homology, Mayer-Vietoris Sequences, long exact sequences.

CLO-PLO Mapping Matrix (Strength version)s

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDAT225.1	3	2	2	3	2	1	2	2	**2.13**
MMTHDAT225.2	3	1	3	2	2	2	3	3	**2.38**
MMTHDAT225.3	3	3	2	1	3	1	2	3	**2.25**
MMTHDAT225.4	3	2	1	3	2	3	2	2	**2.25**
Average PLO	**3**	**2**	**2**	**2.25**	**2.25**	**1.75**	**2.25**	**2.5**	**2.25**

Recommended Books

1. A. Hatcher, Algebraic Topology, Cambridge Univ. Press, Cambridge, 2002.
2. W. Fulton, Algebraic topology: A First Course, Springer-Verlag, 1995.
3. W. Massey, A Basic Course in Algebraic Topology, Springer-Verlag, Berlin, 1991.
4. J. J. Rotman, An Introduction to Algebraic Topology, Springer (India), 2004.
5. J. R. Munkres, Elements of Algebraic Topology, Addison-Wesley, 1984.

2-Year Master's Program in Mathematics (NEP-2020)
Operations Research

MA/M.Sc. Mathematics (2nd Semester) Total Credits: **04**
Course Code: **MMTHDOR225 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of the this course, students will be able to:

CLO1. Formulate and solve linear programming problems using techniques such as the graphical method and the Simplex method.
CLO2. Analyze transportation, assignment, and network flow problems and apply suitable algorithms to find optimal solutions.
CLO3. Apply queueing theory to model and solve real-life problems related to service systems, telecommunications, and manufacturing.
CLO4. Design and implement simulations for optimization, forecasting, and decision-making scenarios. Evaluate and interpret the results of Operations Research models to aid in strategic business, manufacturing, and logistical decisions.

UNIT –I
Operation research: An overview, Linear Programming Problems (LPP): Convex sets and convex functions, Graphical method, Simplex method, Big-M method, Two - phase methods and Revised simplex method, Extreme Point Theorem, Fundamental Theorem of Linear Programming.

UNIT -II
Concept and applications of duality, Primal- Dual relations, Formulation of Dual problem, Duality theorems (weak duality and Strong duality theorems), Complementary slackness theorems and conditions, Dual simplex method. Existence of solution in Transportation Problem (TP), Methods for solving (TP) :, North-West Corner rule, Least Cost Method, Vogel's method and MODI method, Assignment problem: Hungarian method.

UNIT –III
Sensitivity Analysis: Changes in the coefficients of the objective function and Right hand side constants of constraints, Adding a new constraint and a new variable, Network Routing Problem: Dijkstra's Algorithm, Network Scheduling: Rules of Network Construction, PERT and CPM, Probability Consideration in PERT, Distinction between PERT and CPM,

UNIT –IV
Game Theory: Two Person Zero-Sum Games, Games with Pure strategies, Games with Mixed strategies, Maximin - Minimax Principle, Dominance Property, Finding solution of 2x2, 2xm, mx2 games.Equivalence between game theory and linear programming problem (LPP), Simplex method for game problem. Queuing Theory and Simulation, Basic concepts, models (M/M/1, M/M/c, etc.), Little's Law. Queuing Applications: In telecommunications, service systems, and manufacturing. Simulation: Introduction to Monte Carlo simulation, types of simulation, and applications in decision-making.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓	**PLO →**	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	**Average CLO**
MMTHDOR225.1		3	3	3	2	3	3	2	2	**2.63**
MMTHDOR225.2		3	3	2	2	2	3	2	3	**2.5**
MMTHDOR225.3		3	3	2	2	1	3	2	3	**2.38**
MMTHDOR225.4		3	3	2	2	1	3	3	3	**2.5**
Average PLO		**3**	**3**	**2.25**	**2**	**1.75**	**3**	**2.25**	**2.75**	**2.5**

Recommended Books:

1. Kanti Swarup, P. K. Gupta, & M. M. Singh, Operation Research. Sultan Chand & Sons, 20th Edition, 2010.
2. Taha, H.A., Operations Research: An Introduction, Pearson, 10th Edition, 2017
3. Hillier, F.S., & Lieberman, G.J. Introduction to Operations Research, McGraw-Hill Education, 10th Edition, 2014.
4. Vanderbei, R.J. Linear Programming: Foundations and Extensions, Springer, 4th Edition, 2014.
5. Gross, D., & Harris, C.M. Fundamentals of Queueing Theory, Wiley, 4th Edition, 2008.

2-Year/1-Year Master's Program in Mathematics (NEP-2020)
Functional Analysis

MA/M.Sc. Mathematics (3rd Semester) Total Credits: **04**
Course Code: **MMTHCFA325 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): Upon completion of this course, students will be able to

CLO1. Distinguish between Banach and Hilbert spaces, and analyze their structural and topological differences.

CLO2. Apply the concept of orthogonal decomposition in Hilbert spaces and examine the role of orthonormal sets and sequences in functional spaces.

CLO3. Represent bounded linear functionals using inner products and interpret the Riesz Representation Theorem in Hilbert spaces.

CLO4. Develop a foundational understanding of linear operators and functional spaces, with an emphasis on their applications in mathematical and scientific problem-solving.

UNIT-I

Banach Spaces: Normed space, definition and examples. Banach spaces, subspaces, quotient spaces, continuous linear operators and their characterization, completeness of the space L(X,Y) of bounded linear operators (and itsconverse), incompleteness of C[a, b] under the integral norm, finite dimensional Banach spaces,equivalence of norms on finite dimensional space and its consequences, dual of a normed linear space, , duals of lpn, Co , lp (p≥1), C[a, b].

UNIT-II

Hahn Banach theorem (extension form) and its applications, Uniform boundedness, principle and weak boundedness, dimension of an ∞ -dimensional Banach space, conjugate of a continuous linear operator and its properties, Banach-Steinhauss theorem, open mapping and closed graph theorems, counterexamples to Banach-Steinhauss, open mapping theorem and closed graph theorems for incomplete domain and range spaces, separable Banach spaces and the separability of some concrete Banach spaces (Co, C[0,1], lp, p≥1), reflexive Banach Spaces, closed subspace and the dual of a reflexive Banach space, examples of reflexive and non-reflexive Banach spaces.

UNIT-III

Hilbert spaces: definition and examples, Cauchy's Schwartz inequality, parallogram law, orthonormal systems, Bessel's inequality and Parseval's Identity for complete orthonormal systems, Riesz-Fischer theorem, Gram Schmidt process, o.n basis in separable Hilbert spaces.

UNIT-IV

Projection theorem, Riesz Representation theorem, counterexample to the projection theorem and Rieszrepresentation theorem for incomplete spaces, Hilbert property of the dual of a Hilbert space and counter examples of incomplete inner product spaces, reflexivity of Hilbert space, adjoint of a

Hilbert space operator, weak convergence and Bolzano-Weirstrass property in Hilbert Spaces, normal and unitary operators, finite dimensional spectral theorem for normal operators.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHCFA325.1	3	3	3	2	3	2	1	3	**2.5**
MMTHCFA325.2	3	3	3	1	2	3	3	3	**2.63**
MMTHCFA325.3	3	3	3	2	2	3	2	3	**2.63**
MMTHCFA325.4	3	2	2	3	2	2	3	3	**2.5**
Average PLO	**3**	**2.75**	**2.75**	**2.25**	**2.25**	**2.5**	**2.25**	**3**	**2.57**

Recommended Books:

1. Erwin Kreyszig, Introductory Functional Analysis with Applications, Wiley Publishers, reprint 2015.

2. B. V. Limaya, Functional Analysis, New Age International Pvt. Ltd; 3rd edition, 2014.

3. C. Goffman & G. Pedrick, A First Course in Functional Analysis, American Mathematical Society; 2nd edition, 2017.

4. J.B. Conway, A Course in Functional Analysis, Springer, 4th Edition, 1994.

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

DIFFERENTIAL GEOMETRY

MA/M.Sc. Mathematics (3rd Semester) Total Credits: **04**
Course Code: **MMTHCDG325 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of the course, the students will be able to:

CLO1. Analyze and characterize curves in terms of their curvature, torsion, and Frenet-Serret frame, including applications to space curves and helices.

CLO2. Understand and compute key concepts of regular surfaces, including the first and second fundamental forms, and analyze the geometric properties of surfaces like normal curvature and principal curvatures.

CLO3. Apply differential geometry concepts to study Gaussian and mean curvature, minimal surfaces, isometries, and coordinate systems.

CLO4. Derive and apply the Gauss-Bonnet theorem, geodesic equations, and fundamental theorems for surfaces, and solve geodesic problems on different surfaces.

UNIT-I

Parametrized Curves, Regular curves, Arc length, Reparameterization by arc-length, Arc-length is independent of parameterization, plane and space curves, Frenet-Serret frame. Characterization of plane and space curves in terms of their curvature and torsion. Fundamental theorem of space curves. Helix, necessary and sufficient condition for a space curve to be helix. Involutes and evolutes of space curves. Global properties of curves: Simple closed curves, Isoperimetric Inequality, Four Vertex Theorem.

UNIT -II

Regular surfaces, Change of coordinates. The Tangent Plane, The First Fundamental Form (metric), Area element, and properties of metric, Orientable and Non-Orientable surfaces. Gauss map, differential of the Gauss map is self adjoint operator. Second Fundamental form. Normal curvature, Normal curvature in terms of second fundamental form. Principal curvatures and principle directions, Meusnier's theorem. Classification of points with prescribed principal curvatures, Euler's formula.

UNIT-III

Gaussian and mean curvature, Hilbert's theorem and its applications. Weingarten equation, Gaussian curvature in terms of area, line of curvature, Rodrigue's formula for line of curvature. Joachimsthal's Theorem, Dupin's Theorem. Ruled and Minimal surfaces. Isothermal coordinates. A surface is minimal if and only if its coordinate functions are harmonic. Isometry between surfaces, local isometry, and characterization of local isometry.

UNIT -IV

Christoffel symbols, Theorema Egregium. Gauss equations and Manardi Codazzi equations for surfaces, fundamental theorem for regular surface. (Statement only). Geodesics: geodesic curvature, geodesic curvature is intrinsic, equations of geodesic, geodesic on sphere and pseudo sphere, geodesic as distance minimizing curves. Gauss-Bonnet theorem (statement only), geodesic triangle on sphere, implication of Gauss-Bonnet theorem for geodesic triangle.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓	PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHCDG325.1		3	3	2	1	3	2	3	3	**2.5**
MMTHCDG325.2		3	3	2	2	3	2	1	3	**2.38**
MMTHCDG325.3		3	3	3	1	3	2	1	3	**2.38**
MMTHCDG325.4		3	3	3	3	3	2	3	3	**2.88**
Average PLO		**3**	**3**	**2.5**	**1.75**	**3**	**2**	**2**	**3**	**2.54**

Recommended Books:

1. M. P. Do Carmo, Differential geometry of curves and surfaces, Dover Publications, 2nd Ed. 2016.
2. Sebastian Montiel, Antonio Ros, Curves and surfaces, AMS, 2nd Edition, 2009.
3. K.K. Dube, Differential geometry and Tensors, I.K. International Publishing House, 2009.
4. Andrew Pressley, Elementary Differential Geometry, Springer Undergraduate Mathematics Series, 2nd edition , 2010.

MEASURE THEORY

MA/M.Sc. Mathematics (3rd Semester) Total Credits: **04**
Course Code: **MMTHCMT325 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: **Marks 28,** Theory: **Marks 72** Time Duration: **2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of the course, the students will be able to:

CLO1. Understand and apply the fundamental concepts of measure theory, including outer measure, Borel sets, Lebesgue measurability, and the existence of non-measurable sets.

CLO2. Characterize measurable functions, and analyze convergence properties such as almost everywhere convergence, convergence in measure, and Egoroff's theorem.

CLO3. Develop a strong foundation in Lebesgue integration, including the equivalence between Riemann and Lebesgue integrals, and apply important theorems like Fatou's lemma and the Dominated Convergence Theorem.

CLO4. Study the properties of absolute continuity, bounded variation, and their relationships, and apply Vitali's covering lemma to solve problems involving differentiation of monotone functions.

UNIT -I

Measure theory: definition of outer measure and its basic properties, outer measure of an interval as its length, countable additivity of the outer measure, Borel measurable sets and Lebesgue measurability of Borel sets, Cantor set, existence of non- measurable sets and of measurable sets which are not Borel, outer measure of monotonic sequences of sets.

UNIT -II

Measurable functions and their characterization, algebra of measurable functions, Stienhauss theorem on sets of positive measure, Ostroviski's theorem on measurable solution of $f(x+y)=f(x)+f(y), x, y \in R$, convergence a.e., convergence in measure and almost uniform convergence, their relationship on sets of finite measure, Egoroff's theorem.

UNIT -III

Lebesgue integral of a bounded function, equivalence of $L-$¿integrability and measurability for bounded functions, Riemann integral as a Lebesgue integral, basic properties of Lebesgue –integral of a bounded function, fundamental theorem of calculus for bounded derivatives, necessary and sufficient condition for Riemann integrability on $[a,b]$, $L-$¿integral of non- negative measurable functions and their basic properties, Fatou's lemma and monotone convergence theorem, $L-$¿ integral of an arbitrary measurable function and basic properties, dominated convergence theorem and its applications.

UNIT -IV

Absolute continuity and bounded variation, their relationships and counter examples, indefinite integral of an L-integrable function and its absolute continuity, necessary and sufficient condition for bounded variation, Vitali's covering lemma and a. e., differentiability of a monotone function f and $\int f' \leq f(b)-f(a)$.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHCMT325.1	3	3	2	2	3	1	2	3	**2.38**
MMTHCMT325.2	3	3	2	2	2	1	2	3	**2.25**
MMTHCMT325.3	3	3	3	2	3	3	3	3	**2.88**
MMTHCMT325.4	3	3	3	3	2	3	1	3	**2.63**
Average PLO	**3**	**3**	**2.5**	**2.25**	**2.5**	**2**	**2**	**3**	**2.54**

Recommended Books:

1. P.K. Jain, V.P. Gupta, Lebesgue measure and Integration, John Wiley and Sons, 1986
2. R. Goldberg, Methods of Real Analysis, Dover Publications, 2nd Edition, 1980.
3. G. De Barra, Measure Theory and Integration, Narosa Publishing House,1st Edition, 2003.
4. W. Rudin, Principles of Mathematical Analysis, McGraw-Hill Education, 3rd Edition, 1976.
5. Chae, Lebesgue Integration, Springer, 1st Edition, 2000.
6. S. M. Shah and Saxena, Real Analysis, Discovery Publishing House, 1st Edition,1994.

2-Year/1-Year Master's Program in Mathematics (NEP-2020)
ADVANCED COMPLEX ANALYSIS

MA/M.Sc. Mathematics (3rd Semester) Total Credits: **04**
Course Code: **MMTHDCA325 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: **Marks 28,** Theory: **Marks 72** Time Duration: **2½ hrs**

Course Learning Outcomes(CLO's): After successful completion of this course, students will be able to:

CLO1. Understand and apply advanced integral techniques in complex analysis such as the residue theorem, Poisson-Jensen formula, and Parseval's identity to evaluate complex integrals and solve boundary value problems.
CLO2. Analyze the behavior of power series, explore the principles of analytic continuation and univalent functions, and apply reflection principles and Borel's theorem in function theory.
CLO3. Examine the structure of analytic functions through symmetric and orthogonal polynomials and utilize tools from matrix analysis in the context of complex variables.
CLO4. Investigate the role of critical points, convex hulls, and Gauss-Lucas theorem in understanding the distribution of zeros of polynomials and extend classical results like Jensen's theorem in real and complex analysis.

UNIT -I

Calculus of Residues: Cauchy's residue theorem, evaluation of integrals by the method of residues, Parseval's Identity, Blashke's theorem. Poisson integral formula for circle and half plane, Poisson-Jensen formula, Estermann's uniqueness theorem and Hadamards three circle theorem**.**

UNIT -II

Power series: Cauchy-Hadamard formula for the radius of convergence, theorems on power series. The principle of analytic continuation and its uniqueness, functions with natural boundaries e.g., $\sum z^{n!}, \sum z^{2^n}$. Schwarz reflection principle. Functions with positive real part, Borel's theorem, univalent functions, area theorem, Bieberbach's conjecture (statement only) and Koebe's ¼ theorem. Space of analytic functions, a - points of an analytic function and related results.

UNIT -III

Fundamental theorem of algebra (revisited), symmetric polynomials, the continuity theorem, orthogonal polynomials, general properties, the classical orthogonal polynomials, tools from matrix analysis.

UNIT -IV

Critical points in terms of zeros, fundamental results and critical points, convex hulls and Gauss-Lucas theorem, some applications of Gauss-Lucas theorem, extensions of Gauss-Lucas theorem, average distance from a line or a point, real polynomials and Jenson's theorem, extensions of Jenson's theorem.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDCA325.1	3	3	3	2	3	3	1	3	**2.63**
MMTHDCA325.2	3	3	2	1	3	1	2	2	**2.13**
MMTHDCA325.3	3	3	3	3	2	3	2	2	**2.63**
MMTHDCA325.4	3	3	3	3	3	1	3	3	**2.75**
Average PLO	**3**	**3**	**2.75**	**2.25**	**2.75**	**2**	**2**	**2.5**	**2.53**

Recommended Books:

1. L. V. Ahlfors, Complex Analysis (3rd Edition), McGraw-Hill Education, 1979.
2. S. Ponnusamy, Foundations of Complex Analysis (2nd Edition), Narosa Publishing House, 2005.
3. Zeev Nehari, Conformal Mapping, Dover Publications, 2012.
4. Richard A. Silverman, Complex Analysis with Applications, Dover Publications, 1984.
5. John B. Conway, Functions of One Complex Variable I (2nd Edition), Graduate Texts in Mathematics, Vol. 11, Springer, 1978.

2-Year Master's Program in Mathematics (NEP-2020)
ADVANCED GRAPH THEORY

MA/M.Sc. Mathematics (3rd Semester) Total Credits: **04**
Course Code: **MMTHDGT325 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: **Marks 28,** Theory: **Marks 72** Time Duration: **2½ hrs**

Course Learning Outcomes(CLO's):

CLO1: Understand various graph colorings, like vertex, edge and map coloring and computation of chromatic numbers associated to them. Applying well known theorems of Brook and Vizing for investigation of structure of graphs and using graph coloring to solve real world problems.
CLO2: Understand the definitions, properties and applications of matchings in graphs. Distinguishbetween different types of matchings, such as maximum matchings, perfect matchings and maximal matchings. Apply the concepts of matching to solve real-world problems, such as optimal assignment problems, scheduling, and resource allocation. Understand various matching and factorization theorems such as Hall's, Tutte's, and f-factor theorems. Understand the relationship between matchings and other graph concepts like independent sets, covering, and vertex coloring.
CLO3: Explore edge graphs, total graphs and eccentricity sequences. Use theorems like Whitney's and Lesniak's to understand structural graph properties. Existence of graphs with given sequence (set) of positive integers to be eccentricity sequence (set).
CLO4: Examine graphs associated with groups and vice versa and apply theorems like Frucht's to study algebraic properties of graphs. Understand use of linear algebra, particularly eigenvalues and eigenvectors, in revealing insights of graph properties. Construct and utilize graph matrices, adjacency and Laplacian, to understand graph connectivity, clustering and random walk behavior. Explore the relationship between graph spectra and combinatorial properties.

UNIT- I
Colorings: Vertex coloring, chromatic number $\chi(G)$, bounds for $\chi(G)$, Brooks theorem, edge coloring, Vizing's theorem, map coloring, six color theorem, five color theorem, every graph is four colourable iff every cubic bridgeless plane map is 4-colorable, every planar graph is 4-colorable iff $\chi'(G) = \mathbf{3}$. Heawood map coloring theorem, uniquely colorable graphs.

UNIT – II
Matchings: Matchings and 1-factors, Berge's theorem, Hall's theorem, 1-factor theorem of Tutte, antifactor sets, f-factor theorem, f-factor theorem implies 1-factor theorem, Erdos- Gallai theorem follows from f-factor theorem, degree factors, **k**-factor theorem, factorization of $\mathbf{K}_n$.

UNIT - III
Edge graphs and eccentricity sequences: Edge graphs, Whitney's theorem on edge graphs, Beineke's theorem, edge graphs of trees, edge graphs and traversibility, total graphs, eccentricity sequences and sets, Lesniak theorem for trees, construction of trees, neighbourhoods, Lesniak theorem graphs.

UNIT -IV
Groups in graphs and graph spectra: Automorphism groups of graphs, graph with a given group, Frucht's theorem, Cayley digraph, spectrum of a graph, spectrum of some graphs-regular graph, compliment of a graph, edge graph, complete graph, complete bipartite, cycle and path, Laplacian spectrum, energy of a graph, Laplacian energy.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ / PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDGT325.1	3	3	2	2	3	3	2	3	**2.63**
MMTHDGT325.2	3	3	3	2	3	3	2	3	**2.75**
MMTHDGT325.3	3	3	3	3	3	2	3	3	**2.88**
MMTHDGT325.4	3	3	3	3	3	3	1	3	**2.75**
Average PLO	**3**	**3**	**2.75**	**2.5**	**3**	**2.75**	**2**	**3**	**2.75**

Recommended Books:

1. R. Balakrishnan, K. Ranganathan, A Text Book of Graph Theory, Springer-Verlag, New York (2012).
2. B. Bollobas, Extremal Graph Theory,Springer (2002).
3. F. Harary, Graph Theory, Narosa (2001).
4. Narsingh Deo, Graph Theory with Applications to Eng. and Comp. Sci, PHI. (1979)
5. S. Pirzada, An Introduction to Graph Theory, Universities Press, Orient Blackswan, (2012).
6. W. T. Tutte, Graph Theory, Cambridge University Press. (2016).
7. D. B. West, Introduction to Graph Theory, Pearson (2022).

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

MATHEMATICAL BIOLOGY

MA/M.Sc. Mathematics (3rd Semester) Total Credits: **04**
Course Code: **MMTHDMB325 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: **Marks 28,** Theory: **Marks 72** Time Duration: **2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of this course, students will be able to:

CLO1. Understand the principles and types of mathematical modeling, and how to formulate, solve, and interpret models in biological systems.
CLO2. Analyze growth and decay models, both linear and nonlinear, and understand their relevance to real-world biological phenomena**.**
CLO3. Apply matrix-based population models (e.g., Leslie matrices**),** and explore classical models like Fibonacci's rabbits and the golden ratio in biological contexts.
CLO4. Construct and evaluate models in ecology and epidemiology, including predator-prey systems and disease transmission models and understand bio-fluid mechanics and diffusion processes within biological systems, and apply physical laws to interpret physiological behaviors.

UNIT I:
Overview of mathematical modeling: definitions, importance, and scope, Types of models: deterministic vs stochastic, discrete vs continuous, linear vs nonlinear, Steps in model development: formulation, solution, and interpretation, Linear and nonlinear growth and decay models, Population models: Leslie matrices, Continuous models for single-species populations, Logistic growth model. Fibonacci's rabbits, golden ratio, and their applications in biology, Introduction to compartment models, Limitations of biological models

UNIT II:
Basic terminology in ecology, Mathematical models for interacting populations, Types of interactions: predator-prey, competition, symbiosis, Lotka–Volterra system, Equilibrium points and stability analysis, Geometrical interpretation of predator-prey models, Concepts of almost linear systems.

UNIT III:
Epidemiology fundamentals, Mathematical models for communicable diseases: SI, SIS, SIR, and SIR endemic models, Case studies: HIV/AIDS models, Concepts: window period, ELISA testing, Modeling of sexually transmitted diseases, Vaccination strategies and control measures.

UNIT IV:
Diffusion in biology: Fick's law of diffusion, Fick's perfusion law, Diffusion through slabs and membranes, Bio-fluid mechanics: Types of fluid flows and viscosity, Continuity equation and equation of motion, The circulatory system: heart, arteries, blood composition, Mathematical models of blood flow, Poiseuille's flow and its applications. Stewart Hamilton Method for measuring cardiac output. Enzyme kinetics and Michaelis-Menten model.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓	PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDMB325.1		3	2	3	2	3	3	2	3	**2.63**
MMTHDMB325.2		3	3	2	2	3	3	3	3	**2.75**
MMTHDMB325.3		3	2	2	1	3	3	1	2	**2.13**
MMTHDMB325.4		3	2	3	3	3	3	2	3	**2.75**
Average PLO		**3**	**2.25**	**2.5**	**2**	**3**	**3**	**2**	**2.75**	**2.57**

Books Recommended

1. J. N. Kapur, Mathematical Modelling, New Age International Publishers, 2015.
2. J.D. Murray Mathematical Biology (An Introduction, Vol. I & II), Springer- Verlag, 2002 (vol.1) & 2003 (vol. 2).
3. J.N. Kapur, Mathematical Model in Biology and Medicines, Affiliated East-West Press, New Delhi, 1985
4. S. I. Rubinow, Introduction to Mathematical Biology, John Wiley andSons, 1975.
5. MA Khanday, Introduction to Modeling and Biomathematics, Dilpreet Publishers New Delhi, 2016.
6. Jaffrey R. Chasnov, Lecture Notes on Mathematical Biology, Hong Kong Press, 2010.

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

Fourier and Wavelet Analysis

MA/M.Sc. Mathematics (3rd Semester) Total Credits: **04**
Course Code: **MMTHDFW325 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 Time Duration: 2½ hrs.

Course Learning Outcomes(CLO's): Upon completion of this course, students will be able to

CLO1. Understand the fundamentals of Fourier transforms and apply them to solve differential equations.
CLO2. Analyze and apply continuous and discrete wavelet transforms, including their basic properties and key examples.
CLO3. Explore multi resolution analysis (MRA) and construct orthonormal wavelet bases using scaling functions.
CLO4. Examine advanced wavelet structures such as spline, Daubechies,and biorthogonal wavelets, and their applications.

Unit I

Fourier Transforms and Their Applications: Definition and examples of Fourier transforms in $L^2(R)$, basic properties of Fourier transforms, Convolution theorem, Plancherel and Parseval's formulae, Poisson summation formula, Shannon-Whittaker sampling theorem, Heisenberg's uncertainty principle, Applications of Fourier transforms to ordinary and partial differential equations (Laplace, heat and wave equations).

Unit II

Wavelet Transforms: Definition and examples of windowed Fourier transform, Continuous wavelet transform and its basic properties, wavelets by convolution, Haar wavelet, Morlet wavelet, Mexican hat wavelet, resolution of the wavelet transform, Parsevals' and inversion formulae for wavelet transform, characterization of range, Discrete wavelet transform with examples.

Unit III

Multiresolution Analysis: Multiresolution analysis (MRA), properties of scaling functions, construction of orthonormal wavelet bases, examples of MRA based wavelets (Haar, Shannon and Meyer wavelets), fast wavelet transform, applications of basic equations, characterization of MRA wavelets and scaling functions.

Unit IV

Elongations of MRA-Based Wavelets: Construction and examples of Spline wavelets (Franklin and Battle-Lemarié wavelets), compactly supported wavelets, Daubeachies wavelets, biorthogonal wavelets, wavelet packets, Harmonic wavelets.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDFW325.1	3	2	2	2	3	3	2	3	**2.5**
MMTHDFW325.2	3	3	2	1	3	3	2	3	**2.5**
MMTHDFW325.3	3	3	3	2	3	3	2	3	**2.75**
MMTHDFW325.4	3	2	3	3	3	3	1	3	**2.63**
Average PLO	**3**	**2.5**	**2.5**	**2**	**3**	**3**	**1.75**	**3**	**2.6**

Recommended Books:

1. Jonas Gomes and Luiz Velho, From Fourier Analysis to Wavelets, Springer, 2015.
2. M. Pinsky, Introduction to Fourier Analysis and Wavelets, Brooks/Cole Publishing, 2002.
3. F.A. Shah and A.Y. Tantary, Wavelet Transforms: Kith and Kin, CRC Press, 2023.
4. A. Henandez and G. Weiss, A First Course on Wavelets, CRC Press, 1996.
5. L. Debnath and F. A. Shah, Wavelet Transforms and Their Applications, Springer, 2015.
6. I. Daubechies , Ten Lectures on Wavelets, SIAM, Philadelphia, 1992.

2-Year/1-Year Master's Program in Mathematics (NEP-2020)
FIELDS AND GALOIS THEORY

MA/M.Sc. Mathematics (4th Semester) Total Credits: **04**
Course Code: **MMTHCFG425 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of this course, students will be able to:

CLO1. Comprehend the structure and properties of fields and their extensions, and apply this knowledge to solve problems in algebra and geometry.
CLO2. Identify and work with separable and normal extensions, and understand their significance in algebraic structures.
CLO3. Study the role of automorphisms and Galois groups in field extensions, and apply Galois Theory to solve polynomial equations.
CLO4. Delve into advanced topics such as cyclic extensions, Artin-Schreier extensions, and Galois groups over finite fields, and understand their applications in various areas of mathematics.

Unit I
Fields: Prime fields and their structure, field extensions, finite, algebraic and transcendental extensions. Algebraic elements and algebraic integers. Roots of polynomials, remainder and factor theorems. Kronecker's theorem. Algebraically closed fields and related results.

Unit II
Splitting field: Splitting field of a polynomial, existence and uniqueness of splitting field of a polynomial. Separable and inseparable extensions. The primitive element theorem. Finite fields, classification of finite fields. Perfect fields.

Unit III
Automorphisms and Galois groups: Automorphisms of field extensions, fixed fields, Galois fields. Normal extensions and Fundamental theorem of Galois theory. Quadratic extensions. Construction with straight edge and compass.

Unit IV
Advanced topics in Galois Theory: Roots of unity and cyclotomic polynomials, cyclic extensions. Study of Galois groups in the context of finite fields. Solvability by radicals, condition for Galois group Gal(G\F) to be solvable, insolvability of the general quintic equation.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHCFG425.1	3	3	2	2	3	2	1	3	**2.38**
MMTHCFG425.2	3	3	2	1	3	1	3	3	**2.38**
MMTHCFG425.3	3	3	3	2	3	3	2	3	**2.75**
MMTHCFG425.4	3	3	3	3	3	2	1	3	**2.63**
Average PLO	**3**	**3**	**2.5**	**2**	**3**	**2**	**1.75**	**3**	**2.54**

Recommended Textbooks

1. D. S. Dummit and R. M. Foote, Abstract Algebra – Wiley, 3rd Edition, 2004.
2. I. N. Herstein,Topics in Algebra, Wiley India, 2nd Edition, 2006.
3. Ian Stewart, Galois Theory, Chapman and Hall/CRC, 4th Edition, 2015.
4. D. J. H. Garling, A Course in Galois Theory – Cambridge University Press, 2013

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

RESEARCH PROJECT

MA/M.Sc. Mathematics (4th Semester) Total Credits: **12**
Course Code: **MMTHPDI425** Total Marks: 2**00**

The details are given in the Regulations of the Program.

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

INTERNSHIP

MA/M.Sc. Mathematics (4th Semester) Total Credits: **04**

Course Code: **MMTHISO425** Total Marks: 1**00**

The details are given in the Regulations of the Program

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

RIEMANNIAN GEOMETRY

MA/M.Sc. Mathematics (4th Semester) Total Credits: **04**
Course Code: **MMTHDRG425 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of this course, students will be able to:

CLO1. Understand and construct differentiable manifolds, atlases, and smooth maps, and analyze their structure using charts and transition functions.

CLO2. Explain the concepts of immersions, embeddings, submanifolds, and vector bundles; compute and interpret tangent and cotangent spaces on manifolds.

CLO3. Apply Riemannian metrics, connections, and curvature tensors (including scalar and Ricci curvatures) to study the geometric properties of Riemannian manifolds.

CLO4. Analyze submanifolds and hypersurfaces using second fundamental form, Gauss, Codazzi, and Ricci equations, and explore their role in the intrinsic and extrinsic geometry of manifolds.

Unit-I
Manifolds: Topological manifold, Atlas, Smooth Manifold, Examples of manifolds, Differentiable structure on a manifold, Space of smooth maps, Differential of a smooth map.

Unit-II
Immersion, Embedding and submanifolds with examples, tangent space of submanifolds, Vector fields and smooth maps, Lie brackets, Vector bundles, Cotangent bundle, tangent covectors on manifolds.

Unit-III
Riemannian metric, Riemannian manifolds, Partition of unity, Affine connection, Riemannian connection, Riemannian curvature, Scalar curvature, Ricci curvature, Bianchi identities, First fundamental form, An idea of Model spaces.

Unit-IV
Distribution on manifolds, Submanifolds of Riemannian manifold, Hypersurfaces, Second fundamental form, Gauss and Weingarten formulae, Equation of Gauss, Codazzi and Ricci.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDRG425.1	3	3	2	2	3	2	1	3	**2.37**
MMTHDRG425.2	3	3	2	2	3	2	2	3	**2.5**
MMTHDRG425.3	3	3	3	1	3	2	2	3	**2.5**
MMTHDRG425.4	3	3	3	3	3	2	2	3	**2.75**
Average PLO	**3**	**3**	**2.5**	**2**	**3**	**2**	**1.75**	**3**	**2.53**

Recommended books:

1. J. M. Lee, Riemannian Geometry - An introduction to curvature, Graduate Texts in Mathematics, Springer, 1997.
2. M. P. do-Carmo, Riemannian geometry, Birkhäuser, Boston, Basel, Berlin, 1992.
3. B.-Y Chen, Geometry of Submanifolds, Dover Publications, 1973
4. W. M. Boothby, An introduction to Differential Manifolds and Riemannian Geometry, Academic Press; 2nd edition, 1986.
5. Kumaresan, Riemannian geometry, Techno World, 2nd edition, 2022.

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

ADVANCED FUNCTIONAL ANALYSIS

MA/M.Sc. Mathematics (4th Semester) Total Credits: **04**
Course Code: **MMTHDAF425 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of this course, students will be able to

CLO1. Understand and apply the Hahn-Banach and Banach Fixed Point theorems to functional and differential equations.
CLO2. Analyze spectral properties of bounded operators and explore Banach algebras.
CLO3. Study compact operators, their spectra, and solve related operator equations.
CLO4. Examine unbounded operators, their adjoints, and spectral representations in Hilbert spaces.

Unit-I
Relationship between analytic and geometric forms of Hahn-Banach theorem, applications of Hahn-Banach theorem. Banach Fixed point theorem and its generalizations. Applications of Banach Fixed point theorem to linear equations, differential equations and integral equations.

Unit-II
Spectral theory in finite dimensional normed spaces: Basic concepts, spectral properties of bounded linear operators. Properties of resolvent and spectrum. Banach algebras and its properties.

Unit-III
Compact linear operators on normed spaces. Spectral Properties of Compact linear operators. Operator equations involving compact linear operators. Spectral Properties of bounded self-adjoint linear operator.

Unit-IV
Unbounded linear operators and their Hilbert adjoint operators. Symmetric and self-adjoint linear operators. Closed linear operators and closures. Spectral Properties of self-adjoint linear operators. Spectral representation of Unitary operators.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDFA425.1	3	3	3	3	3	2	1	3	**2.63**
MMTHDFA425.2	3	3	2	2	3	2	2	3	**2.5**
MMTHDFA425.3	3	3	3	2	3	2	1	3	**2.5**
MMTHDFA425.4	3	3	3	2	3	2	3	3	**2.75**
Average PLO	**3**	**3**	**2.75**	**2.25**	**3**	**2**	**1.75**	**3**	**2.6**

Recommended Books:

1. Erwin Kreyszig, Introductory functional Analysis with Applications, Wiley Publication, Reprint 2015.
2. J.B. Conway, A Course in Functional Analysis, Springer, 4th Edition, 1994.
3. Walter Rudin, Functional Analysis, McGraw-Hill, Edition 2010
4. B. V. Limaya, Functional Analysis, New Age International Pvt. Ltd; 3rd edition, 2014.

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

ADVANCED MEASURE THEORY

MA/M.Sc. Mathematics (4th Semester) Total Credits: **04**
Course Code: **MMTHDMT425 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of this course, students will be able to:

CLO1. Understand and differentiate between semi-rings, rings, algebras, and σ-algebras of sets, and construct measures and outer measures on various set structures.

CLO2. Analyze finite and σ-finite measure spaces, extend measures uniquely to σ-algebras, and apply the Monotone Class Theorem in the construction of product measures.

CLO3. Relate improper Riemann integrals to Lebesgue integrals, and compute integrals using approximation techniques and the Riemann–Lebesgue Lemma.

CLO4. Characterize absolutely continuous functions in terms of Lebesgue integrals, apply the fundamental theorem of calculus in the context of Lebesgue integration, and understand the structure and inequalities in Lp spaces.

UNIT -I

Semi-ring, ring, algebra and σ- algebra of sets, measures on semi-rings, examples of various measure spaces, outer measure associated with a set function and basic properties, measurable sets associated with an outer measure as a σ- algebra, outer measure induced by a measure.

UNIT -II

Finite and σ- finite measure spaces and relationship, measurable sets of finite measure space, extension of measure to σ- algebra and its uniqueness, non-measurable sets. Product measures and product σ- algebra, measurable rectangles, monotone class and elementary sets, Monotone class theorem.

UNIT -III

Improper Riemann integral, criteria for improper Riemann integral as a Lebesgue integral, calculation of some improper Riemann integrable functions viz: $\int_0^\infty e^{-x^2}dx$; $\int_0^\infty e^{-x^2}\cos(2xt)\,dx$, $t \in R$, $\int_0^\infty \frac{\sin(x)}{x}e^{-xt}dx, t \geq 0$; $\int_0^\infty \frac{e^{-xt}}{x}dx\, t>0$. Approximation of integrable functions, Riemann-Lebesgue lemma.

UNIT -IV

For $f \in L_1[a,b], F' = f, a.e.$ on $[a,b]$. If f is absolutely continuous on [a, b] with $f' = 0$ a.e., then f is constant. Characterization of an absolutely continuous function as an indefinite Lebesgue integral. Non-Lebesgue integrability of f where $f(x) = x^2 \sin(1/x^2), f(0) = 0$ on $[0,1]$. Fundamental theorem of calculus for the Lebesgue integral. A brief introduction to Lp spaces. Holder's and Minkowki's inequalities.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ **PLO** →	PLO1	PLO 2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	**Average CLO**
MMTHDMT425.1	3	3	3	3	3	2	1	3	**2.62**
MMTHDMT425.2	3	3	3	2	3	3	2	3	**2.75**
MMTHDMT425.3	3	2	3	2	3	2	2	3	**2.5**
MMTHDMT425.4	3	2	3	2	3	2	3	3	**2.63**
Average PLO	**3**	**2.5**	**3**	**2.25**	**3**	**2.25**	**2**	**3**	**2.63**

Recommended Books:

1. C. D. Aliprantis and O. Burkinshaw, Principles of Real Analysis, Academic Press Inc. 2nd Edition (1990).
2. Chae, S.B., Lebesgue Integration, Springer Verlag, 2nd Edition (1995).
3. Rudin, W., Principles of Mathematical Analysis, McGraw Hill (2023).
4. Barra, De. G., Measure theory and Integration, New Age International Publishers, 3rd Edition (2022).
5. Rana , I. K., An Introduction to Measure and Integration, Narosa Publications 2nd Edition (2005).

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

HOMOLOGICAL ALGEBRA

MA/M.Sc. Mathematics (4th Semester) Total Credits: **04**
Course Code: **MMTHDHA425 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): After the completion of this course, students will be able to:

CLO1. Demonstrate a deep understanding of ring theory concepts including ideals, homomorphisms, radicals, and apply results like the Chinese Remainder Theorem and Prime Avoidance Lemma in algebraic structures.

CLO2. Analyze modules over rings, explore their structures using tools such as exact sequences, tensor products, localization, and comprehend important results like Nakayama's Lemma.

CLO3. Understand chain conditions on rings and modules, apply the Hilbert Basis Theorem, and explore primary decomposition in Noetherian and Artinian rings.

CLO4. Apply the language of category theory including functors, natural transformations, and exactness in abelian categories to study algebraic structures in a more general setting.

Unit-I

Review of modules, sub-modules, module homomorphisms. Finitely generated modules, Nakayama lemma, exact sequences, free and projective modules, Tensor product of modules, flat modules. Restriction and extension of scalars. Rings and modules of fractions and localization.

Unit-II

Chain conditions, Noetherian rings. Hilbert basis theorem, primary decomposition in Notherian rings. Artinian rings and related results, modules over PID. Modules of finite length and primary Decomposition.

Unit-III

Definitions and examples of categories, functors and natural transformations, adjoint functors, definition of an additive category, kernels and cokernels, abelian categories, exact sequences, exact, left exact, and right exact functors.

Unit-IV

Projective and injective objects, the category of complexes, snake lemma, cohomology functors. Projective and injective resolutions, examples, null-homotopies, uniqueness of resolutions up to homotopy, definition and basic properties of derived functors, Tohuku viewpoint (universal delta-functors).

CLO-PLO Mapping Matrix (Strength version)

CLO ↓ / PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDHA425.1	3	3	3	2	3	1	2	3	**2.5**
MMTHDHA425.2	3	3	3	3	3	2	1	3	**2.63**
MMTHDHA425.3	3	3	3	2	3	2	3	3	**2.75**
MMTHDHA425.4	3	3	3	3	3	2	3	3	**2.88**
Average PLO	**3**	**3**	**3**	**2.5**	**3**	**1.75**	**2.25**	**3**	**2.69**

Recommended Books

1. Charles A. Weibel, An introduction to homological algebra, Cambridge Studies in Advanced Mathematics, Edition 1, 1995.
2. M. F. Atiyah and I. G. Macdonald, Introduction to Commutative Algebra, Addison-Wesley, 1969.
3. E. Kunz, Introduction to Commutative Algebra and Algebraic Geometry, Birkhäuser, 2015

2-Year/1-Year Master's Program in Mathematics (NEP-2020)

NON-LINEAR FUNCTIONAL ANALYSIS

MA/M.Sc. Mathematics (4th Semester) Total Credits: **04**
Course Code: **MMTHDNL425 (15 hours per credit)** Total Marks: **100**
Continuous Assessment: Marks 28, Theory: Marks 72 **Time Duration: 2½ hrs**

Course Learning Outcomes(CLO's): Upon successful completion of this course, students will be able to:

CLO1. Analyze the properties of convex sets and functions, non-expansive and monotone operators, and apply key fixed point theorems such as Browder's and Minty's Theorem.
CLO2. Understand and apply concepts of differentiability in Banach spaces, including Gateaux and Fréchet derivatives, subdifferentials, and their role in convex analysis.
CLO3. Explore the geometry of Banach spaces through uniform and strict convexity, smoothness, and duality maps, and establish connections with reflexivity and inequalities.
CLO4. Apply variational principles, minimization techniques, and iterative methods such as Mann and Ishikawa to solve variational inequalities and optimization problems using results like the Lax-Milgram Lemma and Lions-Stampacchia Theorem.

Unit-I

Convex sets, convex functions, lower semicontinuous convex functions, non-expansive operators, characterization of projection onto convex sets and their geometrical interpretation, fixed points of non-expansive operators, Browder fixed point theorem, Monotone operators, maximal monotone operator and their properties, resolvents of monotone operators, Minty theorem,.

Unit-II

Gateaux Derivative, Frechet Derivative, subdifferential of convex functions, directional derivatives, characterization of convexity and strict convexity, directional derivatives and subgradients, Gateaux and Frechet differentiability, differentiability and continuity.

Unit-III

Uniformly convex spaces, strictly convex Banach spaces, the modulus of convexity, uniform convexity, strict convexity and reflexivity, inequalities in uniformly convex spaces, smooth spaces, the modulus of smoothness, uniformly smooth spaces, inequalities in uniformly smooth, duality maps in Banach spaces, characterization of some real Banach spaces by the duality map.

Unit-IV

Billinear forms and its applications, Lax-Milgram lemma, minimization of functionals, variational inequalities, relationship between abstract minimization problems and variational inequalities, Lions Stampacchia theorem for existence of solution of variational inequality, Ekeland's variational principle and its applications to fixed point theorems and optimization, Takahashi's minimization theorem, Mann and Ishikawa iterative methods.

CLO-PLO Mapping Matrix (Strength version)

CLO ↓	PLO →	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	Average CLO
MMTHDNL425.1		3	3	3	1	3	2	2	3	**2.5**
MMTHDNL425.2		3	3	3	2	3	2	2	3	**2.63**
MMTHDNL425.3		3	3	3	2	3	2	3	3	**2.75**
MMTHDNL425.4		3	3	3	3	3	3	3	3	**3**
Average PLO		**3**	**3**	**3**	**2**	**3**	**2.25**	**2.5**	**3**	**2.72**

Recommended Books:

1. 1. H. H. Bauschke and P. L. Combettes, Convex Analysis and Monotone Operator Theory in Hilbert Spaces, Springer New York, 2011.
2. D. Kinderlehrer and G. Stampacchia, An Introduction to Variational Inequalities and Their Applications, Academic Press, New York, 1980.
3. A.H. Siddiqi, K. Ahmed and P. Manchanda, Introduction to Functional Analysis with Applications, Anamaya Publishers, New Delhi-2006.
4. M. C. Joshi and R. K. Bose, Nonlinear Functional Analysis and its Applications, WilleyEastern Limited, 1985.
5. C.E. Chidume: Geometric Properties of Banach Spaces and Nonlinear Iterations, Springer-
6. Verlag, London, 2009.
7. V. Berinde: Iterative Approximation of Fixed Points, Springer-Verlag, Berlin Heidelberg, 2007.