University of Mumbai

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Academic Authorities,
Meetings & Services (AAMS)
Room No. 128, M. G. Road, Fort,
Mumbai – 400 032.
Tel. 022-68320033

Re- accredited with A ++ Grade (CGPA 3.65) by NAAC
Category- I University Status awarded by UGC

No.2026/May/AAMS-III/C-75/42966 Date: 08th May, 2026

CIRCULAR:-

Attention of all the Principals of the Affiliated Colleges & Autonomous Colleges, all Academic Heads of University Departments, the Directors of the Recognized Institutions/Centers, Director, Centre for Distance & Online Education, Director, Dharmaveer Anand Dighe Thane Sub-Campus, Co-ordinator, School of Engineering and Applied Sciences, Kalyan Sub-Campus, Director, Chitrakar Padmabhushan Dr.Dhananjay Keer Ratnagiri Sub-Campus, Director, Sindhudurg Sub-Campus, Principal, Vishwabhushan Bharatratna Dr. B. A. Ambedkar College, Ambadave, Ratnagiri and Principal, V.V. Dalvie College, Talere, Sindhudurg is invited to this office Circular No. AAMS/ICD/2025-26/ 37 of dated 27 May, 2025 relating to the NEP UG & PG Syllabus.

They are hereby informed that the recommendations made by the **Board of Studies in Mathematics** at its meeting held on 22nd January, 2026 vide item No. 3 (a) and subsequently passed by the Board of Deans at it's meeting held on 17th March, 2026 vide item No. 6.3 (N) have been accepted by the Academic Council at its meeting held on 25th March, 2026 vide item No. 6.23 (N). In accordance therewith syllabus of **B.A / B.Sc. (Mathematics) (Scheme - III) (Sem V & VI)** (NEP 2020) is introduced as per appendix with effect from the academic year 2026-27.

(The said circular is available on the University's website www.mu.ac.in).

MUMBAI – 400 032
08th May, 2026

(Dr. Prasad Karande)
REGISTRAR

To,

All the Principals of the Affiliated Colleges & Autonomous Colleges, all Academic Heads of University Departments, the Directors of the Recognized Institutions/Centers, Director, Centre for Distance & Online Education, Director, Dharmaveer Anand Dighe Thane Sub-Campus, Co-ordinator, School of Engineering and Applied Sciences, Kalyan Sub-Campus, Director, Chitrakar Padmabhushan Dr.Dhananjay Keer Ratnagiri Sub-Campus, Director, Sindhudurg Sub-Campus, Principal, Vishwabhushan Bharatratna Dr. B. A. Ambedkar College, Ambadave, Ratnagiri and Principal, V.V. Dalvie College, Talere, Sindhudurg.

AC./6.23(N)/25/3/2026

Copy forwarded with Compliments for information to:-

1) The Chairman, Board of Deans,
2) The Dean, Faculty of Science,
3) The Chairman, **Board of Studies in Board of Studies in Mathematics**
4) The Director, Board of Examinations and Evaluation,
5) The Director, Department of Students Development,
6) The Director, Department of Information & Communication Technology,
7) The Director, Centre for Distance and Online Education (CDOE)Vidyanagari,
8) The Deputy Registrar, Admission, Enrolment, Eligibility & Migration Department (AEM),

Copy forwarded for information and necessary action to :-	
1	The Deputy Registrar, (Admissions, Enrolment, Eligibility and Migration Dept)(AEM), dr@eligi.mu.ac.in
2	The Deputy Registrar, Result unit, Vidyanagari drresults@exam.mu.ac.in
3	The Deputy Registrar, Marks and Certificate Unit,. Vidyanagari dr.verification@mu.ac.in
4	The Deputy Registrar, Appointment Unit, Vidyanagari dr.appointment@exam.mu.ac.in
5	The Deputy Registrar, CAP Unit, Vidyanagari cap.exam@mu.ac.in
6	The Deputy Registrar, College Affiliations & Development Department (CAD), deputyregistrar.uni@gmail.com
7	The Deputy Registrar, PRO, Fort, (Publication Section), Pro@mu.ac.in
8	The Deputy Registrar, Executive Authorities Section (EA) eau120@fort.mu.ac.in He is requested to treat this as action taken report on the concerned resolution adopted by the Academic Council referred to the above circular.
9	The Deputy Registrar, Research Administration & Promotion Cell (RAPC), rapc@mu.ac.in
10	The Deputy Registrar, Academic Appointments & Quality Assurance (AAQA) dy.registrar.tau.fort.mu.ac.in ar.tau@fort.mu.ac.in
11	The Deputy Registrar, College Teachers Approval Unit (CTA), concolsection@gmail.com
12	The Deputy Registrars, Finance & Accounts Section, fort draccounts@fort.mu.ac.in
13	The Deputy Registrar, Election Section, Fort drelection@election.mu.ac.in
14	The Assistant Registrar, Administrative Sub-Campus Thane, thanesubcampus@mu.ac.in
15	The Assistant Registrar, School of Engg. & Applied Sciences, Kalyan, ar.seask@mu.ac.in
16	The Assistant Registrar, Ratnagiri Sub-centre, Ratnagiri, ratnagirisubcentar@gmail.com
17	The Director, Centre for Distance and Online Education (CDOE), Vidyanagari, director@idol.mu.ac.in
18	Director, Innovation, Incubation and Linkages, Dr. Sachin Laddha pinkumanno@gmail.com
19	Director, Department of Lifelong Learning and Extension (DLLE), dlleuniversityofmumbai@gmail.com

Copy for information :-	
1	P.A to Hon'ble Vice-Chancellor, vice-chancellor@mu.ac.in
2	P.A to Pro-Vice-Chancellor pvc@fort.mu.ac.in
3	P.A to Registrar, registrar@fort.mu.ac.in
4	P.A to all Deans of all Faculties
5	P.A to Finance & Account Officers, (F & A.O), camu@accounts.mu.ac.in

To,

1	The Chairman, Board of Deans pvc@fort.mu.ac.in
2	**Faculty of Humanities,** **Offg. Dean** 1. Prof.Anil Singh Dranilsingh129@gmail.com **Offg. Associate Dean** 2. Prof.Manisha Karne mkarne@economics.mu.ac.in 3. Dr.Suchitra Naik Naiksuchitra27@gmail.com
	Faculty of Commerce & Management, **Offg. Dean,** 1 Prin.Ravindra Bambardekar principal@model-college.edu.in **Offg. Associate Dean** 2. Dr.Kavita Laghate kavitalaghate@jbims.mu.ac.in 3. Prin.Kishori Bhagat kishoribhagat@rediffmail.com

	Faculty of Science & Technology **Offg. Dean** 1. Prof. Shivram Garje ssgarje@chem.mu.ac.in **Offg. Associate Dean** 2. Dr. Madhav R. Rajwade Madhavr64@gmail.com 3. Prin. Deven Shah sir.deven@gmail.com
	Faculty of Inter-Disciplinary Studies, **Offg. Dean** 1.Dr. Anil K. Singh aksingh@trcl.org.in **Offg. Associate Dean** 2.Prin.Chadrashekhar Ashok Chakradeo cachakradeo@gmail.com 3. Dr. Kunal Ingle drkunalingle@gmail.com
3	Chairman, Board of Studies,
4	The Director, Board of Examinations and Evaluation, dboee@exam.mu.ac.in
5	The Director, Board of Students Development, dsd@mu.ac.in DSW direcotr@dsw.mu.ac.in
6	The Director, Department of Information & Communication Technology, director.dict@mu.ac.in

AC – 25/03/2026
Item No. – 6.23 (N)

As Per NEP 2020

University of Mumbai

Syllabus for Major Vertical – 1, 4 & 6 (Scheme – III)		
Faulty of Science & Technology		
Board of Studies in Mathematics		
Name of the Programme – B.A./B.Sc. (Mathematics)		
U.G. Third Year Programme	**Exit Degree**	**B.A./B.Sc. (Mathematics)**
Semester		**V & VI**
From the Academic Year		**2026-27**

University of Mumbai

(As per NEP 2020)

Sr. No.	Heading	Particulars
1	Title of program O:_____________________	B.A./B.Sc. (Mathematics)
2	Exit Degree	B.A./B.Sc. (Mathematics)
3	Scheme of Examination R: _____________	NEP 40% Internal 60% External, Semester End Examination Individual Passing in Internal and External Examination
4	Standards of Passing R: _______________	40%
5	Credit Structure R: SU- 530 E (III) R: SU- 530 F (III)	Attached herewith
6	Semesters	Sem. V & VI
7	Program Academic Level	5.5
8	Pattern	Semester
9	Status	New
10	To be implemented from Academic Year	2026-27

Sd/-
Sign of the BOS Chairman
Prof. B.S. Desale
BOS in Mathematics

Sd/-
Sign of the
Offg. Associate Dean
Dr. Madhav R. Rajwade
Faculty of Science & Technology

Sd/-
Sign of the Offg. Dean
Prof. Shivram S. Garje
Faculty of Science & Technology

Preamble

1) Introduction

The University of Mumbai has brought into force the revised syllabi as per the National Education Policy (NEP 2020) for the First-year B. Sc/ B. A. Programme (Certificate Course) in Mathematics from the academic year 2024-2025. Mathematics has been fundamental to the development of science and technology. In recent decades, the extent of application of Mathematics to real world problems has increased by leaps and bounds. Taking into consideration the rapid changes in science and technology and new approaches in different areas of mathematics and related subjects like Physics, Statistics and Computer Sciences, the board of studies in Mathematics with concern of teachers of Mathematics from different colleges affiliated to University of Mumbai has prepared the syllabus of T.Y.B.Sc. / T. Y. B. A. (degree course) Mathematics. The present syllabi of T. Y. B. Sc./ T. Y. B. A. for Semester V and Semester VI have been designed as per U. G. C. Model curriculum so that the students learn Mathematics needed for these branches, learn basic concepts of Mathematics, and are exposed to rigorous methods gently and slowly. The syllabi of T. Y. B. Sc./ T. Y. B. A. would consist of two semesters and each semester would comprise of seven major courses for T. Y. B. Sc. / T. Y. B. A. Mathematics. These courses contain analysis, calculus, abstract algebra, metric spaces along with elective courses (partial differential equations, integral transform, number theory, operations research and graph theory) and practical courses based on them. These courses develop strong logical thinking of learner and all these are having various applications in many recent trends of science and technology and practical component provides learner with hands-on experience in applying the theoretical concepts learned in all above courses and develops computation skill of learner.

2) Aims and Objectives

1) Give the students a sufficient knowledge of fundamental principles, methods, and a clear perception of in numerous powers of mathematical ideas and tools and know how to use them by modelling, solving, and interpreting.
2) Reacting the broad nature of the subject and developing mathematical tools for continuing further study in various fields of science.
3) Enhancing students' overall development and to equip them with mathematical modelling abilities, problem solving skills, creative talent, and power of communication necessary for various kinds of employment.
4) A student should get adequate exposure to global and local concerns that explore them many aspects of Mathematical Sciences.

3) Learning Outcomes

1. Integral Calculus: This course enables students to understand and apply the concepts of double and triple integrals, line, surface and volume integrals, and vector calculus theorems. It develops the ability to use Green’s, Stokes’, and Gauss’ divergence theorems to solve problems in mathematics, physics, and engineering, and to interpret results in real-world contexts.
2. Group Theory and Ring Theory: This course enables students to understand and apply fundamental concepts of group theory, including groups, subgroups, homomorphisms, and isomorphism theorems. It also develops the ability to analyze ring structures such as rings,

ideals, integral domains, and fields while strengthening logical reasoning and proof-writing skills.

3. Topology of Metric Spaces: This course enables students to understand the fundamental concepts of metric spaces, including open and closed sets, convergence, continuity, and completeness. It develops the ability to analyze topological properties such as compactness and connectedness and to apply rigorous proof techniques in the study of abstract mathematical structures.
4. Basic Complex Analysis: This course enables students to understand the fundamental concepts of complex numbers and complex-valued functions, including analyticity and conformality. It develops the ability to apply Cauchy–Riemann equations, complex integration, and Cauchy's theorems to solve problems, while strengthening analytical thinking and mathematical reasoning skills.
5. Partial Differential Equations: This course enables students to understand the fundamental concepts of partial differential equations and their classifications. It develops the ability to solve first-order partial differential equations using standard analytical methods and to apply these techniques to model and analyze problems arising in mathematics, physics, and engineering.
6. Number Theory and Its Applications: This course enables students to understand fundamental concepts of number theory, including divisibility, prime numbers, congruences and arithmetic functions. It develops the ability to apply number-theoretic techniques to solve problems and explore applications in cryptography, coding theory and related areas.
7. Operations Research: This course enables students to understand fundamental concepts and techniques of operations research, including linear programming, transportation, assignment, and inventory models. It develops the ability to formulate, analyze, and solve real-world optimization and decision-making problems using mathematical modeling and analytical methods.
8. Graph Theory: This course enables students to understand the fundamental concepts of graph theory, including graphs, subgraphs, connectivity, trees, and planar graphs. It develops the ability to apply graph-theoretic methods to solve problems in networks, algorithms, and combinatorial structures while enhancing logical reasoning and problem-solving skills.
9. Integral Transform: This course enables students to understand the fundamental concepts of integral transforms, including Laplace and Fourier transforms. It develops the ability to apply these transforms to solve differential and integral equations and to analyze problems in engineering, physics, and applied mathematics.

B.A./B.Sc. (Mathematics)

Credit Structure (Sem. V & VI)

(B.A./B. Sc.)- Major & Minor

	R: SU- 530 E (III)									
Vertical		1	2		3	4	5	6		
Level	**Semester**	**Major 1**	**Major 2 (Minor)**	**Major 3 (Minor)**	**OE**	**VSC, SEC (VSEC)**	**AEC, VEC, IKS**	**OJT, FP, CEP, CC,RP**	**Cum. Cr. / Sem.**	**Degree/ Cum. Cr.**
		M1	M2	M3						
5.5	V	**Mandatory Courses** Integral Calculus (2) Group Theory (2) Topology of Metric Spaces - I (2) Practical- 5P1 (Based on Integral Calculus and Group Theory) (2) Practical- 5P2 (Based on Integral Calculus and Topology of Metric Spaces - I) (2) **Elective Courses** A. Partial Differential Equations **(2)** + 5P3A (Practical Based on Partial Differential Equations) **(2)** **OR** B. Number Theory and Its Applications -I **(2)** + 5P3B (Practical Based on Number Theory and Its Applications -I) **(2)** **OR** C. Operations Research -I **(2)**	2	----	----	VSC: Computational Machine Learning (2) OR Computational Linear Algebra and Statistics with Scilab (2)	----	CC:2 CEP:2	22	**UG Degree 132**

		+ 5P3C (Practical Based on Operations Research -I) **(2)** **OR** D. Graph Theory -I **(2)** + 5P3D (Practical Based on Graph Theory -I) **(2)**								
	R: SU- 530 F (III)									
	VI	**Mandatory Courses** Basic Complex Analysis (2) Ring Theory (2) Topology of Metric Spaces - II (2) Advanced Real Analysis (2) Practical- 6P1 (Based on Basic Complex Analysis) (2) Practical- 6P2 (Based on Ring Theory) (2) Practical- 6P3 (Based on Topology of Metric Spaces – II and Advanced Real Analysis) (2) **Elective Courses** A. Integral Transforms **(2)** + 6P3A (Practical Based on Integral Transforms) **(2)** **OR** B. Number Theory and Its Applications -II **(2)** + 6P3B (Practical based on Number Theory and Its Applications -II) **(2)**	----	----	----	----	----	OJT :4	22	

		OR C. Operations Research -II **(2)** + 6P3C (Practical based on Operations Research -II) **(2)** **OR** D. Graph Theory -II **(2)** + 6P3D (Practical based on Graph Theory -II) **(2)**								
	Cum Cr.	52	18	8	10	8+2+2	6+4+2	8+6+4	132	
Exit option: Award of UG Degree in Major with 132 credits OR Continue with Major										

[Abbreviation - OE – Open Electives, VSC – Vocation Skill Course, SEC –Skill Enhancement Course, (VSEC), AEC – Ability Enhancement Course, VEC – Value Education Course, IKS – Indian Knowledge System, OJT – on Job Training, FP – Field Project, CEP – Community Engagement Project, CC – Co-Curricular, RP – Research Project]

[* 2 Credit IKS Major paper (Core Subject Specific Theory may be included in Sem. III or V)]

Program Structure for Sem. V & VI
(NEP 2020)

Vertical No		Paper Title		Credits
Sem. V				
1.	Mandatory	1. Integral Calculus		2
		2. Group Theory		2
		3. Topology of Metric Spaces - I		2
		4. Practical – 5P1 (Based on Integral Calculus and Group Theory)		2
		5. Practical – 5P2 (Based on Integral Calculus and Topology of Metric Spaces – I)		2
	Electives	A.	Partial Differential Equations + 5P3A (Practical Based on Partial Differential Equations)	2 + 2 OR
		B.	Number Theory and Its Applications – I + 5P3B (Practical Based on Number Theory and Its Applications – I	2 + 2 OR
		C.	Operations Research – I + 5P3C (Practical Based on Operations Research – I)	2 + 2 OR
		D.	Graph Theory – I + 5P3D (Practical Based on Graph Theory – I)	2 + 2
		(Choose any ONE pair of courses of the above)		
2.	**Minor** (To be selected from other discipline)			2
4.	VSC (practical)	1. Computational Machine Learning 2. Computational Linear Algebra and Statistics with Scilab (Any ONE of these TWO)		2
6.	**CEP** (To be selected from CEP topic list)			2

<table>
<tr><td colspan="4" align="right">Credits</td><td>22</td></tr>
<tr><td colspan="5" align="center">Sem. VI</td></tr>
<tr><td rowspan="13">1.</td><td rowspan="7">Mandatory</td><td colspan="2">1. Basic Complex Analysis</td><td>2</td></tr>
<tr><td colspan="2">2. Ring Theory</td><td>2</td></tr>
<tr><td colspan="2">3. Topology of Metric Spaces – II</td><td>2</td></tr>
<tr><td colspan="2">4. Advanced Real Analysis</td><td>2</td></tr>
<tr><td colspan="2">5. Practical – 6P1 (Based on Basic Complex Analysis)</td><td>2</td></tr>
<tr><td colspan="2">6. Practical – 6P2 (Based on Ring Theory)</td><td>2</td></tr>
<tr><td colspan="2">7. Practical – 6P2 (Based on Topology of Metric Spaces – II and Advanced Real Analysis)</td><td>2</td></tr>
<tr><td rowspan="5">Electives</td><td>A.</td><td>Integral Transforms
+
6P3A (Practical Based on Integral Transforms)</td><td rowspan="5">2 + 2
OR
2 + 2
OR
2 + 2
OR
2 + 2</td></tr>
<tr><td>B.</td><td>Number Theory and Its Applications – II
+
6P3B (Practical Based on Number Theory and Its Applications – II)</td></tr>
<tr><td>C.</td><td>Operations Research- II
+
6P3C (Practical Based on Operations Research- II)</td></tr>
<tr><td>D.</td><td>Graph Theory – II
+
6P3D (Practical Based on Graph Theory – II)</td></tr>
<tr><td colspan="2">(Choose any ONE pair of courses of the above)</td></tr>
<tr><td>6.</td><td>VI</td><td colspan="2" align="center">OJT</td><td>4</td></tr>
<tr><td colspan="4" align="right">Credits</td><td>22</td></tr>
<tr><td colspan="4" align="right">Total Credits</td><td>44</td></tr>
</table>

Sem. - V

Sem. - V

Vertical – 1 Major Mandatory (2+2+2+2+2)

Syllabus
B.A./ B.Sc. (Mathematics)
(Sem.- V)
Name of the Course: Integral Calculus

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course provides a foundational understanding of multiple integrals, line integrals, and surface integrals, essential tools in advanced calculus and vector analysis. It introduces double and triple integrals, change of variables, and integration in various coordinate systems. Students also explore vector fields, parametrized curves and surfaces, and key theorems such as Green's, Stokes', and the Divergence Theorem. Together, these concepts equip learners with powerful mathematical techniques used in physics, engineering, and higher-level mathematics.
2	**Vertical:**	Major
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides an introduction to advanced concepts in calculus with a strong emphasis on rigor. It aims to prepare students for more advanced courses in calculus. The focus of the course is on developing formal proof skills, which not only deepens comprehension of the subject but also extends to broader applications in mathematics. **CO1:** Provide a solid understanding of fundamental principles and methods, equipping students with the skills to apply mathematical ideas and tools through modeling, solving, and interpretation. **CO2**: Illustrate the expansive nature of the subject by fostering the acquisition of essential mathematical tools for continued studies across various scientific fields. **CO3**: Foster students' comprehensive development by placing emphasis on problem-solving skills, nurturing creative talents, and enhancing communication abilities, all of which are vital for a range of employment opportunities. **CO4**: Ensure exposure to both global and local issues within the realm of Mathematical Sciences, allowing learners to explore diverse aspects of the discipline.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1** Understand and remember the fundamental concepts of multiple integrals, including double and triple integrals, Fubini's theorem, change of variables, and line and surface integrals along with vector differential operators such as gradient, curl, and divergence. **OC2**: Apply techniques of multiple integration—using Cartesian, polar, cylindrical, and spherical coordinates—and evaluate line and surface integrals using Green's, Stokes', and the Divergence theorems. **OC3**: Analyze vector fields, parametrized curves, and surfaces to determine properties such	

as conservativeness, compute surface areas, and study the behavior of integrals under transformations and parameter changes.

OC4: Justify/ check the correctness of computed integrals, verify conditions for conservativeness of vector fields, and confirm the applicability of major theorems such as Green's, Stokes', and the Divergence Theorem in specific situations.

OC5: Construct counter examples to illustrate situations where integrability fails, where vector fields do not satisfy conditions for being conservative.

Modules: -

Module 1: **Multiple Integrals (15 Lectures)**

(a) Definition of double (resp: triple) integral of a function and bounded on a rectangle (resp:box), Geometric interpretation as area and volume.
(b) Fubini's Theorem over rectangles and any closed bounded sets, Iterated Integrals. Following basic properties of double and triple integrals proved using the Fubini's theorem like Integrability of the sums, scalar multiples, products, (under suitable conditions) quotients of integrable functions and formulae for the integrals of sums and scalar multiples of integrable functions.
(c) Integrability of continuous functions. Domain additivity of the integral. Integrability and the integral over arbitrary bounded domains.
(d) Change of variables formula (Statement only).
(e) Polar, cylindrical and spherical coordinates, and integration using these coordinates.
(f) Differentiation under the integral sign.

Module 2: **Line, Surface and Volume Integrals (15 Lectures)**

(a) Review of Scalar and Vector fields on $\mathbb{R}^n$, Vector Differential Operators, Gradient, Curl, Divergence.
(b) Paths (parametrized curves) in $\mathbb{R}^n$ (emphasis on $\mathbb{R}^2$ and $\mathbb{R}^3$), Smooth and piecewise smooth paths. Closed paths. Equivalence and orientation preserving equivalence of paths.
(c) Definition of the line integral of a vector field over a piecewise smooth path. Basic properties of line integrals including linearity, path-additivity and behaviour under a change of parameters. Examples.
(d) Line integrals of the gradient vector field, Fundamental Theorem of Calculus for Line Integrals, Necessary and sufficient conditions for a vector field to be conservative.
(e) Green's Theorem (proof in the case of rectangular domains). Applications to evaluation of line integrals.
(f) Parameterized surfaces. Smoothly equivalent parameterizations. Area of such surfaces.
(g) Definition of surface integrals of scalar-valued functions as well as of vector fields defined on a surface. Curl and divergence of a vector field. Elementary identities involving gradient, curl and divergence.
(h) Stoke's Theorem (without proof). Examples.
(i) Gauss' Divergence Theorem. Examples.

10 **Recommended Reference Books:**

1. Apostol, Calculus, Vol. 2, Second Ed., John Wiley, New York, 1969 Section 1.1 to 11.8.
2. James Stewart, Calculus with early transcendental Functions - Section 16.5 to 16.9.
3. Marsden and Jerrold E. Tromba, Vector Calculus, Fourth Ed., W.H. Freeman and Co., New York, 1996 Section 6.2 to 6.4.

11	**Additional Reference Books** 1. T. Apostol, Mathematical Analysis, Second Ed., Narosa, New Delhi. 1947. 2. R. Courant and F.John, Introduction to Calculus and Analysis, Vol.2, Springer Verlag, New York, 1989. 3. W. Fleming, Functions of Several Variables, Second Ed., Springer-Verlag, New York, 1977. 4. M. H. Protter and C.B.Morrey Jr., Intermediate Calculus, Second Ed., Springer-Verlag, New York, 1995. 5. G. B. Thomas and R.L Finney, Calculus and Analytic Geometry, Ninth Ed. (ISE Reprint), Addison- Wesley, Reading Mass, 1998. 6. D. V. Widder, Advanced Calculus, Second Ed., Dover Pub., New York. 1989.	
	Scheme of the Examination	
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.	
12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each semester in an Offline mode.	10
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14	**Format of Question Paper:** The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.

Q. No. 1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: Group Theory

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course offers a structured introduction to group theory, a fundamental aspect of abstract algebra. Students engage with core concepts such as subgroups, order, and symmetry groups, gaining a solid foundation in mathematical abstraction and reasoning. Advanced topics including cosets, normal subgroups, and quotient groups are explored, promoting critical thinking and problem-solving skills. Through real-world examples and mathematical contexts, students develop a deep understanding of mathematical structures and their applications. Emphasizing both theoretical understanding and practical application, the course fosters analytical thinking and prepares students for further studies in mathematics and related fields, promoting critical thinking, creativity, and interdisciplinary learning.
2	**Vertical:**	Major
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course delves into group theory, a fundamental branch of abstract algebra focusing on key concepts including subgroups, order, and symmetry groups, alongside advanced topics like cosets, normal subgroups, quotient groups, direct products, and cyclic groups. It further offers exploration of homomorphisms, isomorphisms, and Cayley's theorem for finite groups. The course combines theory with practical exercises to enhance comprehension and application of group theory, underlining its significance in mathematics and diverse domains. **CO1:** Understand the fundamental concepts and properties of groups, including subgroups, order, and symmetry groups. **CO2**: Explore advanced topics in group theory, such as cosets, normal subgroups, and quotient groups, along with their applications. **CO3**: Analyze the structure of groups through homomorphisms, isomorphisms, and Cayley's theorem for finite groups. **CO4**: Investigate direct products of groups and cyclic groups, including their properties, generators, and relationships with other groups.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1**: explain basic ideas of groups, subgroups, homomorphisms, isomorphisms, internal and external direct products, cyclic groups, and their properties in simple terms. **OC2:** use subgroup criteria to identify subgroups, compute orders of groups and elements,	

	and determine generators for cyclic and finite groups **OC3**: partition groups into cosets, apply Lagrange's theorem to infer possible orders of subgroups, and analyze normality of subgroups. **OC4**: compute kernels and images of homomorphisms; apply the Isomorphism Theorems and Cayley's theorem to identify isomorphic structures. **OC5**: determine when direct products of cyclic groups are cyclic, classify finite and infinite cyclic groups and construct quotient groups, new finite groups using direct products, non-abelian groups and isomorphic groups.
	Modules: - **Module 1**: **Introduction to Group Theory (15 Lectures)**
	(1) Definition and basic properties of groups. Order of a group. Order of an element. Subgroups. Criterion for a subset of a group to be a subgroup. Abelian groups. Centre of a group. Examples of groups including $\mathbb{Z}, \mathbb{Q}, \mathbb{R}, \mathbb{C}, \mathbb{Z}_n,$ Klein 4-group, Quaternion group, Permutation groups: symmetric groups (S_n) and alternating groups (A_n), μ_n ($n-$th roots of unity), S^1(= the unit circle in $\mathbb{C}$), $GL_n(\mathbb{R}), SL_n(\mathbb{R}),$ T_n (= the group of $n \times n$ non-singular upper triangular matrices), L_n (= the group of $n \times n$ non-singular lower triangular matrices), and groups of symmetries of plane figures. (2) Cosets of a subgroup in a group. Lagrange's Theorem. Normal subgroups. Listing normal subgroups of certain groups, Quotient (or Factor) groups. (3) Definition of group homomorphism with simple examples. Kernel and image of a group homomorphism, Fundamental theorem of group homomorphism, Second and third isomorphism theorems of groups. Cayley's theorem for finite groups (Statement Only).
	Module 2: **Direct Products and Cyclic groups (15 Lectures)**
	(1) External direct products of groups, Internal Direct Products, Examples. (2) Definition of Cyclic group, Examples. Properties of cyclic groups and cyclic subgroups. The necessary and sufficient condition for the direct product of cyclic groups to form a cyclic group. (3) Finite and infinite cyclic groups: their subgroups and generators. Properties of generators. Characterization of cyclic groups (as being isomorphic to $\mathbb{Z}$ or $\frac{\mathbb{Z}}{n\mathbb{Z}}$ for some $n \in \mathbb{N}$). Classifications of groups of order up to 7 (without proof)
10	**Recommended Reference Books:** 1. J. B. Fraleigh, A first course in Abstract Algebra, Third edition, Narosa, New Delhi, 1996. 2. P. B. Bhattacharya, S. K. Jain, S. Nagpaul. Basic Abstract Algebra, Second edition, Foundation Books, New Delhi, 1995. 3. I. N. Herstein, Topics in Algebra, Wiley Eastern Limied, Second edition, 2006. 4. N. S. Gopalkrishnan, University Algebra, New Age International Private Limited, 2018. 5. J. Gallian. Contemporary Abstract Algebra. Narosa, New Delhi, 2008.
11	**Additional Reference Books** 1. M. Artin, Algebra, Prentice Hall of India, New Delhi, Second Edition, 2010. 2. T. W. Hungerford. Algebra, Springer, 2003. 3. D. Dummit, R. Foote. Abstract Algebra, John Wiley & Sons, Inc., Third Edition, 2003. 4. I. S. Luther, I.B.S. Passi. Algebra. Vol. I., 1997.

<table>
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<tr><td></td><td colspan="2">The performance of the learners shall be evaluated in two parts.
• Internal Continuous Assessment of 20 marks.
• Semester End Examination of 30 marks.
• A separate head of passing is required for internal and semester-end examinations.</td></tr>
<tr><td>12</td><td>Internal Continuous Assessment: 40%</td><td>Semester End Examination: 60%</td></tr>
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<tr><td>Sr. No.</td><td>Particulars</td><td>Marks</td></tr>
<tr><td>1</td><td>A class test of 10 marks is to be conducted during each semester in an Offline mode.</td><td>10</td></tr>
<tr><td>2</td><td>Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.</td><td>05</td></tr>
<tr><td>3</td><td>Seminar/ group presentation on any one topic related to the syllabus.</td><td>05</td></tr>
</table>
Paper pattern of the Test (Offline Mode with One hour duration):
Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).
Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)</td><td></td></tr>
<tr><td>14</td><td colspan="2">Format of Question Paper:
The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.
<table>
<tr><td colspan="4">Note: Attempt any TWO questions out of THREE.</td></tr>
<tr><td>Q. No. 1</td><td>Module 1 and 2</td><td>Attempt any THREE out of FOUR.
(Each question of 5 marks)
(a) Question based on OC1
(b) Question based on OC2
(c) Question based on OC3
(d) Question based on OC4/OC5</td><td>15 Marks</td></tr>
<tr><td>Q. No. 2</td><td>Module 1 and 2</td><td>Attempt any THREE out of FOUR.
(Each question of 5 marks)
(a) Question based on OC1</td><td>15 Marks</td></tr>
</table></td></tr>
</table>

		(b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: Topology of Metric Spaces-I

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course presents a rigorous introduction to metric spaces and their topological structure. It covers various metrics on standard spaces along with discrete metrics, metric subspaces, and product spaces. Several concepts including open and closed sets, open and closed balls, interior, closure, boundary, Hausdorff property, limit and isolated points, boundedness, distance, and diameter of subsets are developed in detail. This course analyzes continuity, uniform continuity, sequences, and their characterizations, along with continuity of composite functions and the contraction mapping (fixed point) theorem. The course also studies Completeness and Cantor's Intersection Theorem with its classical applications for better understanding of real-world applications of these structures.
2	**Vertical:**	Major
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** **CO1:** To introduce students to the fundamental concepts and structures of metric spaces by studying various metrics on standard mathematical spaces and understanding the notions of open and closed sets, interior, closure, boundary, and related topological properties. **CO2**: To develop the ability to analyze sequences in metric spaces, including convergence, Cauchy sequences, completeness, and classical results such as Cantor's Intersection Theorem and its applications. **CO3**: To develop a clear understanding of the topological properties of functions and their applications. **CO4**: To build problem-solving skills through computation of distances and diameters of sets, construction of open and closed balls, identification of limit and isolated points, and formulation of examples and counterexamples illustrating key properties of metric spaces.	
8	**Course Outcomes (OC):** After completion of the course, students will be able. **OC1**: define and explain the basic concepts of metric spaces, including metrics, open and closed sets, interior, closure, and boundary, convergent sequences, Cauchy sequences, continuity, uniform continuity with suitable examples. **OC2** compute the interior, closure, limit points, diameter of a given subset of a metric space, and compute the distance between two subsets and the distance of a point from a given set. **OC3:** examine convergence, Cauchy sequences, completeness, and related results such as Cantor's Intersection Theorem, and analyze their consequences in different metric spaces.	

	OC4: compare and distinguish between topological structures arising from different metrics and apply Cantor's Intersection Theorem in suitable examples. **OC5:** construct open balls and closed balls in given metric space and construct counter-examples for convergent/Cauchy sequences and continuous/uniformly continuous functions.
	Modules: - **Module 1**: **Metric Spaces and Topological Structures (15 Lectures)**
	(1) Definition and examples of metric spaces such as $\mathbb{R}, \mathbb{R}^2, \mathbb{R}^n$ with its Euclidean, Sup and Sum metrics, l^1 and l^2 spaces of sequences, $C[a,b]$ the space of real valued continuous functions on $[a,b]$. (2) Discrete metric space, Metric induced by the norm (3) Metric subspaces, product of metric spaces (4) Open balls and open sets in a metric space. Examples of open sets in various metric spaces. Properties of open sets. Hausdorff property. Interior of a set and its properties. (5) Closed sets. Closed balls, Examples. Limit point of a set. Isolated point. Closure of a set and its properties. Boundary of a set. Distance of a point from a set, Distance between sets. Diameter of a set. Bounded sets.
	Module 2: **Sequences and Continuity (15 Lectures)**
	(1) Sequences in a metric space. Convergent sequence in metric space. Cauchy sequence in a metric space. Subsequences. Examples of convergent and Cauchy sequences in different metric spaces. Characterization of limit points and closure points in terms of sequences. (2) Definition of complete metric spaces. Examples of complete metric spaces. Completeness property in subspaces (Statements only) (3) Cantor's Intersection Theorem, Converse of Cantor's Intersection Theorem (Statement Only), Nested Interval theorem in $\mathbb{R}$ (without proof), Applications of Cantors Intersection Theorem (without proof) such as (i) The set of real Numbers is uncountable; (ii) Density of rational Numbers; (iii) Intermediate Value theorem. (4) Epsilon-delta definition of continuity. Characterization of continuity at a point in terms of sequences, open sets and closed sets and related examples. Continuity of composite function. (5) Uniform continuity in a metric space, examples (emphasis on $\mathbb{R}$) Contraction mapping (fixed point) theorem.
10	**Recommended Reference Books:** 1. S. Kumaresan; Topology of Metric spaces. 2. E. T. Copson; Metric Spaces; Universal Book Stall, New Delhi, 1996. 3. P. K. Jain, K. Ahmed; Metric Spaces; Narosa, New Delhi, 1996. 4. R. R. Goldberg; Methods of Real Analysis; Oxford and IBH Pub. Co., New Delhi 1970.
11	**Additional Reference Books** 1. T. Apostol; Mathematical Analysis, Second edition, Narosa, New Delhi, 1974. 2. D. Gopal, A. Deshmukh, A. S. Ranadive and S. Yadav; An Introduction to Metric Spaces, Chapman and Hall/CRC, New York, 2020. 3. W. Rudin; Principles of Mathematical Analysis; Third Ed, McGraw-Hill, Auckland, 1976. 4. D. Somasundaram; B. Choudhary; A first Course in Mathematical Analysis. Narosa, New Delhi. 5. G. F. Simmons; Introduction to Topology and Modern Analysis; McGraw-Hi, New York, 1963.

	Scheme of the Examination
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each semester in an Offline mode.	10
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14 Format of Question Paper:

The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.			
Q. No. 1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1	15 Marks

		(b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: 5P1 (Based on Integral Calculus and Group Theory)

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course combines hands-on practice in evaluating double integrals with problem-solving in group theory. Students apply double integrals to compute areas and volumes, while also exploring algebraic structures by verifying group properties and working with groups and subgroups. The course emphasizes practical understanding through guided exercises and applications.
2	**Vertical:**	Major
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course emphases on problem solving and motivates to think on the basic concepts of Algebra and Calculus with rigour and prepares students to study further courses. **CO1.** To give sufficient knowledge of fundamental principles, methods and a clear perception of numerous powers of mathematical ideas and tools and the skills to use them by modelling, solving and interpreting. **CO2.** To reflect the broad nature of the subject and develop mathematical tools for continuing further study in various fields of sciences. **CO3.** To enhance students' overall development, problem solving skills, creative talent, and power of communication. These are necessary for various kinds of employment. **CO4.** To give adequate exposure to global and local concerns that would help learners explore many aspects of Mathematical Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Apply double and triple integrals for computing areas and volumes, and apply basic concepts of group theory to solve algebraic problems. **OC2:** Analyze integrability and evaluate multiple integrals using Fubini's Theorem, and analyze fundamental group properties and homomorphisms. **OC3:** Justify/Check the validity of integration techniques and coordinate changes, and justify group-theoretic results and proofs. **OC4:** Construct appropriate coordinate systems for complex integrals, and construct groups, subgroups, and related algebraic structures.	
9	**Modules: -** **Module 1: Practical for Integral Calculus (Multiple Integrals) (30 Hours)**	

1.	Evaluation of Double Integration in Cartesian Coordinates
2.	Evaluation of Double Integration by reversing order of the integration
3.	Evaluation of the area using Double Integration
4.	Evaluation of Double Integration in Polar Coordinates

5.	Evaluation of Triple Integration in cartesian coordinates
6.	Evaluation of Triple Integration using cylindrical and spherical coordinates
7.	Finding Volume using Triple Integration

Module 2: Practical for Group Theory (30 Hours)

1.	Groups and Order of an Element in a group
2.	Centralizer of an element and center of a Group
3.	Subgroups of a group, Cosets and Lagrange's Theorem
4.	Homomorphism, Kernel, image under group homomorphism and Isomorphism of Groups
5.	Internal and External Direct Products of Groups
6.	Cyclic groups, Subgroups of Cyclic groups and their generators
7.	Product of Cyclic groups and their properties
8.	Characterization of Cyclic groups via Isomorphisms
	Miscellaneous Theory questions based on both modules

10 Recommended Reference Books:

1. Apostol, Calculus, Vol. 2, Second Ed., John Wiley, New York, 1969.
2. James Stewart, Calculus with early transcendental Functions.
3. Marsden and Jerrold E. Tromba, Vector Calculus, Fourth Ed., W.H. Freeman and Co., New York, 1996.
4. J. Gallian. Contemporary Abstract Algebra. Narosa, New Delhi, 2008.
5. P. B. Bhattacharya, S. K. Jain, S. Nagpaul. Basic Abstract Algebra, Second edition, Foundation Books, New Delhi, 1995.
6. J. B. Fraleigh, A first course in Abstract Algebra, Third edition, Narosa, New Delhi, 1996.
7. I. N. Herstein, Topics in Algebra, Wiley Eastern Limied, Second edition, 2006.
8. N. S. Gopalkrishnan, University Algebra, New Age International Private Limited, 2018.

11 Additional Reference Books

1. T. Apostol, Mathematical Analysis, Second Ed., Narosa, New Delhi. 1947.
2. R. Courant and F.John, Introduction to Calculus and Analysis, Vol.2, Springer Verlag, New York, 1989.
3. W. Fleming, Functions of Several Variables, Second Ed., Springer-Verlag, New York, 1977.
4. M. H. Protter and C.B.Morrey Jr., Intermediate Calculus, Second Ed., Springer-Verlag, New York, 1995.
5. G. B. Thomas and R.L Finney, Calculus and Analytic Geometry, Ninth Ed. (ISE Reprint), Addison- Wesley, Reading Mass, 1998.
6. D. V. Widder, Advanced Calculus, Second Ed., Dover Pub., New York. 1989.
7. M. Artin, Algebra, Prentice Hall of India, New Delhi, Second Edition, 2010.
8. T. W. Hungerford. Algebra, Springer, 2003.
9. D. Dummit, R. Foote. Abstract Algebra, John Wiley & Sons, Inc., Third Edition, 2003.

	10. I. S. Luther, I.B.S. Passi. Algebra. Vol. I., 1997.
	Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**

13

Continuous Evaluation through:
Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc.
(at least 3)

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

Paper pattern of the Test (Offline Mode):
Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2)

Duration: 1Hrs
While setting question paper four MCQ on module 1 and four MCQ on module 2 both.

14

Format of Question Paper:

Scheme of examination:
At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

	Marks for Journals: For both Module 1 and Module 2 1. Journal: 5 marks (2.5 marks for each module 1 & module 2) The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

Name of the Course: 5P2 (Based on Integral Calculus and Topology of Metric Spaces- I)

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This practical course focuses on computational and conceptual techniques in line and surface integrals, along with fundamental ideas from the topology of metric spaces. Students will gain hands-on experience in evaluating line and surface integrals, applying integral theorems, and visualizing vector fields, while also exploring metric spaces, open and closed sets, continuity, and convergence through examples and problem-solving activities.
2	**Vertical:**	Major
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course emphases on problem solving and motivates to think on the basic concepts of Calculus and Metric Spaces with rigour and prepares students to study further courses. **CO1.** To give sufficient knowledge of fundamental principles, methods and a clear perception of numerous powers of mathematical ideas and tools and the skills to use them by modelling, solving and interpreting. **CO2.** To reflect the broad nature of the subject and develop mathematical tools for continuing further study in various fields of sciences. **CO3.** To enhance students' overall development, problem solving skills, creative talent, and power of communication. These are necessary for various kinds of employment. **CO4.** To give adequate exposure to global and local concerns that would help learners explore many aspects of Mathematical Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Apply concepts of scalar and vector fields, vector differential operators, and multiple integrals to compute circulation, flux, and work in $\mathbb{R}^2$ and $\mathbb{R}^3$, and apply basic concepts of metric spaces such as open and closed sets, bounded sets, and closure. **OC2:** Analyse parametrized curves and surfaces to formulate and interpret line and surface integrals, and analyse limit points and convergence in metric spaces. **OC3:** Justify / Check whether a given vector field is conservative and verify Green’s, Stokes’, and Gauss’ theorems, and justify completeness and continuity in metric spaces. **OC4:** Construct suitable parametrizations of curves and surfaces to solve problems involving circulation and flux, and distinguish between continuity and uniform continuity in metric spaces.	
9	**Modules: -** **Module 1: Practical for Integral Calculus (Line, Surface and Volume Integrals) (30 Hours)**	

1.	Line Integrals of Scalar Fields
2.	Line Integrals of Vector Fields
3.	Evaluation of Work done using line integral
4.	Green's Theorem
5.	Surface Integrals
6.	Stoke's Theorem
7.	Gauss Divergence Theorem

Module 2: Practical for Topology of Metric Spaces - I (30 Hours)

1.	Metric Spaces, Subspaces and Normed Linear Spaces
2.	Sketching of Open Balls in $\mathbb{R}^2$, Open and Closed sets
3.	Interior of a set, Interior points and Limit Points,
4.	Closure of a set, Dense Sets, Separability and Diameter of a set
5.	Bounded, Convergent and Cauchy Sequences
6.	Complete Metric Spaces
7.	Cantor's Intersection Theorem and Applications
8.	Continuity and Uniform Continuity
	Miscellaneous Theory questions based on both modules

10 Recommended Reference Books:

1. Apostol, Calculus, Vol. 2, Second Ed., John Wiley, New York, 1969.
2. James Stewart, Calculus with early transcendental Functions.
3. S. Kumaresan; Topology of Metric spaces.
4. E. T. Copson; Metric Spaces; Universal Book Stall, New Delhi, 1996.
5. P. K. Jain, K. Ahmed; Metric Spaces; Narosa, New Delhi, 1996.
6. R. R. Goldberg; Methods of Real Analysis; Oxford and IBH Pub. Co., New Delhi 1970.

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1. T. Apostol, Mathematical Analysis, Second Ed., Narosa, New Delhi. 1947.
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4. M. H. Protter and C.B.Morrey Jr., Intermediate Calculus, Second Ed., Springer-Verlag, New York, 1995.
5. G. B. Thomas and R.L Finney, Calculus and Analytic Geometry, Ninth Ed. (ISE Reprint), Addison- Wesley, Reading Mass, 1998.
6. D. V. Widder, Advanced Calculus, Second Ed., Dover Pub., New York. 1989.
7. D. Gopal, A. Deshmukh, A. S. Ranadive and S. Yadav; An Introduction to Metric Spaces, Chapman and Hall/CRC, New York, 2020.
8. W. Rudin; Principles of Mathematical Analysis; Third Ed, McGraw-Hill, Auckland, 1976.
9. D. Somasundaram; B. Choudhary; A First Course in Mathematical Analysis. Narosa, New Delhi.

	10. G. F. Simmons; Introduction to Topology and Modern Analysis; McGraw-Hill, New York, 1963. 11. Expository articles of the MTTS programme.
	Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

Paper pattern of the Test (Offline Mode):

Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2)

Duration: 1Hrs

While setting question paper four MCQ on module 1 and four MCQ on module 2 both.

14 **Format of Question Paper:**

Scheme of examination:

At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and	(5 × 2 = 10 Marks)

	OC4)		

Marks for Journals:

For both Module 1 and Module 2

2. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

SEM V
Vertical – 1
Electives
(2+2)

Syllabus
B.A./ B.Sc. (Mathematics)
(Sem.- V)
(MAJOR – Elective – A)
Name of the Course: Partial Differential Equations

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course introduces first-order partial differential equations and their applications in science and engineering. Topics include curves and surfaces, genesis and classification of PDEs, integrals, and the Cauchy problem. Students learn solution methods such as Lagrange's equation, Charpit's method, Jacobi's method, and Pfaffian equations. The course also covers compatible systems, integrability conditions, and quasi-linear equations.
2	**Vertical:**	Major (Elective – A)
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides an introduction to introduction to partial differential equation and methods for finding solutions and the application of PDE. It aims to prepare students for more advanced courses in partial differential equations. The focus of the course is on developing problem solving skills and critical thinking using applications, and it also extends to broader applications in mathematics. **CO1:** Introduce the fundamental concepts of genesis of first order PDE. **CO2:** Develop an understanding of the classification of first order PDE and varies types of integrals associated with them. **CO3:** Familiarize students with the Cauchy problem and method for solving linear and quasi-linear first order PDE. **CO4:** Train students in solving Lagrange's linear equation, Pfaffian differential equations and determining conditions for integrability. **CO5:** Provide insights into semi-linear and quasi-linear PDEs and develop the ability to formulate and solve corresponding initial value problems.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Explain how to form partial differential equations and different types of integrals of first order PDEs. **OC2:** Solve first order linear PDEs using Lagrange's equation and Pfaffian differential equations.	

	OC3: Describe systems of first order PDEs and determine the necessary and sufficient conditions for compatibility and integrability. **OC4**: Examine first order non-linear PDEs using Charpit's and Jacobi's methods **OC5:** Solve Cauchy problems and initial value problems for quasi-linear equation.
	Modules: - **Module 1**: **First Order Partial Differential Equations (15 Lectures)**
	1. Curves and Surfaces: Parametrically Defined Curve, Implicitly Defined Curve, arc length, Chain rule. 2. Genesis of first order PDE, Classification of first order PDE, linear, semi-linear, quasi-linear and non-linear equations. 3. Obtaining a partial differential equation by Elimination of an arbitrary function and by the elimination of arbitrary constants, Euler's equation for a homogeneous function. 4. Classification of integrals: Integral Surface, Envelopes of family of surfaces, Complete integral, General Integral and Singular integrals. 5. Linear Equation of first order, Lagrange's equation, Pfaffian differential equations.
	Module 2: **Methods of Solving first order PDE (15 Lectures)**
	1. Compatible system of first order PDE, Necessary and sufficient condition for integrability. 2. Charpit's method, Solution of Some standard types of PDE using Charpit's method. 3. Jacobi's method, Jacobi's method to find a complete integral for a first order PDE in two independent variables, The Cauchy problem. 4. Semi linear equations, Quasi-linear equations, first order quasi-linear PDE. 5. Initial value problem for quasi-linear equation. Initial Strips & Characteristic differential equation.
10	**Recommended Reference Books:** For Module 1 (Ref Book: An Elementary Course in Partial Differential Equations by T. Amaranath, 2nd edition, Chapter 1: 1.1, 1.2, 1.3, Lemma 1.3.1, 1.3.2, 1.3.3, 1.4, Theorem 1.4.1, 1.4.2, 1.5, Theorem 1.5.1, Lemma 1.5.1, Theorem 1.5.2, Lemma 1.5.2, 1.6, Theorem 1.6.1 and related examples) For Module 2 (Ref Book: An Elementary Course in Partial Differential Equations by T. Amaranath, 2nd edition, Chapter 1: 1.7, 1.8 Theorem 1.8.1, 1.9, 1.10, Theorem 1.10.1 and related examples)
11	**Additional Reference Books** 1. T. Amaranath n Elementary Course in Partial Differential Equations, 2nd edition, Narosa Publishing house. 2. Ian Sneddon, Elements of Partial Differential Equations, McGraw Hill book. 3. Ravi P. Agarwal and Donal O'Regan, Ordinary and Partial Differential Equations, Springer, First Edition (2009). 4. Dr. M. D. Raisinghania, Advanced Differential Equations, S. Chand & Company Pvt, Ltd. 5. W.E. Williams, Partial Differential Equations, Clarendon Press, Oxford, (1980). 6. K. Sankara Rao, Introduction to Partial Differential Equations, Third Edition, PHI.
	Scheme of the Examination
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks.

	• Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each semester in an Offline mode.	10
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification. (04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14 **Format of Question Paper:**

The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.			
Q. No. 1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks)	15 Marks

				(a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5		

Name of the Course: 5P3A Practical Based on Partial Differential Equations

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course introduces first-order partial differential equations and their applications in science and engineering. Topics include curves and surfaces, genesis and classification of PDEs, integrals, and the Cauchy problem. Students learn solution methods such as Lagrange's equation, Charpit's method, Jacobi's method, and Pfaffian equations. The course also covers compatible systems, integrability conditions, and quasi-linear equations.
2	**Vertical:**	Major (Elective – A)
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides an introduction to introduction to partial differential equation and methods for finding solutions and the application of PDE. It aims to prepare students for more advanced courses in partial differential equations. The focus of the course is on developing problem-solving skills and critical thinking using applications, and it also extends to broader applications in mathematics. **CO1:** Introduce the fundamental concepts of genesis of first order PDE. **CO2:** Develop an understanding of the classification of first order PDE and varies types of integrals associated with them. **CO3:** Familiarize students with the Cauchy problem and method for solving linear and quasi-linear first order PDE. **CO4:** Train students in solving Lagrange's linear equation, Pfaffian differential equations and determining conditions for integrability. **CO5:** Provide insights into semi-linear and quasi-linear PDEs and develop the ability to formulate and solve corresponding initial value problems.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Solve first order linear PDEs using Lagrange's equation and Pfaffian differential equations. **OC2**: Describe systems of first order PDEs and determine the necessary and sufficient conditions for compatibility and integrability. **OC3**: Examine first order non-linear PDEs using Charpit's and Jacobi's methods **OC4:** Solve Cauchy problems and initial value problems for quasi-linear equation.	
9	**Modules: -** **Module 1: Practical for First Order Partial Differential Equations (30 Hours)**	

1.	Formation of Partial Differential Equation by eliminating parameters
2.	Formation of Partial Differential Equation by eliminating arbitrary functions
3.	Examples based on Singular Integral
4.	General solution of Lagrange's equations
5.	Integrability and integral solution of Pfaffian differential equations
6.	Compatibility of first order PDE
7.	One parameter family of compatible first order PDE

Module 2: Practical for Methods of Solving first order PDE (30 Hours)

1.	Examples based on Charpit's method
2.	Examples based on type $f(p,q)=0$
3.	Examples based on type $f(z,p,q)=0$
4.	Examples based on Separable type
5.	Examples based on Clairaut form
6.	Examples based on Jacobi's method
7.	Examples based on Cauchy Problem
8.	Examples based on Quasi-linear equations

Miscellaneous Theory questions based on both modules.

10 Recommended Reference Books:

For Module 1 (Ref Book: An Elementary Course in Partial Differential Equations by T. Amaranath, 2nd edition, Chapter 1: 1.1, 1.2, 1.3, Lemma 1.3.1, 1.3.2, 1.3.3, 1.4, Theorem 1.4.1, 1.4.2, 1.5, Theorem 1.5.1, Lemma 1.5.1, Theorem 1.5.2, Lemma 1.5.2, 1.6, Theorem 1.6.1 and related examples)

For Module 2 (Ref Book: An Elementary Course in Partial Differential Equations by T. Amaranath, 2nd edition, Chapter 1: 1.7, 1.8 Theorem 1.8.1, 1.9, 1.10, Theorem 1.10.1 and related examples)

11 Additional Reference Books

1. T. Amaranath An Elementary Course in Partial Differential Equations, 2nd edition, Narosa Publishing house.
2. Ian Sneddon, Elements of Partial Differential Equations, McGraw Hill book.
3. Ravi P. Agarwal and Donal O'Regan, Ordinary and Partial Differential Equations, Springer, First Edition (2009).
4. Dr. M. D. Raisinghania, Advanced Differential Equations, S. Chand & Company Pvt, Ltd.
5. W.E. Williams, Partial Differential Equations, Clarendon Press, Oxford, (1980).
6. K. Sankara Rao, Introduction to Partial Differential Equations, Third Edition, PHI.

Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations,	

	projects, role play, creative writing, assignments etc. (at least 3) <table><tr><td>Sr. No.</td><td>Particulars</td><td>Marks</td></tr><tr><td>1</td><td>Objective question test</td><td>10</td></tr><tr><td>2</td><td>Overall performance</td><td>05</td></tr><tr><td>3</td><td>Viva</td><td>05</td></tr></table> **Paper pattern of the Test (Offline Mode):** Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2) **Duration: 1Hrs** **While setting question paper four MCQ on module 1 and four MCQ on module 2 both.**	

14 **Format of Question Paper:**

Scheme of examination:

At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

Marks for Journals:

For both Module 1 and Module 2

3. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

(MAJOR – Elective – B)

Name of the Course: Number Theory and Its Applications - I

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course introduces fundamental concepts of number theory, focusing on congruences, factorization techniques and Diophantine equations. It develops classical results such as Fermat's and Euler's theorems and explores methods for solving integer equations, with emphasis on mathematical reasoning and practical applications, particularly in cryptography and computation.
2	**Vertical:**	Major (Elective – B)
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides an introduction to the fundamental concepts of number theory with a strong emphasis on logical rigor and classical methods. It aims to develop a clear understanding of integers, congruences, factorization techniques and Diophantine equations, while preparing students for advanced study in number theory and related areas of pure mathematics. The course focuses on cultivating formal proof techniques and analytical thinking, which deepens conceptual understanding and strengthens mathematical maturity. **CO1:** Develop a solid understanding of core principles and methods in number theory, enabling students to analyze and solve problems involving integers and congruences. **CO2:** Illustrate the depth and scope of number theory by equipping students with essential theoretical tools required for further studies in pure and applied mathematics. **CO3:** Strengthen problem-solving abilities and logical reasoning through rigorous proofs and structured arguments, fostering clarity of mathematical expression. **CO4:** Provide exposure to classical results and foundational ideas in number theory that underpin significant developments within the broader Mathematical Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to: **OC1:** Understand and recall fundamental concepts of number theory, including divisibility, primes, congruences, arithmetic functions, and basic factorization methods. **OC2:** Apply standard theorems and techniques of number theory to solve problems involving linear and higher-degree congruences and classical Diophantine equations. **OC3:** Analyze and interpret integer solutions of equations, residue systems, and congruence relations using appropriate theoretical tools and logical reasoning. **OC4:** Justify results related to solvability or non-solvability of Diophantine equations and congruences through rigorous mathematical proofs. **OC5:** Construct and examine examples and counterexamples illustrating key concepts and theorems	

	in number theory, thereby demonstrating deeper conceptual understanding.	
	Modules: - **Module 1**: **Congruences and Factorization (15 Lectures)**	
	Review of Divisibility, Primes and The fundamental theorem of Arithmetic. Congruences: Definition and elementary properties, Complete residue system modulo m, Reduced residue system modulo m, Euler's function and its properties, Fermat's little Theorem, Euler's generalization of Fermat's little Theorem, Wilson's theorem, Linear congruence, The Chinese remainder Theorem, Congruences of Higher degree, The Fermat-Kraitchik Factorization Method.	
	Module 2: **Diophantine equations and their solutions (15 Lectures)**	
	The linear equations ax + by = c. The equations $x^2 + y^2 = p$; where p is a prime. The equation $x^2 + y^2 = z^2$, Pythagorean triples, primitive solutions. The equations $x^4 + y^4 = z^2$ and $x^4 + y^4 = z^4$ have no solutions (x, y, z) with $x,y,z \neq 0$. Every positive integer n can be expressed as a sum of squares of four integers. Assorted examples: section 5.4 of Number theory by Niven- Zuckermann-Montgomery.	
10	**Recommended Reference Books:** 1. Niven, H. Zuckerman and H. Montogomery, An Introduction to the Theory of Numbers, John Wiley & Sons. Inc. 2. David M. Burton, An Introduction to the Theory of Numbers. Tata McGraw Hill Edition. 3. N. S. Gopalkrishnan: University Algebra, New Age International Ltd, Reprint 2013. 4. G. H. Hardy and E.M. Wright. An Introduction to the Theory of Numbers. Low priced edition. The English Language Book Society and Oxford University Press, 1981. 5. Neville Robins. Beginning Number Theory. Narosa Publications. 6. S.D. Adhikari. An introduction to Commutative Algebra and Number Theory. Narosa Publishing House. 7. K. Ireland, M. Rosen. A classical introduction to Modern Number Theory. Second edition, Springer Verlag. 8. Norman Biggs: Discrete Mathematics, Oxford University Press.	
11	**Additional Reference Books** 1. N. Koblitz; A course in Number theory and Cryptography; Springer. 2. M. Artin; Algebra; Prentice Hall. 3. K. Ireland, M. Rosen; A classical introduction to Modern Number Theory; Second edition, Springer Verlag.	
	<u>Scheme of the Examination</u>	
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.	
12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each semester in an Offline mode.	10
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification. (04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14 Format of Question Paper:

The semester-end examination will be of 30 marks of one hour duration covering the entiresyllabus of the semester.

Note: Attempt any TWO questions out of THREE.			
Q. No. 1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: 5P3B Practical Based on Number Theory and Its Applications

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course is based on problem-solving which is a fundamental aspect of any Mathematics course. While advanced courses often emphasize the theoretical nature of the subject, engaging in problem-solving reinforces concepts and enhances learners' ability to analyze existing problems and devise solutions. This activity not only motivates learners but also empowers them to formulate new results, propose conjectures, and develop innovative theories.
2	**Vertical:**	Major (Elective – B)
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides an introduction to the fundamental concepts of number theory with a strong emphasis on logical rigor and classical methods. It aims to develop a clear understanding of integers, congruences, factorization techniques and Diophantine equations, while preparing students for advanced study in number theory and related areas of pure mathematics. The course focuses on cultivating problem solving techniques and analytical thinking, which deepens conceptual understanding and strengthens mathematical maturity. **CO1:** Develop a solid understanding of core principles and methods in number theory, enabling students to analyze and solve problems involving integers and congruences. **CO2:** Illustrate the depth and scope of number theory by equipping students with essential theoretical tools required for further studies in pure and applied mathematics. **CO3:** Strengthen problem-solving abilities and logical reasoning through rigorous proofs and structured arguments, fostering clarity of mathematical expression. **CO4:** Provide exposure to classical results and foundational ideas in number theory that underpin significant developments within the broader Mathematical Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Apply standard theorems and techniques of number theory to solve problems involving linear and higher-degree congruences and classical Diophantine equations. **OC2:** Analyze and interpret integer solutions of equations, residue systems, and congruence relations using appropriate theoretical tools and logical reasoning. **OC3:** Justify results related to solvability or non-solvability of Diophantine equations and congruences through rigorous mathematical proofs. **OC4:** Construct and examine examples and counterexamples illustrating key concepts and theorems in number theory, thereby demonstrating deeper conceptual understanding.	

9	**Modules: -** **Module 1: Practical for Congruences and Factorization (30 Hours)**

1.	Divisibility and congruences
2.	Residue systems modulo m
3.	Euler's function, Fermat's little Theorem
4.	Euler's generalization of Fermat's little Theorem, Wilson's theorem
5.	Linear congruence
6.	The Chinese remainder Theorem
7.	Congruences of Higher degree
8.	The Fermat-Kraitchik Factorization Method.

Module 2: Practical for Diophantine equations and their solutions (30 Hours)

1.	The linear equations ax + by = c
2.	The equations $x^2 + y^2 = p$; where p is a prime
3.	The equation $x^2 + y^2 = z^2$
4.	Problems on Pythagorean triples, primitive solutions
5.	Problems on the equations $x^4 + y^4 = z^2$ and $x^4 + y^4 = z^4$.
6.	Positive integer n can be expressed as a sum of squares of four integers
7.	Assorted examples: section 5.4 of Number theory by Niven- Zuckermann-Montgomery.
	Miscellaneous Theory questions based on both modules.

10 Recommended Reference Books:

1. Niven H. Zuckerman and H. Montogomery. An Introduction to the Theory of Numbers. John Wiley & Sons. Inc.
2. David M. Burton. An Introduction to the Theory of Numbers. Tata McGraw-Hill Edition.
3. Neville Robins. Beginning Number Theory. Narosa Publications.
4. S. D. Adhikari. An introduction to Commutative Algebra and Number Theory. Narosa Publishing House
5. K. Ireland, M. Rosen. A classical introduction to Modern Number Theory. Second edition, Springer Verlag.

11 Additional Reference Books

1. N. Koblitz; A course in Number theory and Cryptography; Springer.
2. M. Artin; Algebra; Prentice Hall.
3. K. Ireland, M. Rosen; A classical introduction to Modern Number Theory; Second edition, Springer Verlag.

Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**

<table>
<tr><td>13</td><td>Continuous Evaluation through:
Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc.
(at least 3)

<table>
<tr><td>Sr. No.</td><td>Particulars</td><td>Marks</td></tr>
<tr><td>1</td><td>Objective question test</td><td>10</td></tr>
<tr><td>2</td><td>Overall performance</td><td>05</td></tr>
<tr><td>3</td><td>Viva</td><td>05</td></tr>
</table>

Paper pattern of the Test (Offline Mode):
Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2)

Duration: 1Hrs
While setting question paper four MCQ on module 1 and four MCQ on module 2 both.</td><td></td></tr>
<tr><td>14</td><td colspan="2">Format of Question Paper:

Scheme of examination:
At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

<table>
<tr><td>Q. No. 1</td><td>Five out of Eight multiple choice questions (four from module 1 and four from module 2)
(OC1 to OC3)</td><td>Marks
(3 × 5 = 15 Marks)</td></tr>
<tr><td>Q. No.2</td><td>Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)</td><td>(5 × 2 = 10 Marks)</td></tr>
</table>

Marks for Journals:

For both Module 1 and Module 2
4. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.</td></tr>
</table>

(MAJOR – Elective – C)

Name of the Course: Operations Research - I

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	Operations Research is a multidisciplinary field that applies analytical methods to help make better management decisions. It is often called the “science of the better” because it focuses on optimising processes, resource allocation, and decision-making to achieve optimal solutions. The course helps solve complex real-world problems using mathematics and domain-specific knowledge. Operations Research bridges the gap between theory and application, enabling systematic and evidence-based decision-making in various domains. It helps organisations deal with complexities, reduce costs, improve productivity, and gain a competitive edge. Its practical and quantitative approach makes it an essential tool for decision-makers. It has its applications in Agricultural Engineering, Mechanical Engineering, Production and Industrial Engineering, Mechatronics, Environmental Science and for Professionals and Decision-makers
2	**Vertical:**	Major (Elective – C)
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides an introduction to Concepts of Operations Research. It aims to prepare students to develop mathematical models for real life problems and effective decision making. The focus of the course is on developing skills and techniques, which extends to broader applications in mathematics. **CO1:** Provide an understanding of fundamental concepts and tools of the subject. **CO2**: Equips the students to develop mathematical models for making decisions. **CO3**: Foster students' comprehensive development by placing emphasis on problem-solving skills, nurturing creative talents, and enhancing communication abilities, all of which are vital for a range of employment opportunities. **CO4**: Ensures understanding of the techniques to be applied for effective business decisions.	
8	**Course Outcomes (OC):** After successful completion of the course, students will be able to: **OC1:** Understand and recall fundamental concepts of vector spaces, linear independence and dependence, basis, convex sets, polyhedra, faces, and basic terminology related to Linear Programming Problems. **OC2:** Apply graphical and simplex methods to formulate and solve maximization and minimization Linear Programming Problems, including balanced and unbalanced cases.	

	OC3: Analyse Linear Programming Problems to determine feasibility, optimality, unboundedness, degeneracy, and the existence of alternate optimal solutions using simplex-based approaches. **OC4:** Justify the choice of appropriate solution methods such as simplex, Big-M method, or special case handling by examining the relationship between basic feasible solutions, extreme points, and problem characteristics. **OC5:** Construct mathematical models for real-world optimization situations, including Linear Programming and Assignment problems (up to 5×5), and solve them using suitable Operations Research techniques.
	Modules: - **Module 1**: **Introductory concepts and Linear Programming -I (15 Lectures)**
	1. Prerequisites: Vector Spaces, Linear independence and dependence, Basis, Convex sets, Dimension of polyhedron, Faces. 2. Formation of LPP, Solution of LPP with Graphical Method. 3.Theory of the Simplex Method- Standard form of LPP, Feasible solution to basic feasible solutions, Improving BFS, Optimality Condition, Un-bounded solution, Alternative optima, Correspondence between BFS and extreme points.
	Module 2: **Linear Programming -II and Assignment Problems (15 Lectures)**
	1. Simplex Method – Simplex Algorithm, Simplex Tableau. Simplex Method – Case of Degeneracy, Big-M Method, Infeasible solution, Alternate solution, Solution of LPP for unrestricted variable. 2. Maximization and Minimization type problems, Balanced and unbalanced problems, Problems with unique or multiple optimal solutions 3. Simple formulation of Assignment problems, (Maximum 5x5 matrix, upto maximum two iterations after row and column minimization)
10	**Recommended Reference Books:** 1. G.Hadley; Linear Programming; Narosa Publishing, (Chapter 3). 2. G. Hadley; Linear Programming; Narosa Publishing, (Chapter 4 and 9). 3. J.K. Sharma, Operations Research, Theory and Applications. 4. N.S. Kambo, Mathematical Programming Techniques, Revised Addition. Affiliated East-West Press Pvt Ltd.
11	**Additional Reference Books** 1. Hillier and Lieberman, Introduction to Operations Research. 2. Richard Broson, Schaum Series Book in Operations Research, Tata McGrawHill Publishing Company Ltd.
	Scheme of the Examination
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**

13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each semester in an Offline mode.	10
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14 **Format of Question Paper:**

The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.			
Q. No. 1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: 5P3C Practical Based on Operations Research - I

<table>
<tr><th>Sr. No.</th><th>Heading</th><th>Particulars</th></tr>
<tr><td>1</td><td>Description of the course: Including but not limited to:</td><td>Problem-solving is a fundamental aspect of any Mathematics course. While advanced courses often emphasize the theoretical nature of the subject, engaging in problem-solving reinforces concepts and enhances learners' ability to analyse existing problems and devise solutions. This activity not only motivates learners but also empowers them to formulate new results, propose conjectures, and develop innovative theories.</td></tr>
<tr><td>2</td><td>Vertical:</td><td>Major (Elective -C)</td></tr>
<tr><td>3</td><td>Type:</td><td>Practical</td></tr>
<tr><td>4</td><td>Credits:</td><td>2 credits
(1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)</td></tr>
<tr><td>5</td><td>Hours Allotted:</td><td>60 Hours</td></tr>
<tr><td>6</td><td>Marks Allotted:</td><td>50 Marks</td></tr>
<tr><td>7</td><td colspan="2">Course Objectives (CO):
This course emphases on problem solving and motivates to think on the basic concepts of Operations Research with rigour and prepares students for decision making in business problems.
CO1. To give sufficient knowledge of fundamental principles, tools and the skills to use them by modelling, solving and interpreting.
CO2. To reflect the broad nature of the subject and develop mathematical tools for continuing further study in various fields of sciences.
CO3. To enhance students' overall development, problem solving skills, creative talent, and power of communication. These are necessary for various kinds of employment.
CO4. To give adequate exposure to global and local concerns that would help learners explore many aspects of Mathematical and Engineering Sciences.</td></tr>
<tr><td>8</td><td colspan="2">Course Outcomes (OC):
After completion of the course, students will be able to
OC1: Apply the concepts to formulate the problem mathematically and solve it by using graphical methods and simplex methods etc.
OC2: Analyze the solution for optimality, boundedness and unboundedness. Finding the feasible region and classification of solutions as bounded and unbounded and improve the solution obtained to Basic feasible solution
OC3: Justify/ check the solutions of Assignment problems with unique optimal solution and multiple optimal solution
OC4: Construct examples related to assignment problems and travelling salesman problem to find the shortest distance.</td></tr>
<tr><td rowspan="2">9</td><td colspan="2">Modules: -
Module 1: Practical for Linear Programming - I (30 Hours)</td></tr>
<tr><td colspan="2"><table>
<tr><td>1.</td><td>Basic concepts of Vector Spaces, Convex Sets, Formulation of LPP</td></tr>
<tr><td>2.</td><td>Solution of LPP by Graphical method</td></tr>
<tr><td>3.</td><td>Simplex Algorithm, Solution of LPP by Simplex method-I</td></tr>
</table></td></tr>
</table>

4.	Solution of LPP by Simplex method-II
5.	Improving feasible solution to Basic feasible solution
6.	Finding the optimal solution, Problems on Bounded and unbounded solutions
7.	Relationship between BFS and extreme points

Module 2: Practical for Linear Programming -II & Assignment Problems (30 Hours)

1.	Simplex Method – Case of Degeneracy, Big-M Method
2.	Infeasible solution, Alternate solution, Solution of LPP for unrestricted variable.
3.	Balanced and unbalanced problems
4.	Problems with unique optimal solutions
5.	Problems with multiple optimal solutions
6.	Initial solution for Assignment problems
7.	Optimal solution of Assignment problems
8.	Travelling salesman problem

Miscellaneous theoretical questions based on module 1 and 2.

10 Recommended Reference Books:

1. G.Hadley; Linear Programming; Narosa Publishing, (Chapter 3).
2. G. Hadley; Linear Programming; Narosa Publishing, (Chapter 4 and 9).
3. J.K. Sharma, Operations Research, Theory and Aplications.
4. Linear programming by R.K. Gupta
5. N.S. Kambo, Mathematical Programming Techniques, Revised Addition. Affiliated East-West Press Pvt Ltd.

11 Additional Reference Books

1. Hillier and Lieberman, Introduction to Operations Research.
2. Richard Broson, Schaum Series Book in Operations Research, Tata McGrawHill Publishing Company Ltd.
3. Linear Programming for Project Management Professionals by Partha Majumdar.
4. Linear Programming By Lalji Prasad.

Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

	Paper pattern of the Test (Offline Mode): Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2) **Duration: 1Hrs** **While setting question paper four MCQ on module 1 and four MCQ on module 2 both.**	

14 **Format of Question Paper:**

Scheme of examination:

At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

Marks for Journals:

For both Module 1 and Module 2

5. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

(MAJOR – Elective – D)

Name of the Course: Graph Theory - I

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	Graph Theory builds a solid analytical foundation in graph structures and their applications across technology, engineering, and data-driven industries. The course covers graph types, cycles, connectivity, isomorphism, matrix representations, degree sequences, bipartite graphs, and shortest-path algorithms for network optimization. It further explores trees, spanning trees, co-trees, fundamental circuits, and Cayley's formula, emphasizing their role in communication networks and hierarchical system design. Learners study key algorithms, binary and m-ary trees, prefix codes, and Huffman coding for data compression. Topics such as Eulerian graphs and Fleury's algorithm link graph theory to logistics and operational planning, supporting real-world problem solving. Overall, the course equips learners with practical graph-theoretic tools and algorithmic techniques that are highly valued in sectors including IT, Cybersecurity, supply chain management, and data science
2	**Vertical:**	Major (Elective – D)
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course offers a rigorous introduction to the fundamental principles and applications of graph theory, emphasizing structural understanding, logical reasoning, and algorithmic thinking. It aims to prepare students for advanced studies in discrete mathematics, network theory, and theoretical computer science. The focus of the course is on developing the ability to analyze graph structures, construct mathematical arguments, and apply algorithms to real-world problems across science and industry. **CO1:** Provide a strong foundation in the basic concepts, definitions, and properties of graphs, enabling students to model and interpret relationships in diverse systems. **CO2:** Develop proficiency in essential graph-theoretic tools, preparing students for further study in mathematics, computer science, optimization, and network analysis. **CO3:** Enhance analytical and problem-solving abilities by engaging with graph algorithms, logical structures, and practical applications relevant to modern technological domains. **CO4:** Encourage awareness of the role of graph theory in addressing global and local challenges such as communication networks, logistics, data processing, and cybersecurity.	
8	**Course Outcomes (OC):** After successful completion of the course, students will be able to:	

	OC1: Understand and recall fundamental concepts such as graph types, connectivity, degree sequences, graph isomorphism, matrices associated with graphs, and properties of trees and Eulerian graphs. **OC2:** Apply graph-theoretic techniques and algorithms—including BFS, DFS, Dijkstra's, Kruskal's, and Prim's—to solve problems related to shortest paths, spanning trees, network design, and optimization. **OC3:** Analyze the structural properties of graphs, examine conditions for bipartiteness, evaluate graph centers and eccentricities, and interpret the behavior of connectivity, cut edges, and cut vertices. **OC4:** Justify structural characteristics using the Havel–Hakimi theorem, Eulerian criteria, and tree characterizations, and verify correctness of graph-based algorithms. **OC5:** Construct examples and counterexamples related to degree sequences, bipartite graphs, spanning trees, Eulerian and non-Eulerian graphs and minimal spanning trees
	Modules: - **Module 1**: **Basics of Graphs (15 Lectures)**
	1 Definition of general graph, Directed and undirected graph, Simple and multiple graphs, Types of graphs- Complete graph, Null graph, Complementary graphs, Regular graphs, Subgraph of a graph, Vertex and Edge induced sub graphs, Spanning sub graphs. 2 Basic terminology- degree of a vertex, Minimum and maximum degree, Walk, Trail, Circuit, Path, Cycle. Handshaking theorem and its applications, Isomorphism between the graphs and consequences of isomorphism between the graphs, Self-complementary graphs, Connected graphs, Connected components. 3 Matrices associated with the graphs – Adjacency and Incidence matrix of a graph-properties, Bipartite graphs and characterization in terms of cycle lengths. 4 Degree sequence and Havel-Hakimi theorem (statement only), Center and eccentricity of a graph. Distance in a graph- shortest path problems, Dijkstra's algorithm (statement only).
	Module 2: **Trees and Eulerian Graphs (15 Lectures)**
	1 Cut edges and cut vertices and relevant results, Characterization of cut edge, Definition of a tree and its characterizations, 2 Spanning tree and co-tree, Recurrence relation of spanning trees and Cayley formula (statement only) for spanning trees of K_n, Fundamental Circuits and Fundamental Cut Sets. 3 Algorithms for spanning tree-BFS and DFS, Binary and m-ary tree, Prefix codes and Huffman coding, Weighted graphs and minimal spanning trees - Kruskal's and Prim's algorithms (without proof) for minimal spanning trees. 4 Eulerian graph and its characterization, Fleury's Algorithm (without proof).
10	**Recommended Reference Books:** 1. R. Balakrishnan, K. Ranganathan, A Text Book of Graph Theory, Springer-Verlag, New York, 2012. 2. J. A. Bondy and U. S. R. Murty, Graph Theory with Applications. 3. D. B. West, Introduction to Graph Theory, Prentice Hall, 2000. 4. Santanu Saha Ray, Graph Theory with Algorithms and its Applications in Applied Science

	and Technology, Springer 2013
11	**Additional Reference Books** 1. Mehadi Behzad and Gary Chartrand, Introduction to Theory of Graphs. 2. S. A. Choudam, Introductory Graph theory 3. J. Clark and D. A. Holtan, A first look of Graph Theory 4. Gary Chartrand and Ping Zhang, A first course in Graph Theory.
	<u>Scheme of the Examination</u>
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each semester in an Offline mode.	10
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14 **Format of Question Paper:**

The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.

Q. No. 1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: 5P3D Practical Based on Graph Theory - I

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This practical course provides hands-on training in fundamental and advanced graph-theoretic concepts, enabling students to construct, classify, and analyze a wide variety of graphs and their substructures. Through computational experiments and problem-based activities, students compute and interpret key graph parameters such as degrees, connectivity, distances, and degree sequences using classical results including the Handshaking Theorem, Havel–Hakimi theorem, and matrix representations of graphs. The course emphasizes algorithmic thinking by applying graph traversal and optimization techniques such as BFS, DFS, Dijkstra's, Kruskal's, and Prim's algorithms. Students also gain practical experience with trees, spanning trees, cut vertices, and cut edges, along with Eulerian graph characterizations, Fleury's algorithm, and Huffman coding. Overall, the course develops strong analytical reasoning and problem-solving skills for modeling, optimizing, and interpreting real-world network structures.
2	**Vertical:**	Major (Elective -D)
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course offers practical experience with essential and advanced graph-theoretic concepts. Students learn to construct graphs, analyze their properties, and apply key algorithms to real-world networks. The focus is on developing computational proficiency, analytical reasoning, and effective problem-solving skills in network structures. **CO1:** To develop the ability to construct, classify, and analyze various types of graphs and their substructures using foundational graph-theoretic definitions and properties. **CO2:** To enable students to compute and interpret key graph parameters-degrees, connectivity, distances, centers, eccentricities, and degree sequences-while applying the Handshaking Theorem, Havel–Hakimi theorem, and matrix representations of graphs. **CO3:** To build proficiency in identifying graph isomorphism, verifying structural similarities, and applying shortest-path and traversal algorithms such as Dijkstra's, BFS, and DFS. **CO4:** To cultivate practical skills in working with trees, spanning trees, cut vertices, cut edges, fundamental circuits, and applying classical results including Cayley's formula and minimal spanning tree algorithms (Kruskal's and Prim's). **CO5:** To strengthen students' problem-solving abilities by applying Eulerian graph characterizations, Fleury's algorithm, Huffman coding, and tree-based structures in modelling, optimizing, and interpreting real-world network scenarios.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to	

	CO1: Construct, classify, and analyze various types of graphs and subgraphs using fundamental graph-theoretic definitions, terminology, and structural properties. **CO2:** Apply graph algorithms and matrix representations to compute degrees, identify connectivity, examine isomorphism, and verify degree sequences using methods such as the Havel–Hakimi theorem. **CO3:** Implement and evaluate shortest-path and spanning-tree algorithms-including Dijkstra's, BFS, DFS, Kruskal's, and Prim's-to solve optimization and network-based problems. **CO4:** Analyze and interpret the properties of trees, cut vertices, cut edges, Eulerian graphs, and Huffman coding to develop efficient solutions for routing, encoding, and network design tasks. .
9	**Modules: -** **Module 1: Practical for Basics of Graphs (30 Hours)**

1.	Classification of Graphs, subgraphs, Degree Analysis and Handshaking Theorem
2.	Walks, Trails, Paths, Circuits, Cycles and Self-complementary graphs,
3.	Connected graphs, Center, eccentricity and distance in a graph
4.	Isomorphism of Graphs, Matrices associated with the graphs
5.	Self-complementary graphs, Connected graphs,
6.	Degree sequence and Havel-Hakimi theorem
7.	Shortest path problems, Dijkstra's algorithm

Module 2: Practical for Trees and Eulerian Graphs (30 Hours)

1.	Definition of a tree and its characterizations,
2.	Cut vertices. Cut edges and its Characterization
3.	Spanning tree and co-tree, Recurrence relation of spanning trees
4.	Cayley formula for spanning trees, Fundamental Circuits and Cut Sets,
5.	Algorithms for spanning tree-BFS and DFS
6.	Binary and m-ary tree, Prefix codes and Huffman coding
7.	Kruskal's and Prim's algorithm for minimal spanning trees
8.	Eulerian graph and its characterization, Fleury's Algorithm

Miscellaneous theoretical questions based on module 1 and 2.

10 **Recommended Reference Books:**

1. R. Balakrishnan, K. Ranganathan, A Text Book of Graph Theory, Springer-Verlag, New York, 2012.
2. J. A. Bondy and U. S. R. Murty, Graph Theory with Applications.
3. D. B. West, Introduction to Graph Theory, Prentice Hall, 2000.
4. Santanu Saha Ray, Graph Theory with Algorithms and its Applications in Applied Science and Technology, Springer 2013

11 **Additional Reference Books**

1. Mehadi Behzad and Gary Chartrand, Introduction to Theory of Graphs.
2. S. A. Choudam, Introductory Graph theory
3. J. Clark and D. A. Holtan, A first look of Graph Theory
4. Gary Chartrand and Ping Zhang, A first course in Graph Theory.

Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

Paper pattern of the Test (Offline Mode):
Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2)

Duration: 1Hrs
While setting question paper four MCQ on module 1 and four MCQ on module 2 both.

14 Format of Question Paper:

Scheme of examination:
At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

Marks for Journals:
For both Module 1 and Module 2
6. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

Vertical – 4

VSC
(2)
(Practical)

Name of the Course: Computational Machine Learning (VSC)

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	In today's world, the most important assets that an organization has are DATA. Lots of data is around us, which contains lots of information. One needs to tap this information and convert it into knowledge, which can be used by organizations to boost their profit and productivity. That is where machine learning is used. Machine learning is a branch of artificial intelligence that trains to computers to learn from the data to perform tasks without human interference. Today, Machine learning is used in image processing, the medical field, data analysis, social media, customer-based recommendations, and almost everywhere. It was found in 2020 in a survey that 67% percent of companies already used machine learning as a tool, and about 97% of the remaining companies are planning to use it. At the core of machine learning lies Mathematics and Statistics. Hence, for the students of Mathematics, this course will open an avenue where they can explore their career. Hence, this course is fit for the students of Mathematics in today's scenario.
2	**Vertical:**	Vocational Skill Course
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** **CO1:** Understand the machine learning, its uses and how it changes day-to-day life. **CO2**: Apply Python programming language tool like Panda to write a simple program, **CO3:** Visualizing the important characteristics of data using graphs and plots drawn in Matplotlib. **CO4**: Analysis of data using tools of descriptive statistics and probability distribution. **CO5:** Interpretation of data using various tests of Hypothesis and techniques of ANOVA. **CO6:** Building Machine learning modules on different datasets using the Gradient Descent algorithm, Scikit-Learn. **CO7:** Developing various means to ascertain the validation of the module created with the above techniques.	
8	**Course Outcomes (OC):** Upon successful completion of the course, students will be able to: • **OC1**: Understand machine learning concepts and how it influences our day-to-day activities. • **OC2:** Highlights key features of data using various techniques of descriptive statistics	

and by plotting the graphs and plots.

- **OC3**: Build a predictive module on various datasets using different tools of Machine learning.

OC4: Validate the module created by them for accuracy and better prediction.

9 **Modules: -**

Module 1: **Machine Learning with Python (30 Lectures)**

1.	Introduction to Machine Learning. a) Introduction to machine learning: i. Machine learning its application with real life examples. ii. Types of machine learning algorithm. iii. Framework for developing machine learning models. b) Use of Python in Machine learning: i. Introduction of Jupyter notebook. ii. Revisiting basic of python, like declaring variables, conditional statement, loop statement. iii. List, tuples, dictionary and function on these. c) Revisiting Pandas: i. Panda DataFrame: creating DataFrame, loading file with different formats onto DataFrame, displaying information from DataFrame. ii. Slicing and indexing of DataFrame, row and column operation on DataFrame. iii. Handling Missing values. d) Exploration of Data using Visualization (Matplotlib): i. Matplotlib and its uses. ii. Drawing different types of charts and its significance (bar chart, histogram). iii. Drawing different types of plot and its significance (Box plot, scatter plot, pair plot, correlation and Heat map)
2.	Statistical Analysis using Python a) Descriptive statistics and Probability Distribution: i. Measure of central tendency and dispersion. ii. Standard Probability distribution: (Binomial, Poisson, Normal, Uniform), random number generation using probability distribution. iii. Confidence interval, cumulative probability distribution. b) Testing of Hypothesis: i. Z-test, One-sample t-test, two sample t-test, paired sample t-test. ii. Chi-square goodness of fit test. iii. Analysis of variance (ANOVA)
3.	Linear Regression a) Sample linear regression: i. Simple linear regression and its application, Assumptions and properties of linear regression model. ii. Steps in building a Regression model. b) Building Simple Linear Regression Model: i. Creating Feature Set (X) and Outcome Variable (Y). ii. Splitting the Dataset into Training and Validation Sets. iii. Fitting the Model. iv. Printing estimated parameters and interpreting them. c) Model Diagnostics: i. Co-efficient of determination (R-squared).

	ii. Hypothesis test for the regression coefficient. iii. ANOVA for overall model validity. iv. Residual analysis to validate the regression model assumptions. v. Outlier analysis.

Module 2: **Techniques in Machine Learning (30 Lectures)**

1.	Classification Problems: a) Examples of classification problems. b) Binary logistic regression using German credit rating dataset: i. Loading and viewing of datasets. ii. Encoding categorical features. iii. Building logistic regression model iv. Printing model summary. v. Model diagnostic vi. Predicting on test data. vii. Confusion matrix. viii. Measuring accuracy.
2.	Advanced Machine learning techniques: **a)** How machine learn. b) Gradient Descent (GD) algorithm. i. Developing a GD algorithm for Linear regression model. ii. Implementation of GD algorithm. iii. Finding the optimal bias and weights.
3.	Scikit-Learn Library: a) Scikit-Learn library and its uses. b) Scikit-Learn using Iris dataset: i. Data representation in Scikit-Learn. ii. Scikit-Learn's Estimator API iii. Supervised learning: Simple linear regression. iv. Supervised learning: Iris classification. v. Unsupervised learning example: Iris dimensionality. vi. Unsupervised learning: Iris clustering. vii. Application: Exploring Handwritten digits,

List of Practical

Module 1: Introduction to Machine Learning.

Practical 1: Demonstration Machine learning, different types of Machine learning algorithm with real life example

Practical 2: Python Revisit: Basic of python, conditional and loop statement, list, tuples and dictionary.

Practical 3 Revisiting Panda: Introduction of Jupyter Notebook, Creation of panda dataframe, loading the file of different format, rows and columns operations.

Practical 4: Matplotlib for Creation of graphs like bar graph, histogram

Practical 5: Matplotlib for plots like Box plot, scatter plot, pair plot, heatmap.

Practical 6: Descriptive statistics with Python, Computation of Measures of central tendency and dispersions.

Practical 7: Computation of standard probability distribution using Python.

Practical 8: Chi-squared test and analysis of variance with Python.

Practical 9: Building of simple regression model.

	Practical 10: Validation of simple regression model. **Module 2 Techniques in Machine Learning:** Practical 1: Demonstration of classification problems with real life examples. Practical 2: Creation of Binary logistic regression for German credit rating dataset. Practical 3: Validation of Binary logistic regression created for German credit rating dataset. Practical 4: Creation of Linear regression model using Gradient Descent (GD) algorithm. Practical 5: Validation of Linear regression model created using GD algorithm. Practical 6: Programs to illustrate the concept of method overriding and use of super keyword. Practical 7: Demonstration of Scikit-Learn library and its uses. Explanation of Iris dataset. Practical 8: Supervised learning examples: Simple linear regression, Iris classification. Practical 9: Unsupervised learning examples: Iris dimensionality and Iris clustering. Practical 10: Illustration of Scikit-Learn module on any other dataset.
10	**Recommended Reference Books:** 1. 1. Module 1(Section 1, 2, 3): Machine learning using Python, Manaranjan Pradhan, U Dinesh Kumar, Wily 2. Module 2(Section 1, 2): Machine learning using Python, Manaranjan Pradhan, U Dinesh Kumar, Wily. 3. Module 2 (Section 3) Python Data Science Handbook: Essential Tools for Working with Data, Jake VanderPlas, O'Reilly, First Edition
11	**Additional Reference Books** 1. Python for Data Analysis: Data Wrangling with Pandas, NumPy and IPython, Wes Mckinney, O'Reilly, Second edition 2. Data Analysis Numpy, Matplotlib and Pandas, Bernd Klein 3. Introduction to Machine Learning with Python A Guide for Data Scientists, Andreas C. Müller and Sarah Guido, O'Reilly, First Edition 4. Practical Machine Learning with Python Dipanjan Sarkar, Raghav Bali and Tushar Sharma Apress Publication
	<u>Scheme of the Examination</u>
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentation, project, role play, creative writing, assignment etc. (at least 3) Mid semester practical examination of 20 marks will be conducted on **covered syllabus (at least 50% of total syllabus)** of one hour duration as per the	

following pattern.

Sr. No.	Title	Marks
1.	Quiz comprising of MCQs (Attempt any 5 out of 8) (Online/Offline)	05
2.	Class Test comprising of Problems/ Programs (Attempt any 2 out of 4)	10
3.	Viva	05

14 **Format of Question Paper:**

The performance of the learners shall be evaluated into two parts.

- Internal Continuous Assessment of 20 marks.
- Semester End Examination of 30 marks.
- Separate head of passing is required for internal, and semester end practical examination.

Semester End Practical Examination (30 marks):

Semester end practical examination of 30 marks **on entire syllabus** will be conducted of three hours duration as per the following pattern.

Sr. No.	Title	Marks
1.	Problems/ Programs (Attempt any 5 out of 8)	25 Marks
2.	Journal	05 Marks

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

Name of the Course: Computational Linear Algebra and Statistics with Scilab (VSC)

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	Computational Linear Algebra and Statistics with Scilab is designed to build industry-ready analytical and computational skills by integrating core mathematical concepts with hands-on programming. The course develops strong competence in matrix computations, system solving techniques, factorizations, eigenvalue methods, and vector-space analysis skills essential in data science, machine learning, scientific computing, and engineering workflows. Learners apply Scilab to perform high-performance numerical operations, automate linear algebra pipelines, and implement algorithms such as Gaussian elimination, LU decomposition, Gauss–Jordan inversion, and Gram-Schmidt orthogonalization. The statistics module equips students with practical tools for real-world data handling, including data collection, descriptive and inferential analytics, graphical visualization, and variability assessment using modern statistical measures. Students gain working knowledge of correlation analysis, regression modeling with least-squares estimation, and foundational probability concepts crucial for risk modelling and decision-making. By the end of the course, participants will be able to integrate linear algebraic modelling with statistical reasoning to solve industry-grade problems, analyze datasets computationally, and build reliable analytical solutions using Scilab.
2	**Vertical:**	Vocational Skill Course
3	**Type:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
4	**Credits:**	2 credits
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course builds computational skills in linear algebra using Scilab for matrix operations,	

	solving linear systems, and analyzing vector spaces and eigenvalues. It enhances practical problem-solving through numerical methods such as Gaussian elimination, LU decomposition, and orthogonalization. Students also develop strong statistical abilities in data analysis, visualization, regression, and probability to interpret and analyze quantitative information effectively. **CO1:** Develop foundational proficiency in Scilab by working with variables, matrices, and basic data structures, enabling students to perform numerical computation and matrix visualization efficiently. **CO2:** Apply matrix operations, inversion techniques, structural characterizations, and matrix factorizations to solve real-world computational problems in engineering, optimization, and data analysis. **CO3:** Analyze and solve systems of linear equations using row reduction, echelon forms, Gaussian elimination, LU decomposition, and Gauss–Jordan inversion, and interpret solution sets through vector and matrix representations. **CO4:** Investigate vector operations, vector norms, rank–nullity relationships, and matrix subspaces; and apply concepts of vector spaces, bases, and linear transformations to model multidimensional data and linear systems. **CO5:** Compute eigenvalues, eigenvectors, and diagonalization; perform orthogonalization using the Gram–Schmidt process; and apply these tools in applications such as dimensionality reduction, stability analysis, and feature extraction. **CO6:** Collect, summarize, and interpret data using descriptive and inferential statistical methods; compute correlations, regression models, and probability measures; and use Scilab to visualize, analyze, and solve statistical problems relevant to industry and research.
8	**Course Outcomes (OC):** Upon successful completion of the course, students will be able to: **CO1:** Apply Scilab programming constructs and matrix operations to evaluate invertibility, perform factorizations, and solve systems of linear equations using computational techniques such as Gaussian elimination, LU decomposition, and Gauss–Jordan methods. **CO2:** Analyze vector spaces, subspaces, rank–nullity relationships, eigenvalues, eigenvectors, diagonalization, and orthogonalization methods to interpret structural and geometric properties of linear transformations. **CO3:** Perform statistical data analysis by generating frequency distributions, computing descriptive measures, visualizing datasets, and applying probability models, correlation, and regression techniques for data-driven interpretation. **CO4:** Design computational solutions for linear algebra and statistical problems by integrating Scilab tools to model datasets, construct graphical outputs, implement recursive computations, and automate data processing workflows.
9	**Modules: -** **Module 1**: **Linear algebra with Scilab (30 Lectures)** 1. Review of Scilab, Variables, assignment and display, Empty matrix, Eye matrix, Coefficient matrix in Scilab, 2. Matrix Operations, Inverse of a Matrix, Characterisations of Invertible Matrices, Partitioned Matrices, Matrix Factorizations 3. Systems of Linear Equations, Row Reduction and Echelon Forms, Vector Equations, Solution Sets of Linear Systems, 4. Applications of Linear Systems, Gaussian elimination, LU decomposition of a matrix, Gauss - Jordan method of calculating the inverse of a matrix 5. Define vectors and their operations, norm of vector, Finding Rank, nullity, Row

space, Column Space of a Matrix, diagonalizable matrix,

6. Vector Spaces and Subspaces, Null Spaces, Column Spaces, and Linear Transformations, Linearly Independent Sets, Bases,
7. Eigenvectors and Eigenvalues, Characteristic Equation and Diagonalization, Gram-Schmidt Orthogonalization

Module 2: Descriptive Statistics with Scilab (30 Hours)

1. Introduction, Data Collection and Descriptive Statistics, Inferential Statistics and Probability Models, Populations and Samples
2. Describing Data Sets, Frequency Tables and Graphs, Relative Frequency Tables and Graphs, Grouped Data, Plotting charts/graphs
3. Summarizing Data Sets, Sample Mean, Sample Median, and Sample Mode, Sample Variance and Sample Standard Deviation, Sample Percentiles and Box Plots,
4. Chebyshev's Inequality, Paired Data Sets and the Sample Correlation Coefficient
5. Regression equation, least squares estimators of the Regression parameters
6. Elementary probability, Sample Space and Events, Venn Diagrams and the Algebra of Events, Axioms of Probability, Sample Spaces Having Equally Likely Outcomes, Conditional Probability, Independent events

List of Practical

	Module 1: Linear algebra with Scilab (30 Lectures)
1	Matrices, and Special Matrices (Empty, Eye, Coefficient Matrices), Performing Basic and Advanced Matrix Operations in Scilab
2	Computing Matrix Inverses, Partitioned Matrices and Implementing Basic Matrix Factorizations using Scilab.
3	Solving Linear Systems: Row Reduction, Echelon Forms, and Vector Equation Interpretation in Scilab.
4	Determining Solution Sets of Linear Systems, analyzing Consistency and Gaussian Elimination using Scilab.
5	Gauss–Jordan Methods to Compute Matrix Inverse and implementing LU Decomposition using scilab
6	Vector Operations in Scilab, Computing Rank, Nullity, Row Space, and Column Space of Matrices in Scilab.
7	Analyzing Vector Spaces and Subspaces: Basis, Linear Independence, and Dimension using Scilab.
8	Finding Eigenvalues and Eigenvectors and Solving Characteristic Equations with Scilab.
9	Matrix Diagonalization: Testing Diagonalizability and Constructing Similarity Transformations.
10	Implementing the Gram–Schmidt Orthogonalization Process and Constructing Orthonormal Bases in Scilab.
	Module 2: Descriptive Statistics with Scilab (30 Hours)
1	Data Import and Organization in Scilab: Creating Data Sets and Identifying Populations and Samples
2	Construction of Frequency Tables, Relative Frequency Tables, and Grouped Data Using Scilab
3	Plotting Histograms, Bar Charts, Pie Charts, and Frequency Polygons in Scilab

	4	Computation of Descriptive Measures: Mean, Median, Mode, Variance, and Standard Deviation in Scilab
	5	Calculation of Percentiles, Quartiles, Interquartile Range, and Box Plots in Scilab
	6	Verification of Chebyshev's Inequality Using Real or Simulated Data in Scilab
	7	Analysis of Paired Data Sets: Computing Covariance and Sample Correlation Coefficient in Scilab
	8	Fitting a Simple Linear Regression Model and Computing Least Squares Estimates in Scilab
	9	Simulation of Random Experiments: Sample Space, Events, and Venn Diagram Interpretation in Scilab
	10	Probability Computations Using Axioms, Equally Likely Outcomes and Conditional Probability in Scilab

10	**Recommended Reference Books:** 1. Linear Algebra and Its Applications David C. Lay, Steven R. Lay and Judi J. McDonald 3rd Edition, Pearson 2. Scilab Textbook Companion for Linear Algebra and Its Applications by D. C. Lay 3. Introduction to Probability and Statistics for Engineers and Scientists 3rd Ed, Sheldon M. Ross, Elsevier Academic Press 4. Scilab Textbook Companion for Probability and Statistics for Engineers and Scientists by Sheldon. M. Ross
11	**Additional Reference Books** 1. Stephen L. Campbell, Jean-Philippe Chancelier and Ramine Nikoukhah: Modeling and Simulation in Scilab/Scicos. Springer USA, 2006. 2. Sandeep Nagar, Introduction to Scilab: For Engineers and Scientists. Apress publisher, New York, USA, 2017. 3. A.S.Nair, SCILAB (A free software to MATLAB), S. Chand Publishing, New Delhi, India, 2012. 4. Scilab for beginners. - www.scilab-enterprises.com
	Scheme of the Examination
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.

11	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
12	**Continuous Evaluation through:** Quizzes, Class Tests, presentation, project, role play, creative writing, assignment etc. (at least 3) Mid semester practical examination of 20 marks will be conducted on **covered syllabus (at least 50% of total syllabus)**	

of one hour duration as per the following pattern.

Sr. No.	Title	Marks
1.	Quiz comprising of MCQs (Attempt any 5 out of 8) (Online/Offline)	05
2.	Class Test comprising of Problems/ Programs (Attempt any 2 out of 4)	10
3.	Viva	05

13 **Format of Question Paper:**

The performance of the learners shall be evaluated into two parts.

- Internal Continuous Assessment of 20 marks.
- Semester End Examination of 30 marks.
- Separate head of passing is required for internal, and semester end practical examination.

Semester End Practical Examination (30 marks):
Semester end practical examination of 30 marks **on entire syllabus** will be conducted of three hours duration as per the following pattern.

Sr. No.	Title	Marks
1.	Problems/ Programs (Attempt any 5 out of 8)	25 Marks
2.	Journal	05 Marks

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

Sem. – VI

Sem. - VI

Vertical – 1 Major Mandatory (2+2+2+2+2+2+2)

Syllabus
B.A./ B.Sc. (Mathematics)
(Sem.- VI)
Name of the Course: Basic Complex Analysis

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course offers a concise yet comprehensive introduction to Complex Analysis, covering the fundamentals of complex numbers, analytic functions, and harmonic functions. Students will learn key techniques of complex integration, including Cauchy's theorem and integral formula, and explore power series, Taylor and Laurent expansions, and classification of singularities. The course also introduces Mobius transformations and the residue theorem, providing essential tools for understanding and evaluating complex functions and integrals.
2	**Vertical:**	Major
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides an introduction to complex analysis with a strong emphasis on rigor. It aims to prepare students for more advanced courses in complex analysis. The focus of the course is on developing formal proof skills, which not only deepens comprehension of the subject but also extends to broader applications in mathematics. **CO1:** Provide a solid understanding of fundamental principles and methods, equipping students with the skills to apply mathematical ideas and tools through modeling, solving, and interpretation. **CO2**: Illustrate the expansive nature of the subject by fostering the acquisition of essential mathematical tools for continued studies across various scientific fields. **CO3**: Foster students' comprehensive development by placing emphasis on problem-solving skills, nurturing creative talents, and enhancing communication abilities, all of which are vital for a range of employment opportunities. **CO4**: Ensure exposure to both global and local issues within the realm of Mathematical Sciences, allowing learners to explore diverse aspects of the discipline.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Understand and remember the fundamental concepts of complex analysis, including complex numbers, the complex plane, polar coordinates, and basic properties of analytic functions, such as Cauchy-Riemann equations and Mobius transformations. **OC2**: Apply the principles of complex integration, including evaluating line integrals along	

	various paths, using Cauchy's theorem and Cauchy's integral formula, and expanding functions into Taylor and Laurent series with appropriate radius and disc of convergence. **OC3**: Analyze the properties and behavior of analytic functions, including their harmonic properties, singularities, and residues, and investigate their application to complex power series and singularity classification (removable, pole, or essential singularities). **OC4**: Justify/ check the validity of statements regarding analytic functions, continuity, and differentiability in the complex domain using the Cauchy-Riemann equations. **OC5:** Construct counter examples to demonstrate the failure of various properties in complex analysis, such as showing the non-analytic nature of a function at a given point, or constructing examples where power series do not converge within a certain radius, or Laurent series expansion fails to exist at an isolated singularity.
9	**Modules: -** **Module 1**: **Introduction to Complex Analysis (15 Lectures)**
	Review of complex numbers: Complex plane, polar coordinates, exponential map, powers and roots of complex numbers, De Moivre's formula, $\mathbb{C}$ as a metric space (No questions to be asked), bounded and unbounded sets, point at infinity-extended complex plane, sketching of set in complex plane. (a) Convergence of sequences of complex numbers and related results, Limit of a function $f : \mathbb{C} \to \mathbb{C}$, real and imaginary part of functions, continuity at a point and algebra of continuous functions. (b) Derivative of $f : \mathbb{C} \to \mathbb{C}$, comparison between differentiability in real and complex sense, Cauchy-Riemann equations, sufficient conditions for differentiability, analytic function, algebra of analytic functions (without proof), chain rule, basic results of analytic functions like, if f(z) = 0 everywhere in a domain D, then f(z) must be constant throughout D. (c) Harmonic functions and harmonic conjugate. (d) Mobius transformations: definition and examples. (e) Exponential function, its properties. trigonometric functions and hyperbolic functions.
	Module 2: Complex Integration, Complex Power Series and Laurent's Series (15 Lectures)
	(a) Evaluation the line integral $\int f(z)dz$ over a line segment, parabolic and circular path, Cauchy' theorem, Cauchy integral formula and its extension and related examples. (b) Taylor's theorem for analytic function and examples. (c) Power series of complex numbers and related results. Radius of convergences, disc of convergence, uniqueness of series representation, examples. (d) Definition of Laurent series, Definition of isolated singularity, statement (without proof) of existence of Laurent series expansion in neighbourhood of an isolated singularity, type of isolated singularities viz. removable, pole and essential defined using Laurent series expansion, examples. (e) Statement of Residue theorem and calculation of residue. (f) Evaluation of integrals using residue theorem.
10	**Recommended Reference Books:** 1. J.W. Brown and R.V. Churchill, Complex analysis and Applications: Sections 18, 19, 20, 21, 23, 24, 25, 28, 33, 34, 47, 48, 53, 54, 55, Chapter 5, page 231 section 65, define residue

	of a function at a pole using Theorem in section 66 page 234, Statement of Cauchy's residue theorem on page 225, section 71 and 72 from chapter 7.
11	**Additional Reference Books** 1. Robert E. Greene and Steven G. Krantz, Function theory of one complex variable. 2. T.W. Gamelin, Complex analysis.
	Scheme of the Examination
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each semester in an Offline mode.	10
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification. (04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2×3)

14 **Format of Question Paper:**

The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.

Q.No.1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q.No.2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q.No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: Ring Theory

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	The course delves into the principles of ring theory, encompassing integral domains, fields, and ideals. It emphasizes the significance of fundamental concepts such as units, quotient rings, and factorization, exploring their applications in various mathematical contexts. Through the study of ring homomorphisms and isomorphisms, students gain insights into the structural properties of rings. Concrete examples and problem-solving exercises facilitate the application of abstract theories to real-world scenarios. The course aims to promote analytical thinking, problem-solving abilities, and a deeper understanding of abstract algebraic structures.
2	**Vertical:**	Major
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** The course covers fundamental concepts in ring theory, including integral domains, fields, and ideals, along with their properties and applications. It explores the structure of rings through units, quotient rings, and factorization. It further offers deep understanding of ring homomorphisms, isomorphisms, and their implications. Through concrete examples, students learn to classify rings and solve problems related to factorization. The course aims to develop analytical and problem-solving skills, deepen theoretical understanding, and foster critical thinking in the context of abstract algebraic structures. **CO1:** Understand fundamental concepts of rings, including integral domains and fields. **CO2**: Explore ideals, quotient rings, prime ideals, maximal ideals and their interrelations in the context of commutative rings. **CO3**: Develop proficiency in the ring homomorphisms, isomorphisms, and factorization in rings. **CO4**: Apply abstract concepts to concrete examples, such as polynomial rings and specific integral domains, and various factorization properties in determining the structure of rings.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1**: explain rings, integral domains, fields, ideals, quotient rings, homomorphisms, isomorphisms, and their basic properties **OC2**: identify subrings, units, ideals, prime ideals, maximal ideals and compute the	

characteristic of a ring

OC3: form sums/products of ideals, and characterize and identify prime and maximal ideals via their quotient rings.

OC4: compute kernels and images of homomorphism, apply the isomorphism theorems and contrast between Euclidean domains, principal ideal domains, and unique factorization domains with examples

OC5: apply division algorithm, analyze divisibility, irreducible, prime elements, use of Eisenstein's criterion and construct quotient rings and counter-examples of Euclidean domains, principal ideal domains, and unique factorization domains

9 **Modules: -**

Module 1: Rings and Ideals (15 Lectures)

1) Definition and elementary properties of rings (where the definition should include the existence of unity), commutative rings, integral domains and fields. Examples including $\mathbb{Z}, \mathbb{Q}, \mathbb{R}, \mathbb{Z}/n\mathbb{Z}, \mathbb{C}$, $M_n(\mathbb{R})$, $\mathbb{Z}[i], \mathbb{Z}[\sqrt{2}], \mathbb{Z}[\sqrt{-5}], \mathbb{Z}[X], \mathbb{R}[X], \mathbb{C}[X], (\mathbb{Z}/n\mathbb{Z})[X]$. Subring of a ring.

2) Description of the units in various rings. Results such as: Field is an integral domain, A finite integral domain is a field. $\mathbb{Z}/p\mathbb{Z}$, where p is a prime, as an example of a finite field. Characteristic of a ring. Examples. Elementary facts such as: the characteristic of an integral domain is either 0 or a prime number.

3) Ideals in a ring. Sums and products of ideals. Quotient rings. Examples. Prime ideals and maximal ideals. Characterization of prime ideals and maximal ideals in a commutative ring in terms of their quotient rings. Prime and maximal ideals in various rings.

Module 2: Isomorphism and Factorization (15 Lectures)

1) Homomorphisms and isomorphism of rings. Kernel and the image of a homomorphism. Fundamental Theorem of homomorphism of a ring. Second and third isomorphism Theorem of rings (without proof)

Notions of Euclidean domain (ED), principal ideal domain (PID). Examples such as $\mathbb{Z}$, $\mathbb{Z}[i]$ and polynomial rings. Relation between these two notions (ED ⇒ PID).

2) Divisibility in a ring. Irreducible and prime elements. Examples.

Division algorithm in $F[X]$ (where F is a field). Monic polynomials, greatest common divisor of $f(x), g(x) \in F[X]$ (not both 0) (Examples only). Relatively prime polynomials in $F[X]$, irreducible polynomial in $F[X]$. Examples of irreducible polynomials in $(\mathbb{Z}/p\mathbb{Z})[X]$ (p prime), Eisenstein Criterion (without proof).

3) Notion of unique factorization domain (UFD). Elementary properties. Norm function on $\mathbb{Z}[\sqrt{d}]$ where ▯ is not divisible by the square of a prime and its properties,

Results (without proof):

(i) $\mathbb{Z}[\sqrt{-5}]$ is not a UFD

<table>
<tr><td></td><td>(ii) Every PID is UFD
(iii) $\mathbb{Z}[X]$ is UFD but not a PID
(iv) If R is a UFD then R[X] is UFD</td></tr>
<tr><td>10</td><td>Recommended Reference Books:
1. P. B. Bhattacharya, S. K. Jain, and S. R. Nagpaul; Basic Abstract Algebra; Second edition, Foundation Books, New Delhi, 1995.
2. John. B. Fraleigh; A First course in Abstract Algebra; Third edition, Narosa, New Delhi, 1996.
3. Joseph A. Gallian; Contemporary Abstract Algebra; Narosa, New Delhi, 2008.
4 Israel Herstein; Topics in Algebra; Second edition, Wiley Eastern Limited, Second edition, 2006.
5. N. S. Gopalakrishnan; University Algebra; Wiley Eastern Limited, 2018.
6. Michael Artin; Algebra; Prentice Hall of India, New Delhi, 2010.</td></tr>
<tr><td>11</td><td>Additional Reference Books
1. Sukumar Das Adhikari; An Introduction to Commutative Algebra and Number theory; Narosa Publishing House, 2001.
2. Thomas W. Hungerford; Algebra; Springer, 2003.
3. David S. Dummit, Richard Foote; Abstract Algebra; John Wiley & Sons, Inc., 2003.
4. L.S. Luthar and I.B.S. Passi, Algebra. Vol. II, Narosa, 1999.
5. U. M. Swamy, A. V. S. N. Murthy; Algebra Abstract and Modern; Pearson, 2011.
6. Charles Lanski; Concepts Abstract Algebra; American Mathematical Society, 2010.
7. M. K. Sen Shamik Ghosh Parthasarathi Mukhopadhyay; Topics in Abstract Algebra; Universities press, 2022.</td></tr>
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</table>

2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).
Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14 Format of Question Paper:

The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.			
Q.No.1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q.No.2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q.No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: Topology of Metric Spaces-II

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course introduces the fundamental topological concepts of Compactness and Connectedness in metric spaces. Students will explore compact metric spaces through the notion of open covers and examine significant equivalent characterizations such as the Heine–Borel theorem and the Bolzano–Weierstrass property. The course also develops a deep understanding of connected and path-connected spaces, including various separation concepts and relationships between connectedness and continuity. Emphasis is placed on rigorous proofs, illustrative examples from real and Euclidean spaces, and applications in continuous functions and analysis.
2	**Vertical:**	Major
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** **CO1:** To introduce students to the core concepts of compactness in metric spaces by studying open covers, equivalent characterizations, and classical results such as the Heine–Borel and Bolzano–Weierstrass properties. **CO2**: To develop the ability to analyze and prove fundamental properties of compact sets, including closedness, boundedness, and behavior under continuous mappings, with emphasis on theory and applications. **CO3**: To develop a clear and rigorous understanding of connected and path-connected spaces through separation concepts, characterization theorems, and the relationship between connectedness and continuity. **CO4**: To build problem-solving skills through the identification of compact, connected, and path-connected sets; construction of illustrative examples and counterexamples.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** recall and explain compact sets, connected sets, path-connected sets, and identify their examples in various metric spaces. **OC2:** apply properties of compact sets and their equivalent characterizations, such as Heine–Borel and Bolzano–Weierstrass, in real metric spaces. **OC3:** examine connectedness and path connectedness in certain metric spaces through its properties and characterizations **OC4:** analyze path-connectedness and evaluate its relationship with connectedness in different metric spaces.	

	OC5: determine connected components of metric spaces and construct examples illustrating differences between connectedness, path-connectedness, and counterexamples to compactness.
9	**Modules: -** **Module 1**: **Compactness (15 Lectures)**
	(1) Definition of a compact metric space using open cover. Examples of compact sets in different metric spaces such as $\mathbb{R}, \mathbb{R}^2, \mathbb{R}^n$ with Euclidean metric. (2) Properties of compact sets: A compact set is closed and bounded, (Converse is not true). A closed subset of a compact set is compact. Union and Intersection of Compact sets. (3) Equivalent characterizations of compactness in $\mathbb{R}$ with usual metric: (i) Sequentially compactness property. (ii) Heine-Borel property. (iii) Closed and boundedness property. (iv) Bolzano-Weierstrass property. (4) Results such as: Continuous image of compact set is compact, every continuous function from a compact metric space is uniformly continuous.
	Module 2: **Connected & Path-Connected Spaces (15 Lectures)**
	(1) Separated sets- Definition and examples. Connected and disconnected sets. Connected and disconnected metric spaces. (2) Results such as: A subset of $\mathbb{R}$ is connected if and only if it is an interval. A continuous image of a connected set is connected. (3) Characterization of a connected space, viz. a metric space is connected if and only if every continuous function from X to $\{1, -1\}$ is a constant function. (4) Path connectedness in $\mathbb{R}^n$, definition and examples. (5) Properties: A path connected subset of $\mathbb{R}^n$ is connected, convex sets are path connected. Connected components. An example of a connected subset of $\mathbb{R}^n$ which is not path connected.
10	**Recommended Reference Books:** 1. R. R. Goldberg, Methods of Real Analysis, Oxford & IBH Publishing, New Delhi. 2. S. Kumaresan, Topology of Metric Spaces. 3. E. T. Copson, Metric Spaces, Universal Book Stall, New Delhi, 1996. 4. Robert Bartle & Donald R. Sherbert, Introduction to Real Analysis, 2nd Edition, John Wiley & Sons.
11	**Additional Reference Books** 1. Walter Rudin, Principles of Mathematical Analysis. 2. T. M. Apostol, Mathematical Analysis, 2nd Edition, Narosa Publishing, New Delhi, 1974. 3. E. T. Copson, Metric Spaces, Universal Book Stall, New Delhi, 1996. 4. P. K. Jain & Khalil Ahmad, Metric Spaces, Narosa Publishing, New Delhi, 1996. 5. Walter Rudin, Principles of Mathematical Analysis, 3rd Edition, McGraw–Hill, Auckland, 1976. 6. D. Somasundaram & B. Choudhary, A First Course in Mathematical Analysis, Narosa Publishing, New Delhi. 7. George F. Simmons, Introduction to Topology and Modern Analysis, McGraw–Hill, New York, 1963. 8. W. A. Sutherland, Introduction to Metric and Topological Spaces.

Scheme of the Examination

The performance of the learners shall be evaluated in two parts.

- Internal Continuous Assessment of 20 marks.
- Semester End Examination of 30 marks.
- A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**

13 **Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc.
(at least 3)

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each semester in an Offline mode.	10
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14 **Format of Question Paper:**

The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.			
Q.No.1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q.No.2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2	15 Marks

		(c) Question based on OC3 (d) Question based on OC4/OC5		
Q.No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks	

Name of the Course: Advanced Real Analysis

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course offers a rigorous study of sequences and series of real-valued functions with emphasis on pointwise and uniform convergence and their influence on continuity, integration, and differentiation. Students learn to recognize when limits of functions preserve key analytical properties and when they fail to do so, using proofs and counterexamples. The course further examines power series, including radius and interval of convergence, term-by-term operations, uniqueness of representation, and the power-series expansions of classical functions such as the exponential, sine, and cosine. Throughout the course, analytical maturity is strengthened through conceptual understanding as well as computational techniques relevant to modern applications.
2	**Vertical:**	Major
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** **CO1:** To introduce students to sequences and series of real-valued functions and develop the concepts of pointwise and uniform convergence through examples and counterexamples. **CO2**: To enable students to analyze how uniform convergence influences continuity, integration, and differentiation of functions. **CO3**: To develop a strong understanding of power series, including radius and interval of convergence, and the analytical behavior of power series on compact subsets. **CO4**: To build problem-solving skills through term-by-term operations on power series and through studying classical functions defined by power series.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1**: define and distinguish pointwise convergence and uniform convergence of sequences and series of functions using suitable examples. **OC2**: apply criteria for convergence of series of functions and verify uniform convergence using results such as the Weierstrass M-test. **OC3**: examine how uniform convergence affects continuity, differentiation, and integration of the limit function on closed and bounded intervals. **OC4:** determine the radius and interval of convergence of power series and analyze convergence on compact subsets. **OC5:** represent classical functions using power series and perform term-by-term	

	differentiation and integration of power series.
9	**Modules: -** **Module 1**: **Sequences and Series of Functions (15 Lectures)**
	(1) Sequence of real-valued functions: definition and examples. Pointwise convergence of a sequence of functions: definition and examples. Uniform convergence of a sequence of functions: definition, examples. (2) Relation between types of convergence: Uniform convergence implies pointwise convergence. Example to show that the converse does not hold. (3) Series of functions: definition and examples. Convergence of series of functions. Weierstrass M-test (statement only) and illustrative examples. (4) Properties of uniform convergence: Continuity of the uniform limit of a sequence of continuous functions. Statement of conditions under which integration and differentiation of a sequence of functions converge to the integral and derivative of the uniform limit on a closed and bounded interval. (5) Consequences of these properties for series of functions: term-by-term integration and term-by-term differentiation (statements only).
	Module 2: **Power Series and Applications (15 Lectures)**
	(1) Power series in $\mathbb{R}$: definition of power series centered at the origin and at a point $a \in \mathbb{R}$. Radius of convergence and region (interval) of convergence, with examples. (2) Uniform convergence of power series on compact subsets of the interval of convergence and examples. (3) Term-by-term differentiation and integration of power series (statements only), with examples. (4) Uniqueness of power series representation. Functions represented by power series and illustrative examples. (5) Classical functions defined by power series: exponential, cosine, and sine functions. Basic properties of the above functions obtained through their power series expansions.
10	**Recommended Reference Books:** 1. R. R. Goldberg, Methods of Real Analysis, Oxford & IBH Publishing, New Delhi. 2. S. Kumaresan, Topology of Metric Spaces. 3. E. T. Copson, Metric Spaces, Universal Book Stall, New Delhi, 1996. 4. Robert Bartle & Donald R. Sherbert, Introduction to Real Analysis, 2nd Edition, John Wiley & Sons. 5. Ghorpade, Sudhir R., & Limaye, Balmohan V. (2018). *A Course in Calculus and Real Analysis*. Springer
11	**Additional Reference Books** 1. Walter Rudin, Principles of Mathematical Analysis. 2. T. M. Apostol, Mathematical Analysis, 2nd Edition, Narosa Publishing, New Delhi, 1974. 3. E. T. Copson, Metric Spaces, Universal Book Stall, New Delhi, 1996. 4. P. K. Jain & Khalil Ahmad, Metric Spaces, Narosa Publishing, New Delhi, 1996. 5. Walter Rudin, Principles of Mathematical Analysis, 3rd Edition, McGraw–Hill, Auckland, 1976.

6. D. Somasundaram & B. Choudhary, A First Course in Mathematical Analysis, Narosa Publishing, New Delhi.
7. George F. Simmons, Introduction to Topology and Modern Analysis, McGraw–Hill, New York, 1963.
8. W. A. Sutherland, Introduction to Metric and Topological Spaces.

<u>Scheme of the Examination</u>

The performance of the learners shall be evaluated in two parts.

- Internal Continuous Assessment of 20 marks.
- Semester End Examination of 30 marks.
- A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**

13 **Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc.
(at least 3)

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each semester in an Offline mode.	10
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14 **Format of Question Paper:**

The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.			
Q.No.1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2	15 Marks

		(c) Question based on OC3 (d) Question based on OC4/OC5	
Q.No.2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q.No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: 6P1 (Based on Basic Complex Analysis)

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	Problem-solving is a fundamental aspect of any Mathematics course. While advanced courses often emphasize the theoretical nature of the subject, engaging in problem-solving reinforces concepts and enhances learners' ability to analyze existing problems and devise solutions. This activity not only motivates learners but also empowers them to formulate new results, propose conjectures, and develop innovative theories.
2	**Vertical:**	Major
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course emphases on problem solving and motivates to think on the basic concepts of Complex Analysis with rigour and prepares students to study further courses. **CO1.** To give sufficient knowledge of fundamental principles, methods and a clear perception of numerous powers of mathematical ideas and tools and the skills to use them by modelling, solving and interpreting. **CO2.** To reflect the broad nature of the subject and develop mathematical tools for continuing further study in various fields of sciences. **CO3.** To enhance students' overall development, problem solving skills, creative talent, and power of communication. These are necessary for various kinds of employment. **CO4.** To give adequate exposure to global and local concerns that would help learners explore many aspects of Mathematical Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Apply basic concepts of complex numbers and functions to solve problems and sketch sets in the complex plane. **OC2:** Analyze convergence, continuity, and differentiability of complex functions using standard criteria. **OC3:** Justify/Check analyticity, harmonicity, and functional properties using appropriate conditions. **OC4:** Construct analytic functions, harmonic conjugates, and Möbius transformations.	
9	**Modules: -** **Module 1: Practical for Introduction to Complex Analysis (30 Hours)**	

1.	Limits and Continuity of Functions of Complex Variables
2.	Derivatives of Functions of Complex Variables
3.	Analytic Functions
4.	Harmonic Function and Harmonic Conjugate
5.	Complex Mapping
6.	Mobius Transformation
7.	Exponential Function and Its Properties

8.	Trigonometric and Hyperbolic Functions

Module 2: Practical for Complex Integration, Complex Power Series and Laurent's Series (30 Hours)

1.	Complex Integration
2.	Cauchy's Theorem
3.	Complex Power Series
4.	Laurent's Series
5.	Singularities
6.	Calculation of Residue
7.	Cauchy's Residue Theorem
	Miscellaneous Theory Questions based on both modules.

10 Recommended Reference Books:

1. J.W. Brown and R.V. Churchill, Complex analysis and Applications.

11 Additional Reference Books

1. Robert E. Greene and Steven G. Krantz, Function theory of one complex variable.
2. T.W. Gamelin, Complex analysis.

Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**

13 Continuous Evaluation through:

Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc.
(at least 3)

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

Paper pattern of the Test (Offline Mode):

Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2)

Duration: 1Hrs

While setting question paper four MCQ on module 1 and four MCQ on module 2 both.

14	**Format of Question Paper:**

Scheme of examination:

At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

Marks for Journals:

For both Module 1 and Module 2

1. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

Name of the Course: 6P2 (Based on Ring Theory)

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	Problem-solving is a fundamental aspect of any Mathematics course. While advanced courses often emphasize the theoretical nature of the subject, engaging in problem-solving reinforces concepts and enhances learners' ability to analyze existing problems and devise solutions. This activity not only motivates learners but also empowers them to formulate new results, propose conjectures, and develop innovative theories.
2	**Vertical:**	Major
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course emphases on problem solving and motivates to think on the basic concepts of Algebra with rigour and prepares students to study further courses. **CO1.** To give sufficient knowledge of fundamental principles, methods and a clear perception of numerous powers of mathematical ideas and tools and the skills to use them by modelling, solving and interpreting. **CO2.** To reflect the broad nature of the subject and develop mathematical tools for continuing further study in various fields of sciences. **CO3.** To enhance students' overall development, problem solving skills, creative talent, and power of communication. These are necessary for various kinds of employment. **CO4.** To give adequate exposure to global and local concerns that would help learners explore many aspects of Mathematical Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Apply fundamental concepts of rings, fields, and their examples. **OC2:** Analyze algebraic properties of rings and fields, including substructures and homomorphisms. **OC3:** Justify/Check properties of ideals, quotient rings, and field extensions. **OC4:** Construct examples of rings, fields, ideals, and ring/field homomorphisms.	
9	**Modules: -** **Module 1: Practical for Rings and Ideals (30 Hours)**	

1.	Introduction to Rings and Fundamental Properties of Rings
2.	Subrings of a ring and Integral Domains
3.	Units and Finite Fields
4.	Characteristic of Rings
5.	Ideals of a ring, Quotient Rings and Ideal generated by set of elements
6.	Prime Ideals
7.	Maximal Ideals

	Module 2: Practical for Isomorphism and Factorization (30 Hours)

1.	Homomorphism of rings, Kernel and Image under ring homomorphism
2.	Isomorphism of Rings
3.	Divisibility of Elements in a Ring, Irreducible & Prime Elements
4.	Division algorithm in F[X] and GCD of polynomials
5.	Irreducible polynomials and Eisenstein Criterion for irreducibility
6.	Euclidean Domains
7.	Principal Ideal Domains
8.	Unique Factorization Domains
	Miscellaneous Theory Questions based on both modules.

10 Recommended Reference Books:

1. J. Gallian. Contemporary Abstract Algebra. Narosa, New Delhi, 2008.
2. P. B. Bhattacharya, S. K. Jain, S. Nagpaul. Basic Abstract Algebra, Second edition, Foundation Books, New Delhi, 1995.
3. J. B. Fraleigh, A first course in Abstract Algebra, Third edition, Narosa, New Delhi, 1996.
4. I. N. Herstein, Topics in Algebra, Wiley Eastern Limied, Second edition, 2006
5. N. S. Gopalkrishnan, University Algebra, New Age International Private Limited, 2018.

11 Additional Reference Books

1. M. Artin, Algebra, Prentice Hall of India, New Delhi, Second Edition, 2010.
2. T. W. Hungerford. Algebra, Springer, 2003.
3. D. Dummit, R. Foote. Abstract Algebra, John Wiley & Sons, Inc., Third Edition, 2003.
4. I. S. Luther, I.B.S. Passi. Algebra. Vol. I., 1997.

Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

Paper pattern of the Test (Offline Mode):

Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5×2)

	Duration: 1Hrs **While setting question paper four MCQ on module 1 and four MCQ on module 2 both.**	
14	**Format of Question Paper:**	

Scheme of examination:

At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

Marks for Journals:

For both Module 1 and Module 2

2. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

Name of the Course: 6P3 (Based on Topology of Metric Spaces- II and Advanced Real Analysis)

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	Problem-solving is a fundamental aspect of any Mathematics course. While advanced courses often emphasize the theoretical nature of the subject, engaging in problem-solving reinforces concepts and enhances learners' ability to analyze existing problems and devise solutions. This activity not only motivates learners but also empowers them to formulate new results, propose conjectures, and develop innovative theories.
2	**Vertical:**	Major
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course emphases on problem solving and motivates to think on the basic concepts of Metric Spaces and Analysis with rigour and prepares students to study further courses. **CO1.** To give sufficient knowledge of fundamental principles, methods and a clear perception of numerous powers of mathematical ideas and tools and the skills to use them by modelling, solving and interpreting. **CO2.** To reflect the broad nature of the subject and develop mathematical tools for continuing further study in various fields of sciences. **CO3.** To enhance students' overall development, problem solving skills, creative talent, and power of communication. These are necessary for various kinds of employment. **CO4.** To give adequate exposure to global and local concerns that would help learners explore many aspects of Mathematical Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **CO1:** Apply concepts of compactness, connectedness, and path connectedness in metric spaces, along with techniques involving sequences, series, and power series of functions, to solve theoretical and computational problems. **CO2:** Analyze the behavior of sequences and series of functions using convergence tests and topological properties such as compactness and connectedness in metric spaces. **CO3:** Justify / Check the validity of convergence, continuity, and topological properties by verifying necessary and sufficient conditions through rigorous mathematical arguments and examples. **CO4:** Construct examples and counterexamples of metric spaces, compact and connected sets, and sequences or power series of functions illustrating various convergence and topological phenomena.	
9	**Modules: -** **Module 1: Practical for Topology of Metric Spaces - II (30 Hours)**	

1.	Compact Sets in $\mathbb{R}$, $\mathbb{R}^2$, $\mathbb{R}^n$
2.	Properties of compact sets
3.	Equivalent Characterizations of Compactness in $\mathbb{R}$
4.	Compactness and Continuity
5.	Separated, Connected and Disconnected Sets
6.	Connected Sets in $\mathbb{R}$ and Continuous Images
7.	Functional Characterization of Connectedness
8.	Path Connectedness in $\mathbb{R}^n$ and Related Properties

Module 2: Practical for Advanced Real Analysis (30 Hours)

1.	Pointwise and Uniform convergence of a sequence of functions
2.	Pointwise and Uniform convergence of a series of functions, Weierstrass M-test
3.	Continuity, differentiation, and integration of sequences and series of functions
4.	Continuity, differentiation, and integration of series of functions
5.	Radius of convergence and interval of convergence of power series
6.	Differentiation and integration of power series
7.	Properties of exponential, sine and cosine functions through power series
	Miscellaneous Theory Questions based on both modules.

10 Recommended Reference Books:

1. S. Kumaresan; Topology of Metric spaces, Narosa Publication.
2. E. T. Copson; Metric Spaces; Universal Book Stall, New Delhi, 1996.
3. R. D. Bhatt; Intermediate Mathematical Analysis, Narosa Publication.
4. P. K. Jain, K. Ahmed; Metric Spaces; Narosa, New Delhi, 1996.
5. R. R. Goldberg; Methods of Real Analysis; Oxford and IBH Pub. Co., New Delhi 1970.
6. Robert Bartle and Donald R. Sherbert, Introduction to Real Analysis, Second Edition, John Wiley, and Sons.
7. Ajit Kumar, S. Kumaresan, Introduction to Real Analysis.
8. T. Apostol. Mathematical Analysis, Second edition, Narosa, New Delhi, 1974.
9. Pugh, C. C. (2015). *Real mathematical analysis* (3rd ed.). Springer
10. Ghorpade, Sudhir R., & Limaye, Balmohan V. (2018). *A Course in Calculus and Real Analysis*. Springer.

11 Additional Reference Books

1. Robert E. Greene and Steven G. Krantz, Function theory of one complex variable.
2. T.W. Gamelin, Complex analysis.
3. G. F. Simmons; Introduction to Topology and Modern Analysis; McGraw-Hi, New York, 1963.
4. D. Somasundaram; B. Choudhary; A first Course in Mathematical Analysis. Narosa, New Delhi.
5. Expository articles of MTTS programme.
6. W. Rudin, Principles of Mathematical Analysis; Third Ed, McGraw-Hill, Auckland,

1976.
7. W. Rudin, Principles of Mathematical Analysis.
8. D. Somasundaram, B. Choudhary. A first Course in Mathematical Analysis. Narosa, New Delhi.
9. Abbott, S. (2015). *Understanding analysis* (2nd ed.). Springer.

<u>Scheme of the Examination</u>

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

Paper pattern of the Test (Offline Mode):
Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2)

Duration: 1Hrs
While setting question paper four MCQ on module 1 and four MCQ on module 2 both.

14 Format of Question Paper:

Scheme of examination:
At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

	Marks for Journals: For both Module 1 and Module 2 3. Journal: 5 marks (2.5 marks for each module 1 & module 2) The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

SEM VI
Vertical – 1
Electives
(2+2)

Syllabus
B.A./ B.Sc. (Mathematics)
(Sem.- VI)
(MAJOR – Elective – A)
Name of the Course: Integral Transforms

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course introduces Laplace and Fourier Transform techniques used to simplify and solve complex mathematical problems. It covers the definition, Transforms of elementary functions, key properties, and evaluation of Laplace & Fourier Transform of various types. Students learn applications to evaluate integrals and solve higher-order linear differential equations.
2	**Vertical:**	Major (Elective – A)
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course introduces Laplace and Fourier Transform techniques used to simplify and solve complex mathematical problems. These tools are widely used in engineering and science for solving linear ODEs and PDEs, analyzing electrical circuits, processing signals, studying heat conduction, vibration analysis, image and audio filtering. **CO1:** To introduce the concept and definition of the Laplace Transform and Fourier Transform. **CO2:** Develop the ability to compute Laplace and Fourier Transforms of elementary functions and use their key properties. **CO3:** To equip students with techniques for finding inverse Laplace Transforms using partial fractions, convolution, and other methods. **CO4:** Apply Laplace Transforms to solve higher-order linear ordinary differential equations and evaluate definite integrals. **CO5:** To provide a strong foundation in Fourier integral representation, Fourier sine and cosine Transforms, and their properties.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Understand the concept of integral Transforms and their corresponding inversion techniques. **OC2:** Use Transform properties such as linearity, shifting, scaling, and convolution effectively. **OC3:** Solve higher order linear ODEs and evaluate definite integrals using Laplace Transform techniques. **OC4:** Apply Fourier integral formulas and compute Fourier sine and cosine Transforms of elementary functions. **OC5:** Evaluate the Fourier Transform of elementary functions such as exponentials, sinusoids,	

	polynomials, and simple piecewise functions.
	Modules: - **Module 1**: **The Laplace Transform (15 Lectures)**
	1. Definition of Laplace Transform, Existence theorem, Laplace Transforms of some elementary functions. 2. Properties of Laplace Transform: Scaling property, Heaviside's First and second Shifting theorem. 3. Laplace Transform of Periodic function, Laplace Transform of $t^n f(t)$ and $\frac{1}{t}f(t)$. 4. Laplace Transform of derivatives and integrals. 5. Inverse Laplace Transform, Properties of Inverse Laplace Transform. 6. Inverse Laplace Transform by partial fraction method, Convolution Theorem. 7. Dirac – delta function, Initial and final value theorem. 8. Application of Laplace Transform to evaluation of integrals and solutions of higher order linear ODE.
	Module 2: **The Fourier Transform (15 Lectures)**
	1. Fourier integral representation, Fourier integral theorem, 2. Fourier Sine & Cosine integral representation, 3. Fourier Transform, Fourier Sine & Cosine Transform pairs, Evaluating Fourier Transform of elementary functions. 4. Properties of Fourier Transform, Transforms of Derivatives, Derivatives of Transforms. 5. Convolution Theorem, Parseval's Identity.
10	**Recommended Reference Books:** 1. Lokenath Debnath and Dambaru Bhatta, Integral Transforms and their Applications, CRC Press Taylor & Francis. 2. I.N.Sneddon, Use of Integral Transforms, Tata-McGraw Hill. 3. L. Andrews and B. Shivamogg, Integral Transforms for Engineers, Prentice Hall of India.
11	**Additional Reference Books** 1. M. D. Raisinghania, H. C. Saxena, H. K. Dass, Integral Transforms, S. Chand & Company Pvt. Ltd., New Delhi 2. Phil Dyke , An Introduction to Laplace Transforms and Fourier Series, Springer 3. V. Sundarapandian, Ordinary & Partial Differential Equations with Laplace Transforms, Fourier Series & Applications, McGraw Hill Education (India edition) 4. J. K. Goyal, K. P. Gupta, G. S. Gupta, Laplace & Fourier Transforms, Pragati Prakashan
	Scheme of the Examination
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc.	

	(at least 3) <table><tr><td>Sr. No.</td><td>Particulars</td><td>Marks</td></tr><tr><td>1</td><td>A class test of 10 marks is to be conducted during each semester in an Offline mode.</td><td>10</td></tr><tr><td>2</td><td>Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.</td><td>05</td></tr><tr><td>3</td><td>Seminar/ group presentation on any one topic related to the syllabus.</td><td>05</td></tr></table>**Paper pattern of the Test (Offline Mode with One hour duration):** Q1: Definitions/Fill in the blanks/ True or False with Justification. (04 Marks: 4 x 1). Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)	
14	**Format of Question Paper:** The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.	

Note: Attempt any TWO questions out of THREE.			
Q. No. 1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: 6P3A - Practical Based on Integral Transforms

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course introduces Laplace and Fourier Transform techniques used to simplify and solve complex mathematical problems. It covers the definition, Transforms of elementary functions, key properties, and evaluation of Laplace & Fourier Transform of various types. Students learn applications to evaluate integrals and solve higher-order linear differential equations.
2	**Vertical:**	Major (Elective – A)
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course introduces Laplace and Fourier Transform techniques used to simplify and solve complex mathematical problems. These tools are widely used in engineering and science for solving linear ODEs and PDEs, analyzing electrical circuits, processing signals, studying heat conduction, vibration analysis, image and audio filtering. **CO1:** To introduce the concept and definition of the Laplace Transform and Fourier Transform. **CO2:** Develop the ability to compute Laplace and Fourier Transforms of elementary functions and use their key properties. **CO3:** To equip students with techniques for finding inverse Laplace Transforms using partial fractions, convolution, and other methods. **CO4:** Apply Laplace Transforms to solve higher-order linear ordinary differential equations and evaluate definite integrals. **CO5:** To provide a strong foundation in Fourier integral representation, Fourier sine and cosine Transforms, and their properties.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Use Transform properties such as linearity, shifting, scaling, and convolution effectively. **OC2:** Solve higher-order linear ODEs and evaluate definite integrals using Laplace Transform techniques. **OC3:** Apply Fourier integral formulas and compute Fourier sine and cosine Transforms of elementary functions. **OC4:** Evaluate the Fourier Transform of elementary functions such as exponentials, sinusoids, polynomials, and simple piecewise functions.	
9	**Modules: -** **Module 1: Practical for The Laplace Transform (30 Hours)**	

1.	Evaluation of Laplace Transform using elementary properties
2.	Evaluation of Laplace Transform of Derivatives and integral
3.	Laplace Transform of periodic functions
4.	Evaluation of inverse Laplace Transform using elementary properties
5.	Evaluation of inverse Laplace Transform using partial fractions
6.	Evaluation of inverse Laplace Transform using convolution theorem
7.	Application of Laplace Transform to evaluation of integrals
8.	Application of Laplace Transform to solution of initial value problems

Module 2: Practical for The Fourier Transform (30 Hours)

1.	Examples based on Fourier integral representation
2.	Examples based on Fourier integral sine and cosine representation
3.	Evaluation of Fourier transforms
4.	Evaluation of Fourier sine and cosine transforms
5.	Examples based on inverse Fourier transforms
6.	Examples based on convolution theorem
7.	Examples based on Parseval's identity

Miscellaneous theory questions based on above two modules.

10 Recommended Reference Books:

1. Lokenath Debnath and Dambaru Bhatta, Integral Transforms and their Applications, CRC Press Taylor & Francis.
2. I.N.Sneddon, Use of Integral Transforms, Tata-McGraw Hill.
3. L. Andrews and B. Shivamogg, Integral Transforms for Engineers, Prentice Hall of India.

11 Additional Reference Books

1. M. D. Raisinghania, H. C. Saxena, H. K. Dass, Integral Transforms, S. Chand & Company Pvt. Ltd., New Delhi
2. Phil Dyke, An Introduction to Laplace Transforms and Fourier Series, Springer
3. V. Sundarapandian, Ordinary & Partial Differential Equations with Laplace Transforms, Fourier Series & Applications, McGraw Hill Education (India edition)
4. J. K. Goyal, K. P. Gupta, G. S. Gupta, Laplace & Fourier Transforms, Pragati Prakashan.

Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

Paper pattern of the Test (Offline Mode):

Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2)

Duration: 1Hrs

While setting question paper four MCQ on module 1 and four MCQ on module 2 both.

14 **Format of Question Paper:**

Scheme of examination:

At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 to OC5)	(5 × 2 = 10 Marks)

Marks for Journals:

For both Module 1 and Module 2

7. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

(MAJOR – Elective – B)

Name of the Course: Number Theory and Its Applications- II

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course presents an in-depth study of central topics in number theory, with emphasis on quadratic residues, reciprocity laws, and continued fractions. It develops rigorous methods for analyzing the concepts while strengthening proof techniques and theoretical understanding essential for advanced study in number theory and related areas of mathematics.
2	**Vertical:**	Major (Elective – B)
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides a rigorous study of fundamental topics in number theory with emphasis on quadratic reciprocity and continued fractions. It aims to develop a solid theoretical understanding of quadratic congruences, rational approximations of irrational numbers, etc while strengthening problem solving techniques and analytical reasoning required for advanced study in pure mathematics. **CO1:** Develop a clear understanding of quadratic residues, Legendre and Jacobi symbols, and the laws of quadratic reciprocity. **CO2:** Illustrate the depth and structure of number theory by equipping students with theoretical tools to analyze quadratic congruences and related arithmetic problems. **CO3:** Strengthen problem-solving abilities and logical reasoning through rigorous proofs involving reciprocity laws and continued fractions. **CO4:** Provide exposure to classical results and foundational ideas in number theory, particularly those arising from continued fractions, that underpin developments in the Mathematical Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to: **OC1:** Understand and recall fundamental concepts related to quadratic residues, Legendre and Jacobi symbols, and continued fractions. **OC2:** Apply standard theorems and techniques to solve problems involving quadratic congruences, reciprocity laws, and rational approximations of irrational numbers. **OC3:** Analyze and interpret properties of quadratic residues, periodic continued fractions, and solutions of classical Diophantine equations like Pell's Equations using appropriate theoretical tools. **OC4:** Justify results concerning solvability, uniqueness, or non-solvability of quadratic congruences and Pell's equations through rigorous mathematical proofs. **OC5:** Construct and examine illustrative examples and counterexamples related to quadratic reciprocity, continued fractions, and Pell's equations, demonstrating deeper conceptual	

understanding.

Modules: -

Module 1: **Quadratic Reciprocity (15 Lectures)**

Quadratic residues and Legendre Symbol, Gauss Lemma, Theorem on Legendre Symbol $\left(\frac{2}{p}\right)$ and $\left(\frac{3}{p}\right)$ and associated results. If p is an odd prime and a is an odd integer with (a, p) = 1 then $\left(\frac{a}{p}\right) = (-1)^t$ where $t = \sum_{k=1}^{\frac{p-1}{2}} \left[\frac{ka}{p}\right]$. Quadratic Reciprocity law. The Jacobi Symbol and law of reciprocity for Jacobi Symbol. Quadratic Congruences with Composite moduli.

Module 2: **Continued Fractions (15 Lectures)**

Finite continued fractions. Infinite continued fractions and representation of an irrational number by an infinite simple continued fraction, Rational approximations to irrational numbers and order of convergence, Best possible approximations. Periodic continued fractions. Pell's equation $x^2 - dy^2 = 1$, where d is not a square of an integer.

10 **Recommended Reference Books:**

1. Niven H. Zuckerman and H. Montogomery. An Introduction to the Theory of Numbers. John Wiley & Sons. Inc.
2. David M. Burton. An Introduction to the Theory of Numbers. Tata McGraw-Hill Edition.
3. Neville Robins. Beginning Number Theory. Narosa Publications.
4. S. D. Adhikari. An introduction to Commutative Algebra and Number Theory. Narosa Publishing House
5. K. Ireland, M. Rosen. A classical introduction to Modern Number Theory. Second edition, Springer Verlag.

11 **Additional Reference Books**

1. N. Koblitz; A course in Number theory and Cryptography; Springer.
2. M. Artin; Algebra; Prentice Hall.
3. K. Ireland, M. Rosen; A classical introduction to Modern Number Theory; Second edition, Springer Verlag

<u>Scheme of the Examination</u>

The performance of the learners shall be evaluated in two parts.

- Internal Continuous Assessment of 20 marks.
- Semester End Examination of 30 marks.
- A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	A class test of 10 marks is to be conducted during each	10

	semester in an Offline mode.	
2	Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.	05
3	Seminar/ group presentation on any one topic related to the syllabus.	05

Paper pattern of the Test (Offline Mode with One hour duration):

Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).

Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)

14 Format of Question Paper:

The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.

Note: Attempt any TWO questions out of THREE.			
Q. No. 1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: 6P3B – Practical Based on Number Theory and Its Applications - II

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course is based on problem-solving which is a fundamental aspect of any Mathematics course. While advanced courses often emphasize the theoretical nature of the subject, engaging in problem-solving reinforces concepts and enhances learners' ability to analyze existing problems and devise solutions. This activity not only motivates learners but also empowers them to formulate new results, propose conjectures, and develop innovative theories.
2	**Vertical:**	Major (Elective – B)
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides a rigorous study of fundamental topics in number theory with emphasis on quadratic reciprocity and continued fractions. It aims to develop a solid practical understanding of quadratic congruences, rational approximations of irrational numbers, etc while strengthening proof techniques and analytical reasoning required for advanced study in pure mathematics. **CO1:** Develop a clear understanding of quadratic residues, Legendre and Jacobi symbols, and the laws of quadratic reciprocity. **CO2:** Illustrate the depth and structure of number theory by equipping students with theoretical tools to analyze quadratic congruences and related arithmetic problems. **CO3:** Strengthen problem-solving abilities and logical reasoning through rigorous proofs involving reciprocity laws and continued fractions. **CO4:** Provide exposure to classical results and foundational ideas in number theory, particularly those arising from continued fractions, that underpin developments in the Mathematical Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Apply standard theorems and techniques to solve problems involving quadratic congruences, reciprocity laws, and rational approximations of irrational numbers. **OC2:** Analyze and interpret properties of quadratic residues, periodic continued fractions, and solutions of classical Diophantine equations like Pell's Equations using appropriate theoretical tools. **OC3:** Justify results concerning solvability, uniqueness, or non-solvability of quadratic congruences and Pell's equations through rigorous mathematical proofs. **OC4:** Construct and examine illustrative examples and counterexamples related to quadratic reciprocity, continued fractions, and Pell's equations, demonstrating deeper conceptual understanding.	

9	**Modules: -** **Module 1: Practical for Congruences and Factorization (30 Hours)**

1.	Solving general quadratic congruences
2.	Quadratic Residues and Euler's Criterion
3.	Properties of Legendre Symbol
4.	Gauss' Lemma
5.	Law of Quadratic Reciprocity
6.	Quadratic congruences modulo power of odd prime
7.	Quadratic congruences modulo power of 2
8.	Quadratic congruences modulo any composite number

Module 2: Practical for Diophantine equations and their solutions (30 Hours)

1.	Writing a rational number as a continued fraction and a finite continued fraction as a rational number
2.	Convergents of a finite continued fraction and properties
3.	Solving a Diophantine equation using continued fraction
4.	Finding the irrational numbers associated to infinite continued fractions
5.	Finding the infinite continued fractions of the irrational numbers
6.	Rational approximations to irrational numbers and order of convergence, Best possible approximations
7.	Solving Pell's equation using infinite continued fractions
	Miscellaneous theory questions based on above two modules

10 Recommended Reference Books:

1. Niven H. Zuckerman and H. Montogomery. An Introduction to the Theory of Numbers. John Wiley & Sons. Inc.
2. David M. Burton. An Introduction to the Theory of Numbers. Tata McGraw-Hill Edition.
3. Neville Robins. Beginning Number Theory. Narosa Publications.
4. S. D. Adhikari. An introduction to Commutative Algebra and Number Theory. Narosa Publishing House
5. K. Ireland, M. Rosen. A classical introduction to Modern Number Theory. Second edition, Springer Verlag.

11 Additional Reference Books

1. N. Koblitz; A course in Number theory and Cryptography; Springer.
2. M. Artin; Algebra; Prentice Hall.
3. K. Ireland, M. Rosen; A classical introduction to Modern Number Theory; Second edition, Springer Verlag.

<u>Scheme of the Examination</u>

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**

13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

Paper pattern of the Test (Offline Mode):

Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2)

Duration: 1Hrs

While setting question paper four MCQ on module 1 and four MCQ on module 2 both.

14 **Format of Question Paper:**

Scheme of examination:

At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

Marks for Journals:

For both Module 1 and Module 2

8. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

(MAJOR – Elective – C)

Name of the Course: Operations Research - II

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	Operations Research is a multidisciplinary field that applies analytical methods to help make better management decisions. It is often called the “science of the better” because it focuses on optimising processes, resource allocation, and decision-making to achieve optimal solutions. The course helps solve complex real-world problems using mathematics and domain-specific knowledge. Operations Research bridges the gap between theory and application, enabling systematic and evidence-based decision-making in various domains. It helps organisations deal with complexities, reduce costs, improve productivity, and gain a competitive edge. Its practical and quantitative approach makes it an essential tool for decision-makers. It has its applications in Agricultural Engineering, Mechanical Engineering, Production and Industrial Engineering, Mechatronics, Environmental Science and for Professionals and Decision-makers
2	**Vertical:**	Major (Elective -C)
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides an introduction to Concepts of Operations Research. It aims to prepare students to develop mathematical models for real life problems and effective decision making. The focus of the course is on developing skills and techniques, which extends to broader applications in mathematics. **CO1:** Provide an understanding of fundamental concepts and tools of the subject. **CO2:** Enable to recognize, devise and solve problems **CO3:** Enable to plan, design and implement safe, efficient, cost effective, sustainable projects to meet societal and environmental needs. **CO4**: Equips the students to develop mathematical models for making decisions. **CO5**: Foster students' comprehensive development by placing emphasis on problem-solving skills, nurturing creative talents, and enhancing communication abilities, all of which are vital for a range of employment opportunities. **CO6**: Ensures understanding of the techniques to be applied for effective business decisions.	
8	**Course Outcomes (OC):** After successful completion of the course, students will be able to: **OC1:** Understand and recall fundamental concepts of Transportation Problems, Queuing	

	models, Poisson processes, and project management techniques such as CPM. **OC2:** Apply appropriate methods to obtain initial and optimal solutions for Transportation Problems, analyze queuing systems, and compute project scheduling parameters using CPM. **OC3:** Analyse transportation, queuing, and project networks to evaluate system performance, identify critical paths, floats, and resource bottlenecks. **OC4:** Justify the selection of suitable optimization and scheduling techniques, including MODI method, queuing models, and project crashing, based on problem characteristics. **OC5:** Construct mathematical and network models for real-world transportation, service systems, and project management problems to determine optimal cost and completion time.
	Modules: - **Module 1**: **Transportation Problems and Queuing Systems (15 Lectures)**
	1.Transportation Problem: Formation of TP, Concepts of solution, feasible solution, Finding Initial Basic Feasible Solution by North West Corner Method, Matrix Minima Method, Vogel's Approximation Method. Optimal Solution by MODI method, Unbalanced and maximization type of TP. 2. Elements of Queuing Model, Role of Exponential Distribution. Pure Birth and Death Models, Generalized Poisson Queuing Model. 3.Specialized Poisson Queues: Steady-state Measures of Performance, Single Serve Models, Multiple Server Models, Self-service Model, Machine servicing Model.
	Module 2: **Network Analysis (15 Lectures)**
	1. Critical Path Method (CPM): Concepts, Construction of a network diagram, node relationships and precedence relationships, Principles of constructing a network diagram, Critical path, Critical and non-critical activities, Project completion time 2. Forward pass and backward pass methods, Calculation of EST, EFT, LST, LFT, Total Float, Free Float, Independent Float, Interfering Float. 3. Project Crashing: Meaning, Normal time, Normal cost, Crash time, Crash cost, Costs involved in Project Crashing, Cost trade off in Project Crashing, Optimal project cost and optimal project completion time.
10	**Recommended Reference Books:** 1. J.K. Sharma; Operations Research; Theory and Applications 2. H.A. Taha, Operations Research, Prentice Hall of India. 3. N.S. Kambo, Mathematical Programming Techniques, Revised Addition. Affiliated East-West Press Pvt Ltd.
11	**Additional Reference Books** 1. Hillier and Lieberman, Introduction to Operations Research. 2. Richard Broson, Schaum Series Book in Operations Research, Tata McGrawHill Publishing Company Ltd.
	<u>Scheme of the Examination</u>
	The performance of the learners shall be evaluated in two parts. • Internal Continuous Assessment of 20 marks. • Semester End Examination of 30 marks. • A separate head of passing is required for internal and semester-end examinations.

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**

13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3) <table><tr><td>Sr. No.</td><td>Particulars</td><td>Marks</td></tr><tr><td>1</td><td>A class test of 10 marks is to be conducted during each semester in an Offline mode.</td><td>10</td></tr><tr><td>2</td><td>Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.</td><td>05</td></tr><tr><td>3</td><td>Seminar/ group presentation on any one topic related to the syllabus.</td><td>05</td></tr></table>**Paper pattern of the Test (Offline Mode with One hour duration):** Q1: Definitions/Fill in the blanks/ True or False with Justification. (04 Marks: 4 x 1). Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)	
14	**Format of Question Paper:** The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.	

Note: Attempt any TWO questions out of THREE.			
Q. No. 1	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: 6P3C- Practical Based on Operations Research - II

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	Problem-solving is a fundamental aspect of any Mathematics course. While advanced courses often emphasize the theoretical nature of the subject, engaging in problem-solving reinforces concepts and enhances learners' ability to analyse existing problems and devise solutions. This activity not only motivates learners but also empowers them to formulate new results, propose conjectures, and develop innovative theories.
2	**Vertical:**	Major (Elective -C)
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course emphases on problem solving and motivates to think on the basic concepts of Operations Research with rigour and prepares students for decision making in business problems. **CO1.** To give sufficient knowledge of fundamental principles, tools and the skills to use them by modelling, solving and interpreting. **CO2.** To reflect the broad nature of the subject and develop mathematical tools for continuing further study in various fields of sciences. **CO3.** To enhance students' overall development, problem solving skills, creative talent, and power of communication. These are necessary for various kinds of employment. **CO4.** To give adequate exposure to global and local concerns that would help learners explore many aspects of Mathematical and Engineering Sciences.	
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Apply the concepts to formulate the Transportation Problem, and solve the problem for initial feasible solution by various methods. **OC2:** Analyse the initial solution and use different methods optimize the initial solution for various types of unbalanced and maximization transportation problems. **OC3:** Justify/check the various types of queuing models for various case studies examples. **OC4:** Construct network diagrams and calculate the optimal project cost and optimal project completion time for various cases.	
9	**Modules: -** **Module 1: Practical for Transportation Problems and Queuing Systems (30 Hours)**	

1.	Formation of TP
2.	Finding Initial Basic Feasible Solution by North West Corner Method, Matrix Minima Method, Vogel’s Approximation Method
3.	Optimal Solution by MODI method
4.	Unbalanced type of TP, Maximization type of TP

5.	Queuing Model, Exponential Distribution
6.	Birth and Death Models
7.	Specialized Poisson Queues: Steady-state Measures of Performance
8	Single Serve Models, Multiple Server Models, Self-service Model, Machine servicing Model

Module 2: Practical for Network Analysis (30 Hours)

1.	Critical Path Method (CPM): Concepts, Construction of a network diagram
2.	Costs involved in Project Crashing, Critical path, Critical and non-critical activities, Project completion time
3.	Forward pass methods, Backward pass methods
4.	Calculation of Total Float, Free Float, Independent Float, Interfering Float
5.	Project Crashing, Normal time, Normal cost, Crash time, Crash cost,Project crashing
6.	Cost trade off in Project Crashing
7.	Optimal project cost and optimal project completion time

Miscellaneous theoretical questions on Module-1 & 2

10 **Recommended Reference Books:**

1.J.K. Sharma; Operations Research; Theory and Applications

2.H.A. Taha, Operations Research, Prentice Hall of India.

3. N.S. Kambo, Mathematical Programming Techniques, Revised Addition. Affiliated East-West Press Pvt Ltd.

11 **Additional Reference Books**

1. Hillier and Lieberman, Introduction to Operations Research.
2. Richard Broson, Schaum Series Book in Operations Research, Tata McGrawHill Publishing Company Ltd.
3. Analysis of Queues: Methods and Applications (Operations Research Series)
4. Fundamentals of Queueing Theory (English, Hardcover, Shortle John F.)

Scheme of the Examination

12	**Internal Continuous Assessment: 40%**	**Semester End Examination: 60%**
13	**Continuous Evaluation through:** Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc. (at least 3)	

Sr. No.	Particulars	Marks
1	Objective question test	10
2	Overall performance	05
3	Viva	05

	Paper pattern of the Test (Offline Mode): Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2) **Duration: 1Hrs** **While setting question paper four MCQ on module 1 and four MCQ on module 2 both.**	
14	**Format of Question Paper:**	

Scheme of examination:

At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

Q. No. 1	Five out of Eight multiple choice questions (four from module 1 and four from module 2) (OC1 to OC3)	Marks (3 × 5 = 15 Marks)
Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

Marks for Journals:

For both Module 1 and Module 2

9. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

(MAJOR – Elective – D)

Name of the Course: Graph Theory - II

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	Graph Theory–II provides an advanced study of graph structures essential for modern computational and network-driven applications. The course covers Hamiltonian graphs, including Ore's and Dirac's theorems, cube graphs, line graphs, and connectivity measures that support reliability analysis in communication and distributed systems. It introduces graph coloring, chromatic polynomials, and key results such as Brooks' and Vizing's theorems, which are widely used in scheduling, register allocation, and resource optimization. Students also explore planar graphs through Euler's formula, non-planarity criteria, dual graphs, and Platonic solids, linking these concepts to visualization, mesh design, and geographic information systems.
2	**Vertical:**	Major (Elective -D)
3	**Type:**	Theory
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	30 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course offers a rigorous introduction to advanced principles and applications of graph theory, emphasizing structural understanding, logical reasoning, and algorithmic thinking. It aims to prepare students for higher studies in discrete mathematics, network theory, and theoretical computer science. **CO1:** Provide a strong foundation in advanced graph concepts such as Hamiltonian graphs, cube graphs, and line graphs, enabling students to model and analyze relationships in diverse systems. **CO2:** Develop proficiency in connectivity and coloring principles, including vertex/edge cuts, chromatic numbers, Brooks' and Vizing's theorems, and chromatic polynomials, for practical problem solving and algorithm design. **CO3:** Enhance analytical and problem-solving abilities by studying planar graphs, Euler's formula, non-planarity criteria, dual graphs, Platonic solids, and graph colorability results. **CO4:** Apply advanced graph-theoretic concepts-including connectivity, coloring techniques, chromatic polynomials, and planarity principles-to model complex networks, solve theoretical and real-world problems	
8	**Course Outcomes (OC):** After successful completion of the course, students will be able to: **OC1:** Understand and recall fundamental concepts of Hamiltonian graphs, cube graphs, line graphs, and graph connectivity, including key theorems such as Ore's, Dirac's, and Whitney's theorems.	

	OC2: Apply vertex and edge coloring techniques, evaluate chromatic numbers, and utilize Brooks' and Vizing's theorems to solve graph coloring problems. **OC3:** Compute and analyze chromatic polynomials and apply their properties to study graph colorability and combinatorial structures. **OC4:** Analyze planar graphs, apply Euler's formula, assess non-planarity, study dual graphs and Platonic solids, and understand planar graph colorability including 5-Color and 4-Color theorems. **OC5:** Construct and evaluate graph models by integrating connectivity, coloring, chromatic polynomials, and planarity concepts to formulate proofs, design examples and counterexamples, and solve advanced applied problems in graph theory..
	Modules: - **Module 1**: **Hamiltonian graphs and Connectivity (15 Lectures)**
	1 Hamiltonian graph, Necessary condition for Hamiltonian graphs using G\S where S is a proper subset of V(G), Sufficient condition for Hamiltonian graphs- Ore's theorem and Dirac's theorem, Hamiltonian closure of a graph 2 Cube graphs and properties like regular, bipartite, Connected and Hamiltonian nature of cube graph, Line graph of graph and simple results. 3 Vertex and edge cuts, vertex and edge connectivity and the relation between vertex and edge connectivity. Equality of vertex and edge connectivity of cubic graphs. Whitney's theorem on 2-vertex connected graphs(without proof).
	Module 2: **Coloring of graphs and Planar Graphs (15 Lectures)**
	1 Vertex coloring- evaluation of vertex chromatic number of some standard graphs, critical graph. Upper and lower bounds of Vertex chromatic Number- Brooks theorem (Statement only). Edge colouring- Evaluation of edge chromatic number of standard graphs such as complete graph, complete bipartite graph, cycle. Vizing Theorem (Statement only). 2 Chromatic polynomial of graphs- Recurrence Relation and properties of Chromatic polynomials. 3 Definition of planar graph. Euler formula and its consequences. Non planarity of K_5 and $K_{3,3}$ graphs, Dual of a graph. Polyhedron in R^3 and existence of exactly five regular polyhedron- (Platonic solids), Colourability of planar graphs- 5-Color theorem for planar graphs (Statement only), 4-color theorem (Statement only).
10	**Recommended Reference Books:** 1. R. Balakrishnan, K. Ranganathan, A Text Book of Graph Theory, Springer-Verlag, New York, 2012. 2. J. A. Bondy and U. S. R. Murty, Graph Theory with Applications. 3. D. B. West, Introduction to Graph Theory, Prentice Hall, 2000. 4. Santanu Saha Ray, Graph Theory with Algorithms and its Applications in Applied Science and Technology, Springer 2013
11	**Additional Reference Books** 1. Mehadi Behzad and Gary Chartrand, Introduction to Theory of Graphs. 2. S. A. Choudam, Introductory Graph theory

<table>
<tr><td></td><td colspan="2">3. J. Clark and D. A. Holtan, A first look of Graph Theory
4. Gary Chartrand and Ping Zhang, A first course in Graph Theory.</td></tr>
<tr><td></td><td colspan="2"><u>Scheme of the Examination</u></td></tr>
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(at least 3)
<table>
<tr><td>Sr. No.</td><td>Particulars</td><td>Marks</td></tr>
<tr><td>1</td><td>A class test of 10 marks is to be conducted during each semester in an Offline mode.</td><td>10</td></tr>
<tr><td>2</td><td>Project on any one topic related to the syllabus or a quiz (offline/online) on one of the modules.</td><td>05</td></tr>
<tr><td>3</td><td>Seminar/ group presentation on any one topic related to the syllabus.</td><td>05</td></tr>
</table>
Paper pattern of the Test (Offline Mode with One hour duration):
Q1: Definitions/Fill in the blanks/ True or False with Justification.
(04 Marks: 4 x 1).
Q2: Attempt any 2 from 3 descriptive questions. (06 marks: 2 × 3)</td><td></td></tr>
<tr><td>14</td><td colspan="2">Format of Question Paper:
The semester-end examination will be of 30 marks of one hour duration covering the entire syllabus of the semester.
<table>
<tr><td colspan="4">Note: Attempt any TWO questions out of THREE.</td></tr>
<tr><td>Q. No. 1</td><td>Module 1 and 2</td><td>Attempt any THREE out of FOUR.
(Each question of 5 marks)
(a) Question based on OC1
(b) Question based on OC2
(c) Question based on OC3
(d) Question based on OC4/OC5</td><td>15 Marks</td></tr>
</table></td></tr>
</table>

Q. No. 2	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks
Q. No.3	Module 1 and 2	Attempt any **THREE** out of **FOUR**. (Each question of 5 marks) (a) Question based on OC1 (b) Question based on OC2 (c) Question based on OC3 (d) Question based on OC4/OC5	15 Marks

Name of the Course: 6P3D- Practical Based on Graph Theory - II

Sr. No.	Heading	Particulars
1	**Description of the course: Including but not limited to:**	This course offers a comprehensive practical exploration of advanced graph-theoretic concepts through hands-on activities and structured experimentation. Students begin by identifying Hamiltonian paths and cycles, applying Ore's and Dirac's theorems, and constructing Hamiltonian closures to understand structural constraints. They work with cube graphs to examine regularity, bipartiteness, connectivity, and Hamiltonian properties, and construct line graphs to study graph transformations. Practical work also includes determining vertex and edge cuts, evaluating connectivity measures, and verifying Whitney's theorem for cubic graphs. Learners further develop skills in vertex and edge coloring, evaluating chromatic numbers, and examining the implications of Brooks' and Vizing's theorems. Additional activities involve computing chromatic polynomials using recurrence relations, testing planarity through Euler's formula, demonstrating non-planarity, and constructing dual graphs. Students also analyze Platonic solids through graph representation. Through these practical tasks, learners gain strong analytical ability and applied proficiency in core areas of graph theory.
2	**Vertical:**	Major (Elective -D)
3	**Type:**	Practical
4	**Credits:**	2 credits (1 credit = 15 Hours for Theory or 30 Hours of Practical work in a semester)
5	**Hours Allotted:**	60 Hours
6	**Marks Allotted:**	50 Marks
7	**Course Objectives (CO):** This course provides practical, hands-on experience with advanced graph-theoretic techniques involving Hamiltonian structures, connectivity analysis, graph coloring, chromatic computations, planarity and duality. Students engage in constructing, transforming, and evaluating graphs while applying classical theorems, computational strategies, and visualization methods vital for modern applications in networks, optimization, and discrete mathematics. The focus is on developing structural understanding, analytical reasoning, and algorithmic skills essential for solving real-world graph-based problems. **CO1:** To develop the ability to construct Hamiltonian paths and cycles, test necessary and sufficient conditions using Ore's and Dirac's theorems, and compute Hamiltonian closures to analyze complex structural behaviors in graphs. **CO2:** To enable students to investigate cube graphs, verify properties such as regularity and bipartiteness, determine Hamiltonian characteristics, construct line graphs, and apply connectivity techniques using vertex and edge cuts. **CO3:** To build proficiency in evaluating vertex and edge connectivity, interpret their relationships, and apply classical results such as Whitney's theorem to determine the structural robustness of cubic and connected graphs. **CO4:** To cultivate practical competence in graph coloring by computing vertex and edge	

	chromatic numbers, verifying theoretical bounds using Brooks' and Vizing's theorems, and applying chromatic polynomial methods and recurrence relations for colorability analysis. **CO5:** To strengthen students' analytical and modelling skills by performing planarity tests, applying Euler's formula, demonstrating non-planarity, constructing dual graphs and Platonic solid representations.
8	**Course Outcomes (OC):** After completion of the course, students will be able to **OC1:** Construct and analyze Hamiltonian paths, Hamiltonian cycles, cube graphs, line graphs, and related structures by applying necessary and sufficient conditions including Ore's and Dirac's theorems to evaluate Hamiltonicity, connectivity, and core structural properties of graphs. **OC2:** Compute and interpret vertex cuts, edge cuts, and both forms of connectivity; examine their interrelationships; and verify classical structural results such as the connectivity of cubic graphs and Whitney's theorem on 2-vertex connectivity. **OC3:** Implement vertex and edge coloring methods for standard graphs, determine chromatic numbers, verify theoretical bounds using Brooks' and Vizing's theorems, and compute chromatic polynomials using recurrence relations and associated properties. **OC4:** Analyze planar and non-planar graphs through planarity testing and Euler's formula, construct dual graphs and Platonic solid representations.
9	**Modules: -** **Module 1: Practical for Hamiltonian graphs and Connectivity (30 Hours)**

1.	Hamiltonian path, cycle, graph and testing Necessary Conditions
2.	Ore's theorem, Dirac's theorem and its properties
3.	Hamiltonian Closure of Graphs
4.	Cube graphs and properties like regular, bipartite, connected and Hamiltonian nature of cube graph
5.	Characterization of Line Graphs
6.	Vertex cuts, edge cuts and Relation Between Vertex and Edge Connectivity
7.	Connectivity of Cubic Graphs, Whitney's theorem

Module 2: Practical for Coloring of graphs and Planar graphs (30 Hours)

1.	Vertex Coloring of graphs, Brooks Theorem
2.	Edge Coloring of graphs, Vizing's Theorem
3.	Chromatic Polynomial of Graphs
4.	Chromatic Polynomial of graphs and its recursive formula
5.	Planarity testing, Euler's Formula
6.	Non-planarity testing and its characteristics
7.	Dual of a graph
8.	Platonic Solids and Graph Representation

Miscellaneous theoretical questions on Module-1 & 2

10	**Recommended Reference Books:** 1. R. Balakrishnan, K. Ranganathan, A Text Book of Graph Theory, Springer-Verlag, New York, 2012. 2. J. A. Bondy and U. S. R. Murty, Graph Theory with Applications. 3. D. B. West, Introduction to Graph Theory, Prentice Hall, 2000. 4. Santanu Saha Ray, Graph Theory with Algorithms and its Applications in Applied Science and Technology, Springer 2013

<table>
<tr><td>11</td><td colspan="2">Additional Reference Books
1. Mehadi Behzad and Gary Chartrand, Introduction to Theory of Graphs.
2. S. A. Choudam, Introductory Graph theory
3. J. Clark and D. A. Holtan, A first look of Graph Theory
4. Gary Chartrand and Ping Zhang, A first course in Graph Theory.</td></tr>
<tr><td></td><td colspan="2"><u>Scheme of the Examination</u></td></tr>
<tr><td>12</td><td>Internal Continuous Assessment: 40%</td><td>Semester End Examination: 60%</td></tr>
<tr><td>13</td><td>Continuous Evaluation through:
Quizzes, Class Tests, presentations, projects, role play, creative writing, assignments etc.
(at least 3)

<table><tr><td>Sr. No.</td><td>Particulars</td><td>Marks</td></tr><tr><td>1</td><td>Objective question test</td><td>10</td></tr><tr><td>2</td><td>Overall performance</td><td>05</td></tr><tr><td>3</td><td>Viva</td><td>05</td></tr></table>
Paper pattern of the Test (Offline Mode):
Q1: (Attempt any 5 from 8) Multiple choice questions. (10 marks: 5 × 2)

Duration: 1Hrs
While setting question paper four MCQ on module 1 and four MCQ on module 2 both.</td><td></td></tr>
<tr><td>14</td><td colspan="2">Format of Question Paper:

Scheme of examination:
At the end of the Semester, Practical examinations of two hours duration and 30 marks shall be conducted based on both the modules.

Paper pattern: The question paper shall have two questions.

<table><tr><td>Q. No. 1</td><td>Five out of Eight multiple choice questions (four from module 1 and four from module 2)
(OC1 to OC3)</td><td>Marks
(3 × 5 = 15 Marks)</td></tr></table></td></tr>
</table>

Q. No.2	Attempt any Two out of Four (two from module 1 and two from module 2). (OC3 and OC4)	(5 × 2 = 10 Marks)

Marks for Journals:

For both Module 1 and Module 2

10. Journal: 5 marks (2.5 marks for each module 1 & module 2)

The students are required to perform 75% of the Practical for the journal to be duly certified. The students are required to present a duly certified journal for appearing at the practical examination, failing which they will not be allowed to appear for the examination.

Letter Grades and Grade Points:

Semester GPA/ Programme CGPA Semester/ Programme	% of Marks	Alpha-Sign/ Letter Grade Result	Grading Point
9.00 - 10.00	90.0 - 100	O (Outstanding)	10
8.00 - < 9.00	80.0 - < 90.0	A+ (Excellent)	9
7.00 - < 8.00	70.0 - < 80.0	A (Very Good)	8
6.00 - < 7.00	60.0 - < 70.0	B+ (Good)	7
5.50 - < 6.00	55.0 - < 60.0	B (Above average)	6
5.00 - < 5.50	50.0 - < 55.0	C (Average)	5
4.00 - < 5.00	40.0 - < 50.0	P (Pass)	4
Below 4.00	Below 40.0	F (Fail)	0
Ab (Absent)	-	Ab (Absent)	0

Vertical – 6

As Per NEP 2020

University of Mumbai

Syllabus for Community Engagement Project (CEP) Vertical-6	
Faulty of Science & Technology	
Board of Studies in Mathematics	
Name of the Programme – B.A./B.Sc. (Mathematics)	
Semester	**V**
Credit	**2**
Duration	**30 hrs (Field Work+ Survey) + 15hrs (Discussion + Report Writing) : Total - 45 hrs**
From the Academic Year	**2026-27**

Name of Faculty:- Science & Technology
Name of Programme :- B.A./B.Sc. (Mathematics)
Duration :- 30 hrs (Field Work+ Survey) + 15hrs (Discussion + Report Writing): Total - 45 hrs

Indicative Topics for CEP

Sr. No.	Name of the Topic
1	Mathematics of Insurance and Risk Assessment for Community Awareness
2	Statistical Study of Employment and Unemployment Trends in the Local Area
3	Mathematical Modelling of Queueing Systems in Banks and Public Offices
4	Survey and Statistical Analysis of Digital Literacy in the Community
5	Mathematics Behind Pricing Strategies and Profit Optimization for Small Vendors
6	Application for Linear Programming in Resource Allocation for Community Welfare Programs
7	Mathematical Study of Rainfall Patterns and Their Impact on Agriculture
8	Mathematical Modelling of Population Growth and Migration Trends in the Town
9	Using Mathematics to Study Traffic Flow and Road Safety in Urban Areas
10	Mathematics Olympiad Training and Mentorship Program for School Student
11	Community Mathematics Festival: Promoting Mathematical Awareness and Engagement
12	Integration of Mathematics and Art: A Community Exhibition and Study
13	Mathematics-Based Game Development as a Tool for Learning and Engagement
14	Statistical and Mathematical Analysis of Cryptocurrency Market Trends
15	Activity-Oriented Mathematics Education for Enhancing Numerical and Financial Literacy among Underprivileged Students
16	Mathematics-Based Academic Support Programs for Children from Economically Weaker Sections
17	Demographic Data Analysis of the Local Community Using Mathematical Tools
18	A Mathematical Investigation of Sleep Patterns and Their Impact on Academic Performance
19	Applying Statistics to Analyze Nutrition and Health Trends in the Local Community
20	Survey-Based Statistical Analysis of Social and Community Issues
21	Mathematical Study of Household Waste Generation and Reduction Strategies
22	Mathematical Modelling for Effective Water Resource Management in the Town
23	Optimization of Public Transportation Systems Using Mathematical Techniques

24	Mathematical Modelling of Economic Growth Patterns of the Town
25	Statistical Analysis of Local Election Results and Voting Trends

The topics are indicative and the faculty members should allot Community Engagement Project that are relevant and important as per core Subject. The Community Engagement Project may be taken individual or in a group up to 5 students with proper guidance from Faculty.

Evaluation Pattern:-

Evaluation during CEP Program involves two key components :-

External Evaluation 60%

Internal Evaluation 40%

Evaluation Chart

(i) External Evaluation (Marks 30)

Criteria	Marks
Objectives, Literature Review , Methodology, Data Analysis, Conclusion and Recommendations	15
Overall Project Report Structure and Style	5
Presentation Skills & Communication	10
Total	30

(ii) Internal Evaluation by Guide (Marks 20)

Criteria	Marks
Attendance, Community interactions completion and interaction with Supervisor	10
Overall Report quality	10
Total	20

*** Please see the Guidelines for Community Engagement Project for UG Students, as per NEP 2020**

Sd/-
Sign of the BOS Chairman
Prof. B.S. Desale
BOS in Mathematics

Sd/-
Sign of the
Offg. Associate Dean
Dr. Madhav R. Rajwade
Faculty of Science & Technology

Sd/-
Sign of the Offg. Dean
Prof. Shivram S. Garje
Faculty of Science & Technology