OUTCOME-BASED CURRICULUM PART-A

Name of the Chairmen of the Department Since its Establishment				
SL. No.	**Name**	**Designation**	**From**	**To**
01.	Khalifa Mohammad Helal	Chairman(In-Charge)	01-07-2007	31-10-2007
02.	Professor Dr. M. Zulfikar Ali	Chairman	01-11-2007	28-02-2009
03.	Khalifa Mohammad Helal	Chairman(In-Charge)	11-08-2009	03-10-2011
04.	Mohammad Anwar Hossen	Chairman(In-Charge)	11-10-2011	06-04-2013
05.	Professor Dr. M. Zulfikar Ali	Chairman	07-04-2013	31-03-2015
06.	Dr. Md. Abdul Hakim	Chairman(In-Charge)	01-04-2015	20-03-2017
07.	Dr. Mohammad Anwar Hossen	Chairman	21-03-2017	20-03-2020
08.	Professor Dr. Khalifa Mohammad Helal	Chairman	21-03-2020	11-09-2023
09.	Professor Dr. Mohammad Anwar Hossen	Chairman	12-09-2023	03-03-2025
10.	Professor Dr. Md. Maruf Hasan	Chairman	03-03-2025	27-04-2025
11.	Professor Dr. Md. Abdul Hakim	Chairman	28-04-2025	Till Now

Program Self-Assessment Committee (PSAC)		
SL. No.	**Name**	**Designation**
01.	Professor Dr. Md. Abdul Hakim	Convener
02.	Professor Dr. Md. Maruf Hasan	Member
03.	Professor Dr. Md. Abdullah Al Mahbub	Member

Committee of Courses			
SL.	**Name**	**Designation**	**Signature**

No.			
01.	Dr. Md.Abdul Hakim Professor	Chairman	
02.	Dr. Khalifa Mohammad Helal Professor	Member	
03.	Dr. Mohammad Anwar Hossen Professor	Member	
04.	Dr. Md. Maruf Hasan Professor	Member	
05.	Dr. Md. Aman Mahbub Professor	Member	
06.	Dr. Md. Ghulam Murtaza Talukder Professor	Member	
07.	Dr. Md. Abdullah Al Mahbub Professor	Member	
08.	Dr. Md. Enamul Karim Associate Professor	Member	
09.	Mrs. Humayra Dil Afroz Assistant Professor	Member	
10.	Mrs. Mahinur Akter Assistant Professor	Member	
Expert Members			
11.	Professor Dr. Mohammed Aman Ullah Department of Mathematics University of Chittagong	Member	
12.	Professor Dr. Md. Motaleb Hossain Department of Mathematics University of Dhaka	Member	
13.	Professor Dr. Md. Sahadat Hossain Department of Mathematics University of Rajshahi	Member	
14.	Professor Dr. Pabel Shahrear Department of Mathematics SUST, Sylhet	Member	
Employer and Alumni			
15.	Joynal Abedin, Additional Director, Bangladesh Bank, Head Office, Motijheel, Dhaka	Invited Guest	
16.	Shuchitro Ranjan Das, Additional District Commissioner, Chandpur, Session: 2006-07, Dept. of Mathematics, CoU (Alumni)	Invited Guest	

OUTCOME-BASED CURRICULUM PART-A

Comilla University at a Glance

Comilla University is a well-known public university in Bangladesh with a venerable legacy and international acclaim for its highest academic standards, diverse educational programs, distinguished faculty, illustrious alumni, varied co-curricular activities and modern infrastructure. It was established in 2006 in the green, peaceful and historically famous location of Kotbari, Comilla, Bangladesh. It is the twenty-sixth public university in Bangladesh.

Comilla University has a beautiful and spacious campus covering an area of 250 acres of land. It has well-designed academic buildings, administrative offices, libraries, laboratories, computer centres, and other necessary infrastructural facilities. The University boasts a dedicated team of highly qualified faculty members renowned for their expertise and commitment to teaching and research. It currently has over 272 faculty members and over 7055 active undergraduate and graduate students. All the faculty members of this University encourage an environment of academic curiosity and critical thinking among students, promoting holistic development. The faculty members enhance the University's reputation and contribute to national and international knowledge enhancement through their scholarly contributions, research endeavors, and publications.

Comilla University offers various undergraduate and postgraduate programs in various disciplines. It has 19 departments under six faculties, including the Faculty of Sciences, Faculty of Arts and Humanities, Faculty of Social Sciences, Faculty of Business Studies, Faculty of Engineering, and Faculty of Law. An student can choose any department under these faculties, such as Mathematics, Physics, Chemistry, Statistics, Pharmacy, Computer Science and Engineering, Information and Communication Technology, English, Economics, Public Administration, Bangla, Anthropology, Archaeology, Journalism and Mass Communication, Law, Accounting and Information Systems, Management Studies, Marketing and Finance and Banking.

Furthermore, this University has a modern library which is a valuable resource for students and faculty, housing a vast collection of books, journals, research papers, and digital resources. The computer centres are equipped with the latest technology, providing students access to high-speed internet and a wide range of software applications. Additionally, the campus has residential halls for both male and female students, ensuring a comfortable living environment.

Comilla University follows a semester system examination curriculum, and the academic curriculum is regularly updated to produce competent human resources to meet the demands of the modern job market. The faculty members are highly qualified, experienced, and dedicated to providing quality education. They employ innovative teaching methods, including interactive lectures, group discussions, and practical sessions, to enhance students' learning experiences.

The University also organizes seminars, conferences, and workshops to foster academic discourse and promote research collaboration. Renowned scholars, researchers, industry professionals, and students can exchange ideas and explore new avenues of knowledge creation through these events. Comilla University encourages students to publish their research findings in renowned national and international journals and conferences with a significant contribution.

Apart from academic programs, Comilla University offers various extracurricular activities for students. The university believes in the holistic development of its students. The university has a rich tradition of cultural programs, sports events, and various clubs and societies catering to diverse interests. Sports events allow students to engage in physical activities, fostering teamwork, discipline, and sportsmanship. The clubs and societies cover various interests, including photography, debate, culture, theatre, science, entrepreneurship, journalism, and social work, enabling students to explore

their passions outside the classroom. This wide range of cultural, sporting and performance opportunities allows every student access to an environment where they can participate and excel.

Department of Mathematics at a Glance

The Department of Mathematics is one of the primary departments of Comilla University. Its initial setup was laid down, and class work started when this university opened its gates for its students to learn and grow. The Department of Mathematics is established to train students to become competent professionals and researchers by earning B.Sc. (Hons.) and MS degrees in Mathematics.

The Department offers two-degree programs: the B.Sc. (Hons.) degree (with mandatory honours final year research-based project work) and the MS degree (Master by Course work and Master by Mixed-Mode). These degree programs emphasize both fundamental and applied topics in mathematics and computational sciences, including real and functional analysis, numerical solutions for the partial differential equations, numerical analysis, finite element and finite difference methods, relativistic and quantum mechanics, kinetic theory, optimal control, operations research, computational fluid dynamics, dynamical systems, mathematical modeling in biology, nonlinear dynamics, soliton theories, high-performance computing and computing architecture, uncertainty quantification, bioinformatics system, and many more. Undergraduate students can pursue a Bachelor of Science (B.Sc.) in Mathematics, which provides a comprehensive understanding of core mathematical principles and their practical applications. The undergraduate programs cover various topics, including calculus, linear algebra, differential equations, abstract algebra, and statistics. The postgraduate program offers mathematical analysis, differential geometry, functional analysis, and numerical analysis courses. The department also offers some elective courses, which allow students to explore their interests in different areas of mathematics. The elective courses included data analysis, number theory, graph theory, measure theory, econometrics, mathematical modelling and so on.

The department is committed to providing its students with a well-rounded education in mathematics. The curriculum includes courses that cover the theoretical foundations of mathematics and courses that focus on the applications of mathematics to other disciplines. For postgraduate students, the department offers a Master of Science (M.S.) program in Mathematics, enabling them to deepen their knowledge and specialize in various subfields of mathematics. The program emphasizes theoretical foundations, promoting critical thinking and problem-solving abilities.

The Department of Mathematics at Comilla University has made several notable contributions to the field of mathematics. The department has published numerous research papers in reputable national and international journals through its research initiatives. These publications have added to the knowledge of mathematics and have been widely cited by researchers worldwide. The department's faculty members have also been invited to present their research findings at prestigious conferences and seminars. Their presentations and collaborations with scholars from other institutions have facilitated knowledge exchange and the exploration of new research avenues.

The department's commitment to quality education has produced exceptional graduates who have excelled in various fields. Many department alumni have pursued higher studies in renowned institutions worldwide and have gone on to establish successful careers as mathematicians, researchers, educators, and professionals in diverse sectors.

The Department of Mathematics at Comilla University boasts modern facilities that enrich students' academic environment. Equipped with well-decorated lecture halls, computer laboratories, and a comprehensive library. The department ensures students have the necessary resources to excel in their studies. Computer laboratories have advanced mathematical software to facilitate simulations, modelling, and data analysis. Furthermore, the department organizes regular seminars, workshops, and conferences, inviting renowned mathematicians and experts to share their knowledge and insights with the faculty and students. These occasions provide a platform for intellectual discussions, fostering collaboration and creating an atmosphere of continuous learning.

The Department of Mathematics at Comilla University actively promotes research and scholarly activities. The faculty members engage in cutting-edge research in various areas of mathematics, contributing to the development of new mathematical theories, models, and applications. The department encourages students to participate in research projects, attend conferences, and publish their findings in reputable journals. The most emphasizes research area is computational mathematics, numerical analysis of partial differential equations, machine learning, computational fluid mechanics, optimization, fuzzy mathematics, mathematical modeling and so on.

The Department of Mathematics boasts a highly qualified and dedicated faculty comprising professors, associate professors, and assistant professors. The faculty members possess extensive academic backgrounds and research expertise in various branches of mathematics. They actively teach research, and mentor students, creating an intellectually stimulating environment within the department. The faculty members impart theoretical knowledge and emphasize practical applications of mathematics in different domains. Their expertise and guidance enable students to explore the depth and breadth of mathematical concepts, fostering critical thinking, problem-solving skills, and creativity.

The Department of Mathematics at Comilla University has established itself as a centre of excellence for mathematical education and research in Bangladesh. With an outstanding faculty, notable achievements, and world-class facilities, the department provides students with a strong foundation in mathematics. It equips them with the necessary skills to excel academically and professionally. At present, the Department of Mathematics offers M. Phil. and Ph.D. programs. As the department continues to evolve, it remains committed to nurturing the next generation of mathematicians and fostering a culture of innovation and academic excellence.

OUTCOME-BASED CURRICULUM PART-B

Title of the Academic Program

Master of Science (MS) in Mathematics

Program Overview

Degree	:	Master of Science (MS)
Abbreviation form of the degree	:	MS in Mathematics
Program Offering Entity (POE)	:	Department of Mathematics
Faculty	:	Faculty of Science
Awarding Institute	:	Comilla University
Location	:	Cumilla-3506, Bangladesh
Bangladesh National Qualification Framework (BNQF) Level	:	09
International Standard Classification Code	:	0541
Method of Study	:	Full Time
Language of Study	:	English
Applicable Session	:	2023-24, 2024-25, 2025-26

Program Learning Outcomes (PLOs)

The Department of Mathematics is among the most dynamic subjects within the Faculty of Science at Comilla University, providing pertinent courses designed to cultivate highly trained graduates with both academic and practical expertise. Graduates of a successful MS Programme in mathematics will be skilled in the following areas:

A. Fundamental Skills

PLO 1 Mathematical Knowledge – Graduates will demonstrate a thorough understanding of mathematical concepts, including notations, terminologies, theories, lemmas, postulates, paradoxes, principles, and problem-solving techniques

PLO 2 Knowledge of Allied Courses – Progresses will be acquainted with allied courses, encompassing Physics, Statistics, Computer Sciences, Information and Communication Technology, Economics, and other relevant professional disciplines.

PLO 3 Analytical Skills – Grad students will possess the ability to reason through basic mathematical principles, employing them to comprehend, analyze, and construct formal arguments supporting theories and lemmas.

B. Social Skills

PLO 4 Interdisciplinary Connections – Graduates will establish connections between mathematical sciences and various scientific and humanistic disciplines.

PLO 5 Teamwork – Persons with an MS degree in mathematics will establish effective interpersonal relationships and demonstrate comfort working collaboratively in a team.

PLO 6 Ethical and Accountable – Students will manifest moral values, social responsibility, accountability, professionalism, academic integrity, and a strong commitment to ethical conduct.

C. Thinking Skills

PLO 7 Mathematical Modeling – MS degree holders will design mathematical models for real-world challenges in areas such as physical, biological, industrial, financial, environmental, engineering, and technology, efficiently solving these models.

PLO 8 Research Competence – Graduate students will generate knowledge by mastering the scientific research process, developing strong critical thinking skills, planning, designing, and conducting individual research to explore new findings.

PLO 9 Applicability – Graduates will possess a predisposition for applying mathematical tools to areas such as physical sciences, financial services, and social sciences. They will have the knowledge, experience, and motivation to address real-world problems.

D. Personal Skills

PLO 10 Computational Expertise – Scholars will demonstrate proficiency in handling computer-related issues, showcasing skills in various computing software and programming languages.

PLO 11 Communication Proficiency – Students with an MS degree in mathematics will effectively share ideas, information, and scientific knowledge through both oral and written means. They will also organize, conduct, interact positively, and present scientific results in seminars, symposiums, workshops, and conferences.

PLO 12 Professional Attitude – Graduates will exhibit a keen commitment to professional duties, maintain a positive attitude, manage emotions effectively, and approach challenges with determination.

OUTCOME-BASED CURRICULUM PART-C

Structure of the Curriculum

<table>
<tr><td>Name of the program</td><td colspan="5">Master of Science (MS)</td></tr>
<tr><td colspan="2">Description</td><td colspan="2">Taught group</td><td colspan="2">Mixed-mode group</td></tr>
<tr><td colspan="2">Duration of the program</td><td colspan="2">01 Year</td><td colspan="2">1.5 Years</td></tr>
<tr><td colspan="2">Number of semesters</td><td colspan="2">02 Semesters</td><td colspan="2">03 Semesters</td></tr>
<tr><td colspan="2">Minimum credit requirement</td><td colspan="2">40 credits</td><td colspan="2">52 credits</td></tr>
<tr><td rowspan="3">Course distribution</td><td>1st Semester</td><td>Courses:
Viva voce:</td><td>18 credits
2 credits</td><td>Courses:
Viva voce:</td><td>18 credits
2 credits</td></tr>
<tr><td>2nd Semester</td><td>Courses:
Viva voce:</td><td>18 credits
2 credits</td><td>Courses:
Viva voce:</td><td>18 credits
2 credits</td></tr>
<tr><td>3rd Semester</td><td colspan="2">-----</td><td>Thesis:</td><td>12 credits</td></tr>
<tr><td colspan="2">Minimum CGPA requirements for graduation</td><td colspan="2">2.25</td><td colspan="2">3.5</td></tr>
<tr><td colspan="2">Maximum academic years of completion</td><td colspan="2">02 Years</td><td colspan="2">03 Years</td></tr>
</table>

Qualifications for admission to the MS program

For admission to the MS Program in any subject, a student should have the following qualifications.

(a) Candidates who have the four (04) years bachelor's degree in mathematics from Comilla University are eligible for direct admission to the MS Program offered by the Mathematics Department.

Note: Students are not eligible for direct admission into the MS program if they have not been admitted within two academic years after obtaining their bachelor's degree. However, he or she will be able to take admission after passing the admission and or oral test conducted by the department.

(b) Candidates seeking admission into the MS in Mathematics must possess a three/four/five-year Bachelor's degree in Mathematics from a Bangladesh University Grants Commission (UGC) recognized University other than Comilla University with 16 years of schooling.

Candidate/s must face an admission test as per the requirements of the Mathematics Department.

Note: Number of seats for admission as post-graduate student/s other than Comilla University will be decided by the Graduate Study Committee (GST) of the Department of Mathematics based on seat capacity.

Semester-wise Distribution of Courses for the Entire Program

MS 1st Semester

ISCED Code	Course Title	Marks	Credits
0541-5101	MATH 5101: Theory of Rings and Modules	100	3
0541-5102	MATH 5102: Advanced Functional Analysis	100	3
0541-5103	MATH 5103: Advanced Fuzzy Mathematics	100	3
0541-5104	MATH 5104: Operations Research	100	3
0541-5105	MATH 5105: Fluid Dynamics	100	3
0541-5106	MATH 5106: Differential and Integral Equations	100	3
0541-5107	MATH 5107: Theory of Relativity	100	3
0541-5108	MATH 5108: Advanced Numerical Analysis	100	3
0541-5109	MATH 5109: Mathematical Hydrology	100	3
0541-5110	MATH 5110: Riemannian Geometry	100	3
0541-5111	MATH 5111: Real Function Theory	100	3
0541-5119	MATH 5119: Viva Voce	50	2

Five courses (from MATH 5101- MATH 5111) will be offered by the Academic Committee, Department of Mathematics, Comilla University.

ISCED Code	Course Title (GED)	Marks	Credits
0533-5112	PHY 5112: Thermodynamics and Statistical Mechanics	100	3
0741-5113	CSE 5113: Mathematical Foundations of Machine Learning	100	3

One course (from PHY 5112- CSE 5113) will be offered by the Academic Committee, Department of Mathematics, Comilla University.

MS 2nd Semester

ISCED Code	Course Title	Marks	Credits
0541-5201	MATH 5201: Lattice Theory	100	3
0541-5202	MATH 5202: Advanced Number Theory	100	3
0541-5203	MATH 5203: Dynamical Systems	100	3
0541-5204	MATH 5204: Geometry of Differential Manifolds	100	3
0541-5205	MATH 5205: Boundary Layer Theory	100	3
0541-5206	MATH 5206: Mathematical Cosmology	100	3
0541-5207	MATH 5207: Quantum Mechanics	100	3
0541-5208	MATH 5208: Finite Element Method	100	3
0541-5209	MATH 5209: Mathematical Biology	100	3
0541-5210	MATH 5210: Computational Fluid Dynamics	100	3
0541-5211	MATH 5211: Information Theory	100	3
0541-5212	MATH 5212: Perturbation Theory	100	3
0541-5219	MATH 5219: Viva Voce	50	2

Five courses (MATH 5201- MATH 5212) will be offered by the Academic Committee, Department of Mathematics, Comilla University.

ISCED Code	Course Title (GED)	Marks	Credits
0413-5213	MGT 5213: Operations Management	100	3
0413-5214	MGT 5214: Quantitative Risk Management	100	3

One course (from MGT 5213- MGT 5214) will be offered by the Academic Committee, Department of Mathematics, Comilla University.

MS 3rd Semester

ISCED Code	Course Title	Marks	Credits
0541-5301	MATH 5301: MS Thesis	100	12

Assessment system of a course

The theoretical course of a 3-credit course will involve three lecture hours per week (a total of 42 lecture hours).

Evaluation of a theoretical course:

Marks allocated for continuous assessment and semester final examination:

Part A: Continuous Assessment (Formative Assessment):		40%
(i)	Class Test and/or Quiz and/or In-course and/or Sudden Test	5
(ii)	Mid-Semester (At least two mid-semester exams)	20
(iii)	Assignment and/or Term paper preparation & Presentation and/or case study and/or Field work	10
(iv)	Attendance	5
Part B: Semester Final Examination (Summative Assessment):		60%

Note:

* For promotion from the 1st semester to the 2nd semester, a student is required to earn a minimum of 50% of the total credit points in the 1st semester on condition that she/he has passed the viva voce.
* Only the removal of `F' (Fail) in any course is allowed. Removal of `F' in any course is permitted by sitting in the final examination only one (1) time in the subsequent semester, excluding the regular examination.

Dissertation/Thesis Evaluation:

The Marks/credits of the Master's Degree Program shall be distributed for Thesis/Dissertation as follows:

Course Type	Credits	Marks	Marks for Viva
Dissertation	12	80	20

Note:

* If a student fails to perform satisfactorily within two months of starting their thesis work in the **Mixed-mode group**, his or her thesis will be cancelled, and he or she will be transferred to the **Taught group** of the Master of Science.

OUTCOME-BASED CURRICULUM

PART-D

Detailed Outcome-based Course Curriculum

for

Master of Science (MS)

MS 1st Semester

Course Title	**THEORY OF RINGS AND MODULES**	**ISCED Code**	0541-5101
		Course Code	MATH 5101
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Linear Algebra, Geometry, Group Theory	**Total Marks**	100

Rationale

A ring is an important fundamental concept in algebra and includes integers, polynomials and matrices as some of the basic examples. Ring theory has applications in number theory and geometry. A module over a ring is a generalization of a vector space over a field. The study of modules over a ring $\mathbb{R}$ provides us with an insight into the structure of $\mathbb{R}$. In this course, we shall develop ring and module theory, leading to the fundamental theorems of Wedderburn and some of their applications.

Course Objectives

This course aims to develop the general theory of rings (especially commutative ones) and then study in some detail a new concept, that of a module over a ring. Both abelian groups and vector spaces may be viewed as modules, and important structure theorems for both follow from the general theory. The theory of rings and modules is key to many more advanced algebra courses, e.g. Algebraic Number Theory.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Become familiar with rings and fields, and understand the structure theory of modules over a Euclidean domain, along with its implications.
CLO2	Write precise and accurate mathematical definitions of objects in ring theory.
CLO3	Use mathematical definitions to identify and construct examples and to distinguish examples from non-examples.
CLO4	Validate and critically assess a mathematical proof.
CLO5	To understand how every finitely generated module is a homomorphic image of a free module.

Course Contents

Course Contents		Hours	CLOs
1.	Rings of fractions and embedding theorems. Local rings and Noetherian rings.	05	1, 2
2.	Rings with Ore conditions and related theorems.	04	1, 2
3.	Field extensions and finite fields. Wedderburn's theorem on finite-dimensional rings.	06	1, 3
4.	Jacobson's work on the commutativity of rings.	04	1, 3, 4
5.	Modules, submodules and direct sums, R-homomorphisms and quotient modules.	07	1, 5
6.	Completely reducible and free modules.	04	1, 3, 5
7.	Sequences and exact sequences of modules. Projective and injective modules.	04	1, 3, 4
8.	Semisimple and simple rings.	03	1, 2
9.	Noetherian and Artinian modules. Wedderburn-Artin theorem.	05	1, 2

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	–	♦	♦	♦	♦	–	–	–	–
CLO3	♦	♦	–	♦	♦	♦	♦	♦	♦	♦	–	–
CLO4	♦	♦	♦	♦	♦	♦	–	♦	♦	♦	♦	–
CLO5	♦	♦	♦	♦	–	♦	♦	♦	♦	♦	♦	♦

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative) & Final exam (Summative)
CLO5	Lecturing and Student Activity	Midterm & Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Musili, C.**, *Introduction to Rings and Modules*. Narosa Publishing House, 1997.
ii.	**Paley, H. & Weichsel, P.M.**, *A First Course in Abstract Algebra.* Pearson, 2002.
iii.	**Zariski, O. & Samuel, P.**, *Commutative Algebra.* Springer, 1975.

Supplementary Readings

i.	**Lamback, J.**, .*Lecture on Ring and Modules.* American Mathematical Society, 2009.
ii.	**Aggarwal, R.S.**, *A Textbook on Modern Algebra.* S. Chand & Co., 1973.
iii.	**Kenneth, M.**, *Elements of Modern Abstract Algebra.* Harper & Brothers, 1958.

Course Title	**ADVANCED FUNCTIONAL ANALYSIS**	**ISCED Code**	0541-5102
		Course Code	MATH 5102
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Functional Analysis	**Total Marks**	100

Rationale

Functional analysis plays an important role in the applied sciences as well as in mathematics itself. These notes are intended to familiarize the student with the basic concepts, principles and methods of functional analysis and its applications, and they are intended for senior undergraduate or beginning graduate students. The notes are elementary assuming no prerequisites beyond knowledge of linear algebra and ordinary calculus (with epsilon-delta arguments). The notes should hence be accessible to a wide spectrum of students and may also serve to bridge the gap between linear algebra and advanced functional analysis. Functional analysis is an abstract branch of mathematics that originated from classical analysis. The impetus came from applications: problems related to ordinary and partial differential equations, numerical analysis, calculus of variations, approximation theory, integral equations, and so on. In ordinary calculus, one dealt with limiting processes in finite-dimensional vector spaces (R or R_n), but problems arising in the above applications required a calculus in spaces of functions (which are infinite-dimensional vector spaces).

Course Objectives

This is an excellent advanced course on Functional Analysis. This course's approach is driven by two main factors: the audience and teaching methods. Regarding the audience, the goal is to ensure that the method is comprehensible and applicable to individuals in every area of engineering and physical sciences. In terms of pedagogy, the aim is to render the technical derivations and explanations as clear and straightforward as possible, avoiding oversimplification. Course aims include examining key ideas of Spectral Analysis in Hilbert Spaces, covering topics like bilinear and quadratic forms, symmetric operators, normal and self-adjoint operators, as well as the spectral theorem for bounded self-adjoint operators. Additionally, explore the key ideas of Nonlinear Compact Operators and Monotonicity: Banach Fixed Point theorem with its applications, Schauder fixed point theorem; Frechet derivative, Newton's method for nonlinear operators, as well as positive and monotone operators

Course Learning Outcomes (CLOs

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Know and use the properties of topological linear spaces. Also, explain the concepts of convex sets and hyperplanes, semi-norms, locally convex spaces, weak topology, compact convex sets, duality in Banach spaces.
CLO2	Understand the concept of spectral analysis of linear operators and be able to analyze the necessary problems and theorems on the spectrum and the resolvent operator.
CLO3	Understand the spectral theorem for bounded self-adjoint operator.
CLO4	Use knowledge as basic tools for the development of such areas as quantum mechanics, harmonic analysis and stochastic calculus
CLO5	Study the essential concepts of Nonlinear Compact Operators and Banach Fixed point theorem with applications, Schauder fixed point theorem; Frechet derivative, Newton's method for nonlinear operators, positive and monotone operators.

Course Contents

Course Contents		Hours	CLOs
1.	**Topological Linear Spaces:** Convex sets and hyperplanes, semi-norms, locally convex spaces, weak topology, compact convex sets, duality in Banach spaces.	8	1, 4

2.	**Linear Operators:** Continuity and boundedness, fundamental properties of bounded operators, uniform boundedness principle, conjugate of bounded linear operators, adjoint operator and its duality, bounded linear operators in Hilbert spaces, unbounded linear operator.	8	1, 2, 3, 4
3.	**Spectral Analysis of Linear Operators**: Spectrum and the resolvent operator, spectrum of a bounded linear operator, compact operators.	8	3, 4, 5
4.	**Spectral Analysis in Hilbert Spaces:** Bilinear and quadratic forms, symmetric operators, normal and self-adjoint operators, the spectral theorem for bounded self-adjoint operators, unbounded self-adjoint operators.	9	5, 5
5.	**Nonlinear Compact Operators and Monotonicity:** Banach Fixed point theorem with applications, Schauder fixed point theorem, Frechet derivative, Newton's method for nonlinear operators, positive and monotone operators.	9	5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	-	♦	-	-	-	-	-	-	-	-	-
CLO2	♦		♦	-	-	-	-	-	-	-	-	-
CLO3	-	-	-	-	-	-	-	-	-	-	-	-
CLO4	-	-	-	♦	-	♦	♦	-	-	-	-	-
CLO5	-	-	♦	-	-	♦	-	-	-	-	-	-

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Quiz/ Homework (Formative)
CLO2	Lecturing and Discussion	Midterm (Summative)
CLO3	Lecturing and Visual Presentation	Assignment (Formative) and Midterm (Summative)
CLO4	Lecturing, Student Activity and Discussion	Midterm (Summative)
CLO5	Lecturing and Discussion	Final Exam (Summative)

Learning Materials

Recommended Readings

i.	**Kreyszig E.,** Introductory Functional Analysis with Applications,*John Willey & Sons,* 1978.
ii.	**Rudin, W.,** Functional Analysis, *Tata Mcgraw-Hill, Inc., 2nd Edition*, 1991**.**

Supplementary Readings

i.	**Taylor A.E.,** Introduction to functional analysis, *John Wiley & Sons, Inc.,* 1967.
ii.	**Oden J. T. and Demkowicz J.,** Applied Functional Analysis, *CRC press, 3rd Edition,* 2018.

Course Title	**ADVANCED FUZZY MATHEMATICS**	**ISCED Code**	0541-5103
		Course Code	MATH 5103
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Fundamentals of Mathematics, Fuzzy Mathematics	**Total Marks**	100

Rationale

Advanced Fuzzy Mathematics has become an acknowledged research subject in both pure and applied mathematics, showing how this theory is highly applicable and productive in many applications. Despite being a core subject for many years, fuzzy mathematics still attracts researchers to put forth solutions for prime issues with certain features questioned by these notions. Advanced fuzzy mathematics can effectively deal with a wide spectrum of problems in the physical world via cooperation, which may be beyond the capability of classical techniques. This course covers the basic concepts of fuzzy sets, fuzzy set operations, fuzzy groups and rings. This course also covers the topics of fuzzy topological spaces, fuzzy continuous functions, compact fuzzy topological spaces and connected fuzzy topological spaces and some theorems related to these topics.

Course Objectives

After successive completion of this course, students will explore the following: facility with the main, big theorems of fuzzy mathematics, learning the fundamental concepts of fuzzy topological spaces and subspaces, ability to use duality in various contexts and theoretical results from the course in concrete situations, capacity to work with families of applications appearing in the course, particularly specific calculations needed in the context of famous theorem, be able to produce examples and counter-examples illustrating the mathematical concepts presented in the course, understand the statements and proofs of important theorems and be able to explain the key steps in proofs, sometimes with variation.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Gather Knowledge about elementary concepts, including basic types of fuzzy sets.
CLO2	Meaning and significance of the emergence of fuzzy set theory.
CLO3	Examine the linguistic variables and fuzzy equations and Explain the fundamental concepts and theorems of fuzzy topology.
CLO4	Construct fuzzy topological space examples and counter examples and describe continuity on fuzzy topology and weakly fuzzy topological space.
CLO5	Distinguish among different fuzzy topological spaces and Clearly describe the compactness and connectedness of fuzzy topological spaces.

Course Contents

	Course Contents	Hours	CLOs
1.	Fuzzy set, fuzzy subset, empty fuzzy set, equality of two fuzzy sets, complement of a fuzzy set, union and intersection of fuzzy sets, De Morgan's laws. Product of fuzzy sets, fuzzy point and fuzzy singleton, function and some basic results, definition of fuzzy groups, rings, etc.	4	1, 2, 3, 4
2.	Fuzzy topological spaces and subspaces. Open and closed fuzzy sets, base and sub-base, interior and closure of a fuzzy set. Neighbourhood of a fuzzy point and a fuzzy singleton. Quasi-coincidence of a fuzzy singleton. Product spaces.	10	1, 5
3.	Fuzzy continuous function and some basic results. Lower and upper semi-continuous functions. Good extension, strong and weak a-cut, initial property, weakly induced fuzzy topological spaces.	6	3, 4

4.	Separation axioms: i) To T_1 and T_2 fuzzy topological spaces, ii) R_0 and R_I Fuzzy topological spaces, iii) regular and normal fuzzy topological spaces, and iv) a-separation properties.	8	3, 4
5.	Compact fuzzy topological spaces and some theorems on compactness. Comparison of different compactness Notions. A- compactness.	10	4, 5
6.	Connected fuzzy topological spaces, Comparison of some different fuzzy connectedness concepts. Some theorems on fuzzy connected spaces.	4	4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	♦	–	–	♦	♦	–	–	♦	–	♦
CLO2	–	♦	♦	♦	–	–	–	♦	♦	♦	♦	–
CLO3	♦	♦	♦	–	♦	♦	♦	♦	–	♦	♦	–
CLO4	–	–	♦	♦	♦	–	♦	♦	–	♦	♦	♦
CLO5	–	♦	♦	♦	♦	♦	♦	♦	♦	♦	–	♦

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative) & Final exam (Summative)
CLO5	Lecturing and Student Activity	Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Lowen, R.,** *On the existence of Natural Non-topological fuzzy topological spaces*, Hel Derinann Verlage, Berlin, 1985.
ii.	**Kaufman, A., Zimmermann, H. J. and Jones, A.,** *Fuzzy Set Theory andApplications*, D. Riedel Publications Co., 1986.
iii.	**Palaniappan, N.,** *Fuzzy Topology*, Narosa Publishing House, India, 2008.

Supplementary Readings

i.	**Kaufman, A.,** *Introduction to the theory of fuzzy subsets*, CAD Press, 1975.

Course Title	OPERATIONS RESEARCH	ISCED Code	0541-5104
		Course Code	MATH 5104
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Linear Algebra, Numerical Analysis, Linear Programming	**Total Marks**	100

Rationale

Operations Research (OR), also known as Management Science, is the study of scientific approaches to decision-making problems. Through mathematical modelling, it aims to design, improve, and operate complex systems in the most effective manner possible. This comprehensive course covers various areas of OR. The module includes topics such as linear programming, the bounded variable simplex algorithm, transportation and assignment problems, job sequencing, network models, dynamic programming, integer programming, game theory, and nonlinear programming. Analytic techniques and computer packages will be employed to solve problems encountered in various real-life application-oriented decision-making scenarios.

Course Objectives

The objectives of this course are to:

1. Formulate real-world problems as mathematical programming models.
2. Implement and solve these models using various software packages.
3. Address specialised linear programming problems, such as transportation and assignment problems.
4. Solve network models, including the shortest path, minimum spanning tree, and maximum flow problems.
5. Understand the applications of, basic methods for, and challenges in integer programming.
6. Gain knowledge on modelling and solving problems using dynamic programming.
7. Learn optimality conditions for both single- and multiple-variable unconstrained and constrained nonlinear optimisation problems.
8. Acquire corresponding solution methodologies for the aforementioned optimisation problems.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Students will be able to model and solve real-life-oriented problems, such as transportation and assignment problems. Additionally, they will develop the ability to connect these problems with network models.
CLO2	They will be familiarised with job scheduling problems along with their solution procedures.
CLO3	The application of a bounded variable linear program will be understood in modelling several network models.
CLO4	They will learn modelling with integer programming along with the solution techniques and students will get some basic background on Dynamic programming and Game theory.
CLO5	They will be able to solve constrained and unconstrained nonlinear optimisation problems and Students will be able to develop applications using the familiar software tools (EXCEL/SOLVER, LINDO, MATLAB, MATHEMATICA, etc.) to solve problems.

Course Contents

Course Contents		Hours	CLOs
1.	Basic Concepts: Introduction, the nature, Scope and role of operations research, Main operations research, Study, modelling in operations research, General methods for solving operations research models.	5	1, 3

2.	Decision making in operations research, Advanced Linear Programming.	3	1, 2, 4
3.	Goal-Programming, Single Objective Versus Multiple Goals, A Goal-Programming Algorithm.	4	1, 2, 3
4.	Integer Linear programming: Introductions and Illustrative Applications, Integer-Programming Solution, Algorithm, Dynamic programming.	5	1, 2, 4
5.	Decision Theory: Decision under Risks, Decision Trees, and Decision under Uncertainty.	6	2, 3, 5
6.	Markovian Decision process, Scope of the Markovian Decision problems, Finite-stage Dynamic Programming Model, Infinite Stage model, Inventory model.	6	1, 2,
7.	Game theory: Matrix game, Optimal solution of two-person zero-sum game, mixed strategies, Graphical solution of (2Xn) and (Mx2) games, solution of (mxn) games by Linear Programming.	6	1, 4, 5
8.	Non-Linear Programming: General optimisation problem, concave and convex function optimisation of convex function, General Non-Linear Programming, Lagrange's method for equality and inequality constraints, Kuhn-Tucker method and Quadratic Programming.	7	1, 2, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	♦	–	♦	–	–	–	–	♦	–	–
CLO2	♦	–	♦	–	–	–	–	–	♦	♦	–	♦
CLO3	–	–	♦	–	–	♦	♦	–	–	♦	♦	–
CLO4	–	♦	♦	–	–	–	–	♦	–	–	–	–
CLO5	♦		–	♦	–	♦	♦	–	–	–	–	–

♦Aligned –Not-aligned

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Group Discussion	Presentations (Formative) Midterm, Final exam (Summative)
CLO2	Lecturing and Student Activity	Quiz/Homework (Formative), Midterm (Summative)
CLO3	Lecturing and Group Discussion	Final exam(Summative)
CLO4	Lecturing and Visual Presentation	Assignment and Presentations (Formative), Midterm, and Final exam (Summative)
CLO5	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Taha, H. A.,** *Operations research: an introduction*. Pearson Education India, 2013.
ii.	**Gupta, P. K., & Hira, D. S.,** *Problems in operations research: principles and solutions*. S. Chand, 1991.
ii.	**Holloway, C. A.,** *Decision making under uncertainty: models and choices***.** Prentice-Hall, 1979.
iv.	**Kapoor,V.K., O***perations Research***,** Sultan Chand &Sons, 2011.

Supplementary Readings

i.	**Gupta, P.K. & Mohon, M.**, *Linear Programming & Theory of Games*, S. Chand,1997.
ii.	**Strayer, L.J.K.**, *Linear Programming &Its Applications,*Springer,1989

Course Title	FLUID DYNAMICS	ISCED Code	0541-5105
		Course Code	MATH 5105
Course Hour	3.0 Hr./Week	Credit Value	3
Prerequisite	Hydrodynamics	Total Marks	100

Rationale

Fluid dynamics covers the development of the fundamental equations of fluid mechanics for viscous incompressible fluids and their exact solutions for several cases. Topics include the principles of conservation of mass, momentum and energy, steady and unsteady laminar flow and the theory of very slow motion. This course has a wide range of applications, including calculating forces and moments on aircraft, determining the mass flow rate of petroleum through pipelines, predicting weather patterns and in traffic engineering, etc.

Course Objectives

It is an excellent introductory course on a viscous incompressible flow, which is encountered in several engineering and industrial applications. This course aims to expose the students to the role of viscosity and to familiarise them with the mathematical descriptions of incompressible viscous flows. Some basic flows will be dealt with in this course.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Establish the relation between Lagrangian and Eulerian methods to describe the fluid motion.
CLO2	Discuss dimensional analysis and the physical significance of some useful dimensionless numbers in fluid dynamics.
CLO3	Discuss Newton's law of viscosity, the difference between Newtonian and Non-Newtonian fluids, body and surface forces, stress vector and its various components
CLO4	Establish the relations between the stress and the rate of strain tensor.
CLO5	Apply the laws of conservation of mass, momentum and energy to derive the Equation of continuity, Navier-Stokes and energy equations for the flow of a Viscous incompressible fluid and solve the Navier-Stokes equations for both steady and unsteady laminar flows in various geometries to calculate the velocity distributions and the wall shear stress.

Course Contents

	Course Contents	Hours	CLOs
1.	**Basic Concepts**: Fluid, fluid properties, Laminar and turbulent flow, Viscosity, Kinematics of fluids in motion, Equation of continuity. Dimensional analysis, Dimensionless numbers.	10	1, 2
2.	**General theory of stress and rate of strain:** Newton's law of viscosity, Newtonian and Non-Newtonian fluids, body and surface forces, stress vector and components, Relations between the stress and rate of strain, Transformation of stress components. Nature of strain.	10	2, 3, 4
3.	**Introduction and General Properties of Navier-Stokes equations:** Derivation of the Navier-Stokes equations of motion and their general properties. Equation of motion in cylindrical and spherical coordinate systems. Derivation of the energy equation.	10	4, 5
4.	**General Properties of the equations of motion:** Similarity Laws, Exact solutions of the Navier-Stokes Equations: (i) Steady Plane flows: (a) Couette-Poiseuille flow. (b) Plane stagnation-point. (c) Flow past a circular cylinder. (ii)	12	4, 5

	Steady Axisymmetric flows (a) The Hagen-Poiseuille flow. (b) Flow between two concentric rotating cylinders. (c) Flow at a rotating disk. (iii) Unsteady plane flows: (a) Flow at a wall suddenly set into motion. (b) Flow at an oscillating plate. (c) Unsteady plane stagnation-point flow. (iv) Unsteady Axisymmetric Flows.		

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	–	♦	–	♦	–	♦	–	–	–
CLO3	♦	♦	–	♦		–	♦	♦	♦	–	–	–
CLO4	♦	♦	♦	♦	♦	–	♦	–	♦	–	–	–
CLO5	♦	♦	♦	♦	♦	–	♦	♦	♦	–	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Group Discussion	Presentations (Formative) Midterm & Final exam (Summative)
CLO2	Lecturing and Student Activity	Quiz/Homework (Formative), Midterm (Summative)
CLO3	Lecturing and Group Discussion	Final exam (Summative)
CLO4	Lecturing and Visual Presentation	Assignment and Presentations (Formative), Midterm, and Final exam (Summative)
CLO5	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Schlichting, H., & Gersten, K.**, *Boundary-layer theory*. Springer, 2016.
ii.	**Raisinghania, M.D.**, *Fluid dynamics with complete hydrodynamics and boundary layer theory*. S. Chand Publishing, 2013.
iii.	**Batchelor, G.K.**, *An introduction to fluid dynamics*. Cambridge University Press, 2000.

Supplementary Readings

i.	**Charlton, F.**, *The textbook of fluid dynamics*. Cambridge University Press, 1967.
ii.	**Pop, I., & Ingham, D.B.,** *Convective heat transfer: mathematical and computational modelling of viscous fluids and porous media*. Elsevier, 2001.
iii.	**Bansal, J.L.**, *Viscous fluid dynamics*. Oxford & IBH Publishing Company, 1977.

Course Title	**DIFFERENTIAL AND INTEGRAL EQUATIONS**	**ISCED Code**	0541-5106
		Course Code	MATH 5106
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Ordinary Differential Equations I & II, Partial Differential Equations and Linear Algebra	**Total Marks**	100

Rationale

This course is intended to develop rigorous, practical and analytic skills in **Differential and Integral Equations** (DIE). It is intended to illustrate various applications of differential and integral equations to technical problems as well. The laws of nature are expressed as differential and integral equations. Scientists and engineers must know how to model the world in terms of differential and integral equations, and how to solve those equations and interpret and analyse the solutions. This course focuses on theoretical aspects of linear and nonlinear differential and integral equations and their applications in science and engineering. More details are given in the course goals below.

Course Objectives

To give knowledge on some basic mathematical analysis of solutions of differential and integral equations.

1. To know how to interpret the solutions of DIE.
2. To learn about the application DIE to model and analyse real-life problems.
3. Numerical solutions of integral equations.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Explain the concept of differential and integral equations.
CLO2	Expresses the existence-uniqueness theorem of differential and integral equations.
CLO3	Explains basic properties of solutions of DIE and acquire knowledge about the relation between differential and integral equations
CLO4	Obtain analytic solutions of differential equations and examine the stability or instability of the zero solution of both linear and nonlinear differential equations and obtain the solutions of Fredholm and Volterra integral equations of the second kind.
CLO5	Obtain analytic and semi-analytic solutions of a class of integral equations and Gain knowledge about the applicability of differential equations and integral equations in various branches of science and engineering.

Course Contents

	Course Contents	Hours	CLOs
1.	Existence and uniqueness theorem for differential equations: Methods of successive approximations, Peano's existence theorem, fixed point methods, Continuation of solutions.	6	1, 2
2.	System of differential equations: Linear systems and their solutions by eigenvalue methods, variation of parameters, Exponentials with applications.	5	3, 4, 5
3.	Integral equations: Conversions of IVP's to integral equations, Differentiation of a function under an integral sign, Relation between differential & integral equation, Solutions of Volterra Integral Equations of second kind, Iterated kernel, Resolvent kernel, VIE of first kind, Solution of FIE, Fredholm first theorem, Uniqueness of solution, Fredholm second & third theorem, Solution of Homogeneous Integral Equation, Continuous solution, Fundamental solution, Integral equation with degenerate kernel	1.	3, 4

4.	Stability theory: Stability of Linear a nonlinear systems of differential equations and Volterra integral equations, Lyapunov functions and determinations of stability.	5	4, 5
5.	Periodic solutions: Periodic solutions of Linear and nonlinear differential and Integral equations.	4	5
6.	Boundary value problems: Homogeneous and Non-Homogeneous differential equations. Eigenvalue problem, Physical Application. Sturm-Liouville theory, Green functions.	10	4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	**PLO1**	**PL02**	**PLO3**	**PLO4**	**PLO5**	**PLO6**	**PLO7**	**PLO8**	**PLO9**	**PLO10**	**PLO11**	**PLO12**
CLO1	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	–	–	–	–	–	♦	–	–	–	–
CLO3	♦	♦	–	–	–	–	–	♦	♦	♦	–	–
CLO4	♦	♦	♦	♦	♦	–	♦	–	–	–	–	–
CLO5	♦	♦	–	♦	♦	–	♦	–	–	–	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	**Teaching-Learning Strategy**	**Assessment Strategy**
CLO1	Lecturing and Student Activity	Quiz/Homework (Formative), Midterm (Summative)
CLO2	Lecture**,** recommended textbook, worksheets, printed solutions and Slide Presentation	Assignment & Presentations (Formative), Midterm & Final exam(Summative)
CLO3	Lecturing, Questioning and Answer Questioning	Homework (Formative), Midterm & Final exam (Summative)
CLO4	Lecturing, Visual Presentation, and Group Discussion	Final exam (Summative)
CLO5	Lecturing and Group Discussion	Assignment, Presentations, Final exam (Summative) Midterm &Final exam(Summative)

Learning Materials

Recommended Readings

i.	**Rahman, M.**, Integral equations and their applications. WIT press, 2007.
ii.	**Atkinson, K. E.**, The numerical solution of integral equations of the second kind (Vol. 4). Cambridge University Press, 1997.
iii.	**Burton, T. A.**, Volterra integral and differential equations (Vol. 202). Elsevier, 2005.
iv.	**Corduneanu, C.**, Principles of differential and integral equations (Vol. 295). American Mathematical Society, 1977.

Supplementary Readings

i.	**Hirsch, M. W., Devaney, R. L., & Smale, S.**, Differential equations, dynamical systems, and linear algebra (Vol. 60). Academic Press, 1974.
ii.	**Burton, T. A.**, Stability & periodic solutions of ordinary & functional differential equations. Courier Corporation, 2005.

Course Title	THEORY OF RELATIVITY	ISCED Code	0541-5107
		Course Code	MATH 5107
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Classical Mechanics, Electromagnetism, Calculus	**Total Marks**	100

Rationale

It is an excellent introductory course on theory of relativity. This is a module principally on Einstein's general theory of relativity, a relativistic theory of gravitation which explains gravitational effects as coming from the curvature of space-time. It provides a comprehensive introduction to material which is currently the subject of enthusiastic study from the theoretical and experimental standpoints. In addition, in order to understand the general theory fully, some familiarity with tensor calculus is required. This will involve some self-study material at the start of the module.

Course Objectives

The objective of this course is to introduce the concept of space-time, the theory of special relativity and some preliminary ideas from general relativity and the mathematical model of the expanding universe.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Explain the fundamental postulates of special relativity and limitations of classical mechanics.
CLO2	Apply Lorentz transformations to solve problems involving time dilation, length contraction, and simultaneity.
CLO3	Analyze relativistic dynamics including energy-momentum relations and mass energy equivalence and evaluate experimental evidences supporting special and general relativity.
CLO4	Solve problems related to general relativity including gravitational time dilation and geodesics in curved space time and communicate complex ideas of relativity through clear mathematical and conceptual reasoning
CLO5	Investigate the relationship between relativity and electromagnetics, particularly the four-dimensional representation of Maxwell's equations and Understand how a black hole is described by the Schwarzschild metric.

Course Contents

	Course Contents	Hours	CLOs
1.	Absolute motion, the necessity of absolute frame, either as an absolute frame. Freshels hypothesis, Fizeaus experiment and Airy's experiment, (Abberation of star). Michelson –Morleys experiment, Einsteins definition of simultaneity, the two postulate of Relativity, Laurent's Transformation, Fitzeralel contraction, Dilation of time, Minkowski's force, variation of mass and energy.	14	1, 2, 5
2.	Four dimensional representation of velocity momentum etc, Energy momentum tensors. Electric magnetic vectors as the component of tensors, electromagnetic field tensor, Transformation of Electric and magnetic vectors, transformation of four current vectors, Invariance of electric charge, Maxwell's Fundamental equation as desirable in relativity, energy momentum of electromagnetic field.	14	1, 3, 4
3.	Principle of covariance. Principle of equivalence. Principle of Mach and Einstein's law of gravitation Potentials. Newton's law: First approximation and Schwarzschild solution of Einstein's equation. Equation of Fundamental metric of Schwarzschild line elements. Trajectory of a particle equation of motion. The three test: The advance of the perihelion of mercury, Shift of the special lines Gravitation, Reflection of the light ways.	14	1, 4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	♦	♦	♦	♦	♦	♦	♦		–	–
CLO2	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO3	♦	♦	–	–	–	♦	–	♦	–		–	–
CLO4	♦	♦	♦	♦	♦	–	♦	–	–	–	–	–
CLO5	♦	–	♦	–	♦	♦	–	♦	♦	♦	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	**Teaching-Learning Strategy**	**Assessment Strategy**
CLO1	Lecturing and Student Activity	Quiz/Homework (Formative), Midterm (Summative)
CLO2	Lecture**,** recommended textbook, worksheets, printed solutions and Slide Presentation	Assignment & Presentations (Formative), Midterm & Final exam(Summative)
CLO3	Lecturing, Questioning and Answer Questioning	Homework (Formative), Midterm & Final exam (Summative)
CLO4	Lecturing, Visual Presentation, and Group Discussion	Final exam (Summative)
CLO5	Lecturing and Group Discussion	Assignment & Presentations (Formative), Midterm &Final exam(Summative)

Learning Materials

Recommended Readings

i.	**French, A. P.**, *Special relativity*. W.W. Norton & Company, 1968.
ii.	**Resnick, R.,** *Introduction to special relativity*. John Wiley & Sons, 1968.
iii.	**Schutz, B. F.,** *A first course in general relativity* (2nd ed.). Cambridge University Press, 2009.
iv.	**Hartle, J. B.,** *Gravity: An introduction to Einstein's general relativity*. Addison-Wesley, 2003.

Supplementary Readings

i.	**Tolman, R. C.,** *Relativity, thermodynamics, and cosmology*. Courier Corporation, 1987.
ii.	**Weinberg, S.,** *Gravitation and cosmology: principles and applications of the general theory of relativity*. John Wiley & Sons, 2013.

Course Title	**ADVANCED NUMERICAL ANALYSIS**	**ISCED Code**	0541-5108
		Course Code	MATH 5108
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Numerical Methods, Ordinary Differential Equations and Partial Differential Equations	**Total Marks**	100

Rationale

This course provides a rigorous foundation in **Finite Difference Methods (FDM)**, a core computational approach for solving ordinary and partial differential equations (ODEs and PDEs). Designed for graduate students in mathematics, engineering, and the physical sciences, the course bridges theoretical understanding with practical implementation. It equips students to model and solve complex real-world problems that are otherwise analytically intractable. Thus, course deepens students' grasp of advanced numerical techniques, building on prior knowledge in numerical methods, ODEs, and PDEs. It emphasizes application through computational tools, enabling students to simulate and analyze physical phenomena such as fluid flow, heat transfer, and wave propagation.

Course Objectives

The objective of this course is to equip students with a strong foundation in finite difference methods for solving ordinary and partial differential equations. Emphasis is placed on the formulation, analysis, and implementation of numerical schemes for a wide range of problems in science and engineering. Students will develop the ability to apply computational tools effectively, analyze the accuracy and stability of methods, and interpret results for real-world applications.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Apply finite difference methods (FDM) to solve linear and nonlinear ordinary and partial differential equations (ODEs and PDEs) arising from various mathematical models.
CLO2	Analyze finite difference approximations for systems of PDEs, focusing on accuracy, stability, and convergence.
CLO3	Identify and evaluate application areas where different types of finite difference methods are effectively used.
CLO4	Formulate and implement suitable numerical techniques to solve PDE-based problems in science and engineering and Interpret and validate numerical results using computational tools, particularly for complex PDEs in applications such as fluid flow, heat transfer, and elasticity.
CLO5	Utilize computational tools and software packages to model, simulate, and solve real-world problems involving more complicated PDEs such as those arising in fluid/heat transport.

Course Contents

	Course Contents	Hours	CLOs
1.	**Introduction to Finite Difference Methods:** Overview of boundary value problems (BVPs) for ODEs; finite difference methods for linear and nonlinear problems; introduction to the Rayleigh-Ritz method.	10	1, 4
2.	**Elliptic Partial Differential Equations (PDEs):** Finite difference formulations for Poisson's and Laplace's equations; matrix formulation of the model; iterative methods for solution; convergence, stability, and error analysis; applications in two spatial dimensions.	10	2, 3, 4, 5

3.	**Parabolic PDEs:** Finite difference schemes for initial-boundary value problems; matrix formulation of the heat equation; forward, backward, and Crank-Nicolson methods; ADI methods for 2D problems; Von Neumann stability and error analysis.	10	2, 4, 5
4.	**Hyperbolic PDEs:** Finite difference methods for wave equations in one and two spatial dimensions; explicit schemes such as Lax-Wendroff and CFL; Wendroff implicit methods; convergence, stability, and error analysis.	12	2, 4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	–	–	–	–	♦	–	–	–	–	–
CLO2	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO3	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO4	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO5	♦	♦	♦	–	–	–	–	–	–	–	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Quiz/Homework (Formative), Midterm (Summative)
CLO2	Lecture**,** recommended textbook, worksheets, printed solutions and Slide Presentation	Assignment & Presentations (Formative), Midterm & Final exam(Summative)
CLO3	Lecturing, Questioning and Answer Questioning	Homework (Formative), Midterm & Final exam (Summative)
CLO4	Lecturing, Visual Presentation, and Group Discussion	Final exam (Summative)
CLO5	Lecturing and Group Discussion	Assignment & Presentations (Formative), Midterm &Final exam(Summative)

Learning Materials

Recommended Readings

i.	**Burden R. L. and Faires J. D.,** Numerical Analysis, *Brooks/Cole*, 2011.
ii.	**Sastry S. S.,** Introductory Methods of Numerical Analysis, *Prentice-Hall of India*, 2008.
iii.	**G.D. Smith**, Numerical solution of Partial differential equations, Clarendon press, Oxford, 1978.
iv.	**Paul D. and David Zachmann**, Applied Partial differential Equations, Harper & Row Publications, New York, 1989.
v.	**Otto S. R. and Denier J. P.,** An Introduction to Programming and Numerical Methods in MATLAB, *Springer*, 2005.

Supplementary Readings

i.	**Celia M.A. & GrayW.G.**, Numerical Methods for Differential Equations, Prentice-Hall Int. Inc., 1992.
ii.	**Phillips G. M. and Taylor P. J.**, Theory and Applications of Numerical Analysis, Academic Press, 1996.
iii.	**Gerald C. F. and Wheatley P. O.**, Applied Numerical Analysis, Pearson, 2011.

Course Title	**MATHEMATICAL HYDROLOGY**	**ISCED Code**	0541-5109
		Course Code	MATH 5109
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Fundamentals of Mathematics, Fuzzy Mathematics	**Total Marks**	100

Rationale

Hydrology treats the flow of water on and below the surface of the Earth. It involves mainly water quality and treats river flood forecasting and groundwater flow to wells. It also treats soil deposition, stream erosion and sediment transport. Bangladesh is a riverine country. We have many international and national rivers. Mathematical Hydrology deals with the occurrence, movement, and storage of water in the Earth system. So, hydrology is a very important subject for our country.

Course Objectives

The objectives of this course are to give a clear concept to students about the use of Hydrology in science and water engineering fields. This course will help the student to identify surface flow, river flow, flood forecasting, measure soil erosion, and channel erosion by using different kinds of conceptual, mathematical and hydrodynamic models.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Identify different kinds of flow.
CLO2	Apply a unit hydrograph to derive a runoff hydrograph.
CLO3	Identify the grain size of soil, soil properties and soil water and Measure soil erosion, sediment transport, and sediment load.
CLO4	Understand the groundwater system and Measure flood, flood forecast and warning.
CLO5	Sketch the models of stochastic and deterministic nature and application of conceptual, mathematical and hydrodynamic models in real-life problems.

Course Contents

	Course Contents	Hours	CLOs
1.	Definition and Introduction to Hydrology: Hydrologic cycle, Hydrologic system model, Hydrologic model classification, and the development of Hydrology. Black box model.	6	1, 2
2.	Hydrologic process: Continuity equation, Discrete time continuity, Momentum equation. Open channel flow, porous medium flow, and Water balances. Precipitation. Evaporation and transpiration. Infiltration and soil moisture, the Green-Ampt method. Groundwater in the Hydrologic cycle.	8	1, 2
3.	Rainfall- runoff relations: Sources of stream flow, excess rainfall and Direct runoff. Abstraction using infiltration Equation, SCS method for abstraction, and index method. Travel time, streamflow, and Hydrographs. Unit Hydrograph methods and their applications, and synthetic unit Hydrograph. Instantaneous Unit Hydrograph (IUH) and its application.	7	2, 5
4.	Flood routing: Basic equations, Reservoir flood routing, River flood routing, Lumped flow routing. Distributed flow routing.	4	4, 5
5.	Frequency Analysis: Rational method. Empirical formulae, Return Period, Extreme value distributions, and Frequency analysis using frequency factors. Linear Channels. Conceptual and Mathematical Models: (i) Nash model (ii) Time area Method Clerk's model (iii) Dooge's model (iv) Chow and Kulandaiswany Model, (V) Muskingum Model.	6	3, 4

6.	Conceptual and Mathematical Models: Nash model, Time area Method, Clerk's model, Dooge's Model, Chow and Kulandaiswamy Model, Muskingum Models.	4	5
7.	Hydrodynamic Models: (i) Saint-Venant Equations from Navier-Stokes Equations, (ii) Kinematic Wave (KW) Models. (iii)Diffusion Wave Models. (iv) Steady dynamic Wave Models. (v) Dynamic Wave Models. (vi) Gravity Wave Models.	6	4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	–	–	–	–	–	♦	–	–	–	–
CLO2	♦	–	♦	–	–	–	–	–	♦	–	–	–
CLO3	♦	♦	–	–	–	♦	–	–	–	♦	–	–
CLO4	♦	–	♦	–	♦	–	♦	–	–	♦	–	–
CLO5	♦	♦	–	–	–	–	–	–	–	–	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Midterm & Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative), Final exam (Summative)
CLO5	Lecturing and Student Activity	Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Linsley Jr, R. K., Kohler, M. A., & Paulhus, J. L.,** Hydrology for engineers, 1975.
ii.	**DuChateau, P., & Zachmann, D. W.**, Applied partial differential equations. Courier Corporation, 2002.
iii.	**Rai, R. K., Ojha, C. S. P., & Singh, V. P.**, Handbook of Applied Hydrologic and Water Resources Engineering. CRC Press, 2025.

Supplementary Readings

i.	**Chow, V. T.**, Bibliography: 1) Handbook of applied hydrology, 1965.
ii.	**Reddy, P. J. R.**, *A textbook of hydrology*. Firewall Media, 2005.
iii.	**Singh, V. P.,** *Hydrologic systems: Rainfall-runoff modeling* (Vol. 1& 2). Prentice Hall, 1988.

Course Title	**RIEMANNIAN GEOMETRY**	**ISCED Code**	0541-5110
		Course Code	MATH 5110
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Topology, Functional Analysis, Differential Geometry	**Total Marks**	100

Rationale

This course is an introduction to the beautiful theory of **Riemannian Geometry**, a subject with no lack of interesting examples. The core of this course will be an introduction to Riemannian geometry - the study of Riemannian metrics on abstract manifolds. This is a classical subject, but it is required knowledge for research in diverse areas of modern mathematics.

Course Objectives

We will try to present the material to prepare for the study of some of the other geometric structures one can put on manifolds. They are indeed the key to a good understanding of it and will therefore play a major role throughout the course.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	understand the basic principles of Riemannian geometry.
CLO2	understand and work with manifolds, tangent spaces and curvature.
CLO3	work with sub-manifolds in their various forms and calculate with the geometry of curves and surfaces.
CLO4	the Riemannian metrics, Levi-Civita connection, and Riemannian geodesics and the Hopf-Rinow theorem.
CLO5	the Gauss-Bonnet theorem and its application and connections on the tangent bundles: torsion, geodesics, the exponential map.

Course Contents

	Course Contents	Hours	CLOs
1.	Introduction: Fundamental notions, Non-Euclidean geometry, symmetric spaces, Riemannian manifolds, Riemannian submanifolds, Pseudo-Riemannian manifolds. Curvature of Riemannian manifolds: Einstein space, Constant Riemannian curvature, Riemannian curvature, Recurrent space, Ricci-recurrent space, Geodesic curvature, scalar curvature, sectional curvature, Ricci curvature, Ricci decomposition, Weyl curvature, conformal curvature tensor and Einstein manifolds. Smooth Manifolds: Functions on smooth manifolds, Pull-back of functions, Tangent vector and tangent space, push-forward of tangent vectors.	6	1, 2, 3
2.	Smooth vector fields, Lie brackets (commutator), Lie algebra, Examples of matrix groups.	6	4
3.	Bundles: Vector bundles, Fibre bundles, Principal bundles, Tangent bundles, Cotangent bundles, Line bundle, Jet bundles, Tensor bundles, dual and normal bundles, sub-bundles. Vector bundle morphisms and isomorphisms. Metrics and Connections: Metrics and connections on bundles, Riemannian metrics. Affine connection, torsion and curvature tensors, Parallel transport, Geodesics, Levi-Civita connection, Coordinate representation of the curvature tensor	8	5
4.	Exterior Differential Calculus: Differential form, Exterior derivatives, exterior algebra (Grassman algebra), Grassman manifolds, projective space, the exterior derivative in calculus, wedge product, Poincaré's Lemma. Fundamental theorem of Riemannian geometry.	8	4, 5

5.	Metrics and Connections: Metrics and connections, Riemannian metrics. Affine connection, torsion and curvature tensors, Parallel transport, Geodesics, Levi-Civita connection, Coordinate representation of the curvature tensors.	6	3, 5
6.	Lie groups and homogeneous spaces: Abstract Lie Groups, Homogeneous space, Formulae for left- and bi-invariant metrics, Riemannian submersions.	8	5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	–	–	–	–	–	–	–	–	–	–
CLO2	♦	–	♦	–	–	–	–	–	–	–	–	–
CLO3	♦	–	♦	–	–	–	♦	–	–	–	–	–
CLO4	♦	♦	–	–	♦	–	–	–	–	–	–	–
CLO5	♦	♦	–	♦	♦	♦	♦	–	–	♦	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Learning through teaching is primarily based on lectures.	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Learning through take-home assignments helps students understand basic concepts and theories of spaces and curvature.	Homework (Formative), Final exam (Summative)
CLO3	Learning through teaching is primarily based on lectures.	Midterm & Final exam (Summative)
CLO4	Learning through take-home assignments helps students understand basic concepts and theories of curves and surfaces.	Presentation, Assignment (Formative) & Final exam (Summative)
CLO5	Lectures	Midterm, Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Lee, J. M.**, *Riemannian Manifolds: An Introduction to Curvature*, Springer, 1997.
ii.	**Jost, J.**, *Riemannian Geometry and Geometric Analysis*, Springer International Publishing AG, 2017.
iii.	**Chern, S.S., Chen, W.H. & Lam,K.S.**, *Lectures on Differential Geometry*, World Scientific India, 2022.

Supplementary Readings

i.	**Isham, C. S.**, *Modern Differential Geometry*, World Scientific, 1999.
ii.	**Arnold, V.I.**, *Mathematical Methods of Classical Mechanics,* Springer-Verlag, 1978.
iii.	**Chen, W.H., Chern, S.S. & Lam, K.S.**, *Lectures on Differential Geometry*, World Scientific, 2000.
iv.	**Darling, R.W.R.**, *Differential Forms and Connections*, Cambridge University Press, 1994.

Course Title	**REAL FUNCTION THEORY**	**ISCED Code**	0541-5111
		Course Code	MATH 5111
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Functional Analysis	**Total Marks**	100

Rationale

The foundational theory of measure and integration emerged during the early 1900s. Today, it is a crucial component in a wide range of mathematical fields, such as probability theory, partial differential equations, functional analysis, harmonic analysis, and dynamical systems. In fact, it has evolved into a unifying concept. Various topics can easily complement a discussion of **Real Function Theory**. The course supports numerous mathematical advancements from the past century by integrating linear algebra and analysis.

Course Objectives

This course aims to cover the essential concepts of measure theory, integration theory, and functional analysis that a contemporary analyst should be familiar with. Its main objective is to emphasize the principles of linear algebra and analysis to navigate infinite-dimensional vector spaces and linear transformations, while also providing advanced theories related to differential equations, measure theory, and both harmonic and complex analysis, as well as elucidating the core concepts of Banach and Hilbert spaces, Lebesgue measure, and more. The relationship between integration and functional analysis is enhanced throughout this course.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Study the abstract theory of measures.
CLO2	Learn the abstract theory integrations. Also, students will be able to generalise the concepts like continuity, convergence, etc., to perform them in a rigorous proof in a wider context.
CLO3	Analyse the abstract theory applications in modern analysis.
CLO4	Inspect the abstract theory of measure space.
CLO5	Assess the abstract theory of Topology. Also, students will be able to distinguish between analysis in infinite and finite-dimensional spaces.

Course Contents

	Course Contents	Hours	CLOs
1.	**Topics of Lebesgue Integration on $\mathbb{R}$:** Uniform integrability, Convergence in Measure, Characterisation of Riemann Lebesgue integrability, Vitali convergence theorem, continuity, absolute continuity, and differentiability of monotone functions.	8	1, 2
2.	**General measure spaces:** Measures and measurable sets, measure induced from the outer measure, an extension of a pre-measure to a measure, signed measure, Hahn and Jordan decomposition.	8	2, 3, 4
3.	**Integration over general measure spaces:** Measurable functions. Integration of measurable functions, the Radon-Nikodym derivative, and its properties.	8	3, 4,5
4.	**Construction of some particular measures:** Product measure and theorem of Fubini and Tonelli, Caratheodory outer measure, and Hausdorff measures in a metric space.	10	4, 5
5.	**Measure and Topology:** Construction of Radon measures, Baire measures. Kakatuni's fixed point theorem, Invariant Borel measures, and von Neumann's theorem.	8	4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	–	♦	♦	♦	♦	–	–	–	–
CLO3	♦	♦	♦	♦	♦	♦	♦	–	♦	–	–	–
CLO4	♦	♦	–	♦	♦	♦	–	♦	♦	–	–	–
CLO5	♦	♦	♦	–	♦	♦	♦	♦	♦	–	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	**Teaching-Learning Strategy**	**Assessment Strategy**
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm& Final exam (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative) & Final exam (Summative)
CLO5	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)

Learning Materials

Recommended Readings

i.	**Folland, G. B.**, *Real analysis: modern techniques and their applications*. John Wiley & Sons, 1999.
ii.	**Natanson, I. P.**, *Theory of functions of a real variable*. Courier Dover Publications, 2016.
iii.	**Langlands, R.**, A Source Book in Classical Analysis, 1975.

Supplementary Readings

i.	**Halmos, P. R.**, *Measure theory* (Vol. 18). Springer, 2013.

Course Title	VIVA VOCE	ISCED Code	0541-5119
		Course Code	MATH 5119
Course Hour		Credit Value	2
Prerequisite	Recommended Books and Lecture Materials	Total Marks	50

Rationale

The viva gives students the chance to show that they have a thorough comprehension of the material and to respond to inquiries about the specifics of their project, thesis, or several first-semester courses. On this stage, they can demonstrate their intelligence and short-term social concerns.

Course Objectives

This is a platform to practice and show their smartness and confidence, as well as to address immediate issues in the society.

The main focus of the assessment is on the advanced mathematics courses designed for graduate program.

Mathematics is a fundamental subject, and job-seeking students ought to explore it in many institutions of the job market. Viva voce is vital for making mathematics acceptable in the business and research realms.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Develop crucial communication skills through oral examinations that promote self-realization and self-expression.
CLO2	Stimulate interactive interaction between candidates and assessors, allowing examinees to demonstrate their abilities and examiners to distinguish between superficial and profound knowledge through extensive questions.
CLO3	Exhibit the ability to tailor questions to the specific needs and abilities of individual students.
CLO4	Conduct real-time tests, which have traditionally been used in job market evaluations, to measure proficiency in several areas.
CLO5	Effectively evaluate top students by using in-depth questions to determine their degree of proficiency and gauge their higher-order cognitive skills.

Course Contents

Course Contents		Hours	CLOs
1.	Students respond orally to questions during the comprehensive viva examination. These tests frequently draw from both the first and second semesters' worth of coursework. A vital component of academic programs, viva exams are frequently administered at the end of each academic year.	First Semester	1, 2, 3, 4, 5
2.	These Viva examinations formed part of the theory component of the final summative examination in the second semester of the first year. Since the Viva Voce is conducted for all students irrespective of their passing status in theory, the exercise is time consuming. To determine the impact of viva voce examinations on summative examination performance, this study has been conducted.		

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	-	♦	-	♦	-	♦	-	-	-	-
CLO2	♦	♦	♦	♦	-	-	-	-	-	-	-	-
CLO3	-	♦	-	♦	-	♦	♦	♦	♦	-	♦	-
CLO4	-	-	♦	-	♦	♦	♦	-	♦	♦	♦	♦
CLO5	-	-	♦	-	-	-	-	-	♦	♦	♦	-

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1-CLO5	Student Activity	Presentation, concept and understanding on the taught courses, communication skills, Smartness and Confidence.

Learning Materials

Recommended Readings

i.	All recommended books of MS Year First Semester.

GED Courses

Course Title	**THERMODYNAMICS AND STATISTICAL MECHANICS**	**ISCED Code**	0533-5112
		Course Code	PHY 5112
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Thermal Physics, Calculus, Mathematical Physics	**Total Marks**	100

Rationale

The course on **thermodynamics and statistical mechanics** will introduce the main principles of thermodynamics and statistical mechanics, including their relationship and applications. The level will be appropriate to prepare students for graduate studies in Applied Mathematics. You will learn how the underlying concepts explain (at a first glance vastly different) topics such as blackbody radiation, paramagnetism, the ideal gas law and the internal mechanism of gas.

Course Objectives

After the successful completion of this course, students will explore the following:

1) Development of basic concepts of equilibrium thermodynamics, including the 0th, 1st and 2nd laws of thermodynamics, thermodynamic potentials.
2) To do essential statistics and apply probability distributions to do some thermodynamic calculations.
3) Get a theoretical knowledge of the concept of ensemble theory: micro canonical & macrocanonical, and apply the ensemble concepts to get a handle on the density of states.
4) Be able to apply the density of states concept to compute thermodynamic properties of a system, including the theory of paramagnetism.
5) An introduction to concepts of ideal Fermi and Bose systems, including a derivation of blackbody radiation as an ultra-relativistic Bose gas and simple Fermi systems in the low temperature limit (so: what are Bose-Einstein condensates, Fermi energy)

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Understand the statistical nature of concepts and laws in thermodynamics, in particular: entropy, temperature, chemical potential, free energies, partition functions, and thermodynamic driving forces.
CLO2	Analyze thermodynamic problems using the concepts of state properties such as temperature, pressure, entropy, and volume, and process variables such as heat and work.
CLO3	Apply thermodynamic concepts such as quasistatic, reversible, adiabatic, intensive, extensive, and isothermal to solve problems in thermodynamics, Relationships Between CV, CP, BT, BS, and αV, Clapeyron's Equation, Maximum Entropy, Equilibrium, and Stability; Some Problems on the above related topics.
CLO4	Apply the concepts and laws of thermodynamics to solve problems in thermodynamic systems, such as gases, heat engines, refrigerators, and system phase transitions, Kinetic Theory of Gases, Velocity Distribution, Maxwell Distribution, Mean-Free-Path, Some Problems, Boltzmann Entropy, Thermodynamic Properties.
CLO5	Explain how a given partial derivative relation relates to a particular experimental measurement and use the methods of statistical mechanics (in particular, the Boltzmann statistics, Bose-Einstein statistics. Statistics, Fermi–Dirac ratio and summation over probabilities) to solve for thermal properties in equilibrium.

Course Contents

	Course Contents	Hours	CLOs
1.	**Elements of Thermal Physics:** Equations of state. Work Co-efficient of Expansion compressibility PVT Systems, Equilibrium States, Processes and Heat, Temperature, Heat Capacity and Specific Heat, Work, Heat, The First Law of thermodynamics and its applications, Conventions, Equilibrium Properties, Relationships between Properties, Ideal Gases, Temperature Change with Elevation, Cyclic Processes, Heat Engines, Solids, Liquids, and Gases, Latent Heats, Van der Waals Model, Classification of Phase Transitions, Idealization and Reversibility, Nonequilibrium Processes and Irreversibility, Heat Conduction.	7	1, 2
2.	**Foundations of Thermodynamics:** Energy, Heat, and Reversibility, Cyclic Processes, Second Law of Thermodynamics and its applications, Carnot Cycles, Absolute Temperature, Temperature Scales, Uniform Scales and Absolute Zero, Entropy, Enthalpy, Clausius' Theorem, Entropy Principle, Entropy and Irreversibility, Useful Energy, The Third Law of thermodynamics and its applications. Differentials of Entropy and Energy, Ideal Gases, Relationships Between CV, CP, BT, BS, and αV, Clapeyron's Equation, Maximum Entropy, Equilibrium, and Stability, Some Problems on the above related topics.	8	1, 2, 3
3.	**Thermodynamic Potentials and Phase Transitions:** Internal Energy, Free Energies, Properties from Potentials, Systems in Contact with a Heat Reservoir, Minimum Free Energy, Two-Phase Equilibrium, Change of phase, Stephan's law, Chemical Potential, Multi-Component Systems, Gibbs Phase Rule, Chemical Reactions, Some Problems on the above related topics.	7	1, 2, 3, 4
4.	**Statistical Thermodynamics:** Molecular Models, Gas Pressure, Equipartition of Energy, Internal Energy of Solids, Degrees of Freedom, Kinetic Theory of Gases, Velocity Distribution, Maxwell Distribution, Mean-Free-Path, Some Problems, Boltzmann Entropy, Thermodynamic Properties, Boltzmann Factors, Maxwell Boltzmann distribution, Boltzmann transport Equation, Mean path, Viscosity, Thermal conductivity, Diffusion.	8	1, 5
5.	**Statistical Mechanics-I:** Ensembles, Probabilities and Averages, Two-Level Systems, Canonical Thermodynamics, Composite Systems, Hamiltonians and Phase Space, Model Hamiltonians, Thermodynamic Properties and Averages, Energy Eigenstates, Einstein Model, Standard Deviation, Energy Fluctuations, Gibbs Paradox.	6	1, 3, 5
6.	**Statistical Mechanics-II:** Plane Wave Eigenstates, Photons, Harmonic Approximation, Phonons, Application of the Boltzmann statistics, Bose-Einstein statistics. Statistics of a photon gas, Difficulties with the Maxwell-Boltzmann statistics, Identical Particles, Exchange Symmetry, Fermi Gases, Bose Gases, Fermi–Dirac and Bose–Einstein Statistics, Density fluctuation in a gas. Theory of Brownian motion, Brownian motion of a galvanometer. The Small-Shot effect.	6	1, 3

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	–	♦	–	–	–	–	–	♦	♦	–
CLO2	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	–	–
CLO3	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	–
CLO4	♦	♦	♦	–	♦	–	♦	–	–	–	–	–
CLO5	–	♦	♦	♦	–	♦	♦	–	–	–	–	–

♦ *Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative) & Final exam (Summative)
CLO5	Lecturing and Student Activity	Homework (Formative), Midterm & Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Hardy, R. J., & Binek, C.**, Thermodynamics and statistical mechanics: an integrated approach. John Wiley & Sons, 2014.
ii.	**Shell, M. S.,** Thermodynamics and statistical mechanics: an integrated approach. Cambridge University Press, 2015.
ii.	**Greiner, W., Neise, L., & Stöcker, H.**, Thermodynamics and statistical mechanics. Springer Science & Business Media, 2012.
iv.	**Landau, L. D., & Lifshitz, E. M.**, Statistical Physics: Volume 5 (Vol. 5). Elsevier, 2013.

Supplementary Readings

i.	**Lal, B., Subrahmanyam, N., & Hemne, P. S.**, Heat, Thermodynamics and Statistical Physics. S. Chand Publishing, 2008.
ii.	**Sears, F. W., & Salinger, G. L.**, Thermodynamics, kinetic theory, and statistical thermodynamics (Vol. 183). Reading, MA: Addison-Wesley, 1975.

Course Title	**MATHEMATICAL FOUNDATIONS OF MACHINE LEARNING**	**ISCED Code**	0741-5113
		Course Code	CSE 5113
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Computer Fundamentals, Discrete Mathematics, Linear Algebra, Probability.	**Total Marks**	100

Rationale

This course will provide a holistic approach to the Mathematical Foundations for Machine Learning (ML). The course is focused on developing mathematical ideas, necessary for machine learning applications, through intuitions and visualizations. The course primarily focuses on three important mathematical domains, namely, Linear Algebra, Probability and Statistics and Multivariable Calculus, on which the ML and data science ideas are built.

Course Objectives

The objective of a "Mathematical Foundations of Machine Learning" course is to equip students with the essential mathematical tools needed to understand, analyze, and implement machine learning algorithms. This includes a strong foundation in linear algebra, calculus, probability, and optimization, enabling students to grasp the theoretical underpinnings of various ML techniques. The course aims to bridge the gap between theoretical mathematics and practical machine learning applications.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Efficiency use matrix algebra tools to analyze and solve systems of linear equations.
CLO2	Learn concepts of linear algebra that form the foundation of data science problems.
CLO3	Learn the basic techniques of constrained and un constrained optimization and understand how these are applied in the context of support vector machines.
CLO4	Learn concepts of dimensionally reduction and principal components analysis.

Course Contents

Course Contents		Hours	CLOs
1.	Vectors, Vector Spaces and Subspaces, Linear Transformations, eigenvalues and eigenvectors	6	1, 2
2.	Orthogonality, Projection and Real symmetric matrices, Singular value decomposition, Principal Component Analysis, Support Vector Machines and Applications	6	1, 2
3.	Probability Foundations - From Events to Bayes' Theorem, Random Variables, Moments of Random Variables	4	1, 2, 4
4.	Jointly Distributed Random Variables, Conditioning of Random variables, Limit Theorems, Sample Geometry, Covariance Matrices and Properties	9	2, 4
5.	Taylor's series, Partial Derivatives, Chain rule, Gradient, Jacobian, Hessian, Matrix Derivatives, Gradient Descent and Stochastic Gradient Descent, Constrained and Unconstrained optimization, Lagrangian, Least Squares and PCA	5	3, 4
6.	Neural Nets, Perceptron, Back Propagation Algorithm, Algorithms for ML - Classification, Clustering and Regression	12	2, 3, 4

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	♦	♦	–	–	–	–	–	–	–
CLO3	♦	♦	–	♦	♦	♦	♦	–	–	–	–	–
CLO4	♦	–	♦	♦	–	♦	♦	♦	♦	–	–	–

♦ *Aligned* –*Not-aligned*

Teaching-Learning VS Assessment Strategy

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative) & Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Courville, A., Goodfelllow, I. and Benjio, Y.**, *Deep Learning*, The MIT Press, 2015.
ii.	**Chollet, F.**, *Deep Learning with Python,* Manning Publications, 2017.
iii.	**Aggarwal, C. C.**, *Neural Networks and Deep Learning: A Textbook*, Springer, 2018.
iv.	**Strang, G.**, *Learning from Data*, Wellesley Cambridge Press, 2019.

Supplementary Readings

i.	**Gibson, A., and Patterson, J.**, Deep Learning: A Practitioner's Approach, O'Reilly, 2017.
ii.	**Diesenroth, M.P., Faisal, A.A and Ong, C.S.**, *Mathematics for Machine Learning*, Cambridge University Press, 2020.

MS 2nd Semester

Course Title	**LATTICE THEORY**	**ISCED Code**	0541-5201
		Course Code	MATH 5201
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Discrete Mathematics, Abstract Algebra	**Total Marks**	100

Rationale

Lattice theory is the study of sets of objects known as lattices. It is an outgrowth of the study of Boolean algebras and provides a framework for unifying the study of classes or ordered sets in mathematics. It is often said that mathematics is a language. If so, group theory provides the proper vocabulary for discussing symmetry. In the same way, lattice theory provides the proper vocabulary for discussing order, and especially systems which are in any sense hierarchies. One might also say that just as group theory deals with permutations, so lattice theory deals with combinations. One difference between the two is that whereas our knowledge of group theory has increased by not more than fifty percent in the last thirty years, our knowledge of lattice theory has increased by perhaps two hundred percent in the last ten years.

Course Objectives

This course has mainly been designed to introduce students to the Lattice Theory. The portion on Lattice Theory discusses Modular, distributive and Boolean Lattices.. Students can acquaint themselves with sublattice, lattice homomorphism and the ideal of the lattice. They will study further aspects of quotient lattice and learn the application of lattice theory.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Understand lattices as algebraic structures.
CLO2	Deal with abstraction.
CLO3	Understand the homomorphism between lattices and Boolean Algebra.
CLO4	Develop mathematical maturity and ability.
CLO5	Develop the construction and verification of formal logical manipulation and Understand polynomials and switching circuits.

Course Contents

	Course Contents	Hours	CLOs
1.	Ordered sets: Ordered sets; diagrams; constructing and deconstructing ordered sets; down-sets and up-sets; order preserving map.	6	1, 2
2.	Lattices and complete lattices: Lattices as ordered sets; lattices as an algebra; sub-lattices and convex sub-lattice of a lattice; product lattice; complete lattice; join irreducible elements.	9	1, 2, 5
3.	Ideals and filters; prime ideals and maximal ideals; Zorn's Lemma; chain conditions and completeness.	7	1, 2, 4
4.	Modular, distributive lattices: Modular and distributive lattices and its characterizations; Stone's separation theorem, Boolean lattice and Boolean algebra.	9	2, 5
5.	Congruence: Introducing congruence; congruences and diagrams; the congruences lattice; factor lattice.	5	4, 5
6.	Lattice homomorphism: homomorphism, endomorphism, isomorphism and related theorems.	6	2, 3, 4

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	♦	♦	–	–	–	–	–	–	–
CLO3	♦	♦	–	♦	♦	♦	♦	–	–	–	–	–
CLO4	♦	–	♦	♦	–	♦	♦	♦	♦	–	–	–
CLO5	♦	♦	♦	♦	♦	♦	–	♦	♦	♦	♦	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative) & Final exam (Summative)
CLO5	Lecturing and Student Activity	Midterm & Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Steven, R.**, .*Lattices and Ordered Sets*. Springer, 2009.
ii.	**Davey, B.A.& Priestley, H.A.**, *Introduction to Lattices and Order.* Cambridge University Press, 2002.
iii.	**Gratzer, G.**, *General lattice theory*. Birkhauser Verlag, 1998.

Supplementary Readings

i.	**Balbs, R. and Dwinger, P.**, *Distributive lattices.* University of Missouri Press, 1974.
ii.	**Birkhoff, G.**, *Lattice Theory***.** American Mathematical Society, 1967.

Course Title	**ADVANCED NUMBER THEORY**	**ISCED Code**	0541-5202
		Course Code	MATH 5202
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Fundamentals of Mathematics, Basic Algebra, Theory of Numbers.	**Total Marks**	100

Rationale

The older term for the **theory of numbers** is arithmetic. By the early twentieth century, it had been superseded by the "theory of numbers". Theory of numbers is such a charming subject of mathematics that many great mathematicians are devoted to it because of its wealth of easily accessible and fascinating questions and its intellectual appeal. German mathematician Carl Friedrich Gauss (1777–1855) said, "Mathematics is the queen of the sciences and theory of numbers is the queen of mathematics." Until the mid-20th century, theory of numbers was considered the purest branch of mathematics, with no direct applications to the real world. The advent of digital computers and digital communications revealed that the theory of numbers could provide unexpected answers to real-world problems. At the same time, improvements in computer technology enabled number theory to make remarkable advances in factoring large numbers, determining primes, testing conjectures, and solving numerical problems once considered out of reach. In contrast to other branches of mathematics, many of the problems and theorems of number theory can be understood by laypersons, although solutions to the problems and proofs of the theorems often require a sophisticated mathematical background.

Course Objectives

The objective of this course is to study of basic structures and properties of integers, primes and other number-theoretic objects in some fashion. Theory of numbers helps improve one's ability in mathematical thinking. Students will be able to prove and apply Euler's criterion, Gauss's Lemma and the laws of quadratic reciprocity and find the quadratic character of an integer. Students will be able to apply the Mobius inversion formula and Ramanujan's formula to find Ramanujan's sum. Students will understand the concepts of Dirichlet series, generating function, Zeta function and Landau symbols. Students will be able to find the generating functions and average order of arithmetical functions.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Understand quadratic residues and quadratic non-residues, the Legendre symbol and the Jacobi symbol.
CLO2	Deal with Euler's criterion, Gauss's Lemma and the laws of quadratic reciprocity
CLO3	Find the quadratic residuosity and determine the solution of the quadratic congruence.
CLO4	Apply Gauss's Lemma to find the quadratic character of an integer and Explain the average order and find the average order of arithmetical functions.
CLO5	Gather knowledge on arithmetical functions, Dirichlet product and multiplicative functions and prove the Mobius inversion formula and Ramanujan's formula to find Ramanujan's sum.

Course Contents

	Course Contents	Hours	CLOs
1.	Quadratic residuacity, Quadratic residues and nonresidues, Euler criterion, Legendre symbol, Gauss's lemma, law of quadratic reciprocity, Jacobi's symbol.	4	1, 2, 3, 4
2.	Average orders of arithmetic functions: Lim sup, Lim inf, average orders of the arithmetical functions. Distribution of prime numbers: Bertrand's postulate, Chebyshev's theorem, the function $\theta(x)$ and $\psi(x)$.	10	1, 5

3.	The prime number theory, elementary proof via Selberg's lemma, and complex analytical proof. Primes in arithmetic progressions, Characters of an Abelian group, L-functions, Dirichlet's proof of the infinitude of primes in arithmetic progressions.	6	4, 5
4.	Algebraic number theory, Noetherian rings and Dedekind domains, ideal classes and the unit theorem, units in real quadratic field.	8	3, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	♦	–	–	♦	♦	–	–	♦	–	♦
CLO2	–	♦	♦	♦	–	–	–	♦	♦	♦	♦	–
CLO3	♦	♦	♦	–	♦	♦	♦	♦	–	♦	♦	–
CLO4	–	–	♦	♦	♦	–	♦	♦	–	♦	♦	♦
CLO5	–	♦	♦	♦	–	♦	♦	–	♦	♦	–	♦

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation& Assignment (Formative), Final exam (Summative)
CLO5	Lecturing and Student Activity	Midterm & Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Hardy G. H. and Wright E. M.,** *An introduction to the theory of numbers*, Oxford University Press.
ii.	**Rose S.,** *A course in number theory*, Oxford University Press.
iii.	**Ireland K. and Rosen M.,** *A Classical Introduction to Modern Number Theory*, Springer, New York.

Supplementary Readings

i.	**Samuel P.,** *Theory of algebraic numbers*, Dover Publication.
ii.	**Niven I., Zuckerman H. S., Montgomery H. L.,** *An Introduction to the Theory of Numbers*, John Wiley and sons.

Course Title	DYNAMICAL SYSTEMS	ISCED Code	0541-5203
		Course Code	MATH 5203
Course Hour	3.0 Hr./Week	Credit Value	3
Prerequisite	Differential Equations, Linear Algebra	Total Marks	100

Rationale

Dynamics is the study of change and how systems change over time. In many branches of study, dynamics is used to evaluate behavior, regardless of whether the system in question reaches equilibrium, repeats in cycles, or performs more complex tasks.

Course Objectives

This course serves as an outstanding introduction to Chaotic Dynamical Systems. Its design is driven by two main factors: the target audience and the teaching methodology. Concerning the audience, the aim is to ensure that the methods are comprehensible and applicable to individuals across various engineering and physical science disciplines. In terms of pedagogy, the goal is to present technical derivations and explanations clearly and straightforwardly, while avoiding oversimplification. The comprehensive toolkit of dynamic activities, including chaos, iteration, fractals, and the Mandelbrot and Julia sets, represents popular and engaging mathematical areas that have emerged in recent decades. R.L. Devaney and other mathematicians have developed these topics in response to the growing demand for making these captivating fields accessible to school-aged students. Both students and educators find these subjects fascinating and well-aligned with themes already integrated into modern mathematical curricula.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Extend their knowledge of calculus to solve problems in difference (and maybe differential) equations
CLO2	Gain insight into the historical advancements and contributions within the field of dynamical systems, along with a general overview of the subject illustrated through three classical examples from chemistry, biology, and physics.
CLO3	Graphical analysis of dynamical systems and understanding phase portraits.
CLO4	Understand simple to complicated dynamics and understand symbolic dynamics.
CLO5	Understand bifurcation theory and chaotic theory and generate fractals and find the topological dimension and fractal dimensions.

Course Contents

Course Contents		Hours	CLOs
1.	Basic concepts: Basic definitions & examples, Phase space, phase portrait, discrete dynamics, continuous dynamics, topological dynamics, ergodic theory, topological conjugacy, fixed and periodic points, graphical analysis, iteration, hyperbolic points, hyperbolic dynamics.	4	1, 2
2.	Chaotic dynamical systems: Definitions of chaos, sensitive dependence on initial conditions, period three theorem, orbit structure, Cantor set, basin of attractor & repellor, strange attractor and Lyapunov exponents.	4	1, 2, 3, 4
3.	Discrete dynamical systems: One parameter family of maps, contractions &fixed-point theorem, stability of fixed points, family of logistic map, tent map, doubling map, linear maps, iterative map, quadratic family of maps, Smale horseshoe map, expanding map.	6	2, 3, 4, 5
4.	Differential dynamical systems: One & two dimensional linear & nonlinear differential equations, sinks, source & saddles, stability, population models, Lotka-Volterra models, Henon map, Lorenz map,	7	3, 4, 5

	hyperbolic fixed point, manifold and sub-manifold, stable and unstable manifold, stable manifold theorem, Hartman-Grobman theorem, Hadamard-Perron theorem, Smale theorem.		
5.	Bifurcations: Bifurcations, bifurcation points, bifurcation of quadratic maps, saddle-node, period-doubling, pitchfork, transcritical bifurcation, bifurcation diagram.	7	2, 4, 5
6.	Symbolic dynamical systems: Sequence spaces, shift map, properties of shift maps, symbolic dynamics, itinerary, sub shift of finite type.	6	5
7.	Fractals: The chaos game, Cantor set revisited, Sierpinski triangle, Koch snowflake, topological dimension, fractal dimension.	6	4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	-	♦	-	-	-	-	♦	-	-	-	-
CLO2	♦	♦	♦	♦	♦	-	-	-	-	♦	-	-
CLO3	-	-	-	-	-	-	-	-	-	-	-	-
CLO4	♦	-	-	♦	-	♦	♦	♦	-	-	-	-
CLO5	-	-	♦	-	♦	♦	-	-	-	-	-	-

♦Aligned –Not-aligned

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Quiz/ Homework (Formative)
CLO2	Lecturing and Discussion	Midterm (Summative)
CLO3	Lecturing and Visual Presentation	Assignment (Formative) and Midterm (Summative)
CLO4	Lecturing, Student Activity and Discussion	Midterm (Summative)
CLO5	Lecturing and Discussion	Final Exam (Summative)

Learning Materials

Recommended Readings

i.	**Katok A. and Hasselblatt B.,** Introduction to modern theory of dynamical systems, *Cambridge University Press,Cambridge* 1995.
ii.	**Devaney R. L.,** A First course in chaotic dynamical systems, *Westview Press* 1992. :

Supplementary Readings

i.	**Holmgren R. A.,** A first course in discrete dynamical systems, *Springer* 2001.
ii.	**Alligood K. L. and Sauer T. D.,** An introduction to dynamical systems, *Yorke* 1990.

Course Title	**GEOMETRY OF DIFFERENTIAL MANIFOLDS**	**ISCED Code**	0541-5204
		Course Code	MATH 5204
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Hydrodynamics, Fluid Dynamics	**Total Marks**	100

Rationale

Geometry of Differential Manifolds is based on three-dimensional basic vector geometry of curves and surfaces with calculus. Understanding of this course will enable students to learn other areas of mathematics such as Differentiable Manifolds, Riemannian Manifolds, Theory of Relativity and cosmology, etc. Upon the successful completion of this course, students will be able to :

i) Apply the concepts of surfaces to find which surfaces are minimal and also to know Weingarten, Gauss and Codazzi equations, Theorema Egregium, fundamental theorem of surface theory, etc.

ii) Students will know the concepts of developable surfaces, ruled surfaces, Gaussian curvature, Geodesics, Geodesic curvature, Liouville's formula, Clairaut's theorem, Bonnetformula and Gauss-Bonnet theorem.

iii) Students will learn about Conformal, isometric and geodesic mapping, Tissot theorem, Theory of differential functions, charts, atlases, differentiable manifolds, smooth maps on Manifolds, Tangent space, Tangent bundles, $\mathbb{C}^\infty$-Vector fields and Lie brackets of vector fields on Manifolds, φ-related vector fields.

Course Objectives

1. To give knowledge on mathematical concepts of space curves and different types of surfaces, this course is very useful.
2. Students will know the concepts of geodesic curvature and its formulae, Liouville's formula, geodesic on a surface of revolution, Clairaut's theorem, Bonnet's formula, geodesics on a Liouville surface, Gauss-Bonnet theorem.
3. Students will learn about the Manifold structure on a topological space, $\mathbb{C}^\infty$-vector fields on manifolds, etc.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Apply Gauss and Weingarten equations to find out TheoremaEgregium and Codazziequations, and describe Riccati equation and its solution with some problems.
CLO2	Explain the concept of a manifold, tangent spaces, and submanifolds and give examples.
CLO3	Know how to check developable surfaces and how to find the Gaussian Curvature, and which surface is a ruled surface or skew.
CLO4	How to find the geodesics for surfaces of plane, sphere, right circular cone, right helicoid, cylinder and torus, etc and Illustrate the differential structure of a manifold with $\mathbb{C}^\infty$-function and topology.
CLO5	Illustrate different types of mapping and their properties, and provethe Tissot theorem by using non-conformal mapping and Apply the concepts of φ-related vector fields to find a lemma, and by using this lemma, a proposition of Lie brackets of vector fields is proved

Course Contents

	Course Contents	Hours	CLOs
1.	Surfaces and properties of surface: Minimal surfaces, theorem of Minimal surfaces, general solution of the natural equations, Riccati equation and its solution, equation of Weingarten, Gauss and Codazzi and their applications, Theorem Equirectangular, Fundamental theorem of surface theory.	4	1
2.	Geodesics on a surface: Geodesics, differential equation of geodesics, geodesics on plane, surface, sphere, right circular cone, right helicoids, cylinder, torus, etc., geodesics curvature *Kg* and its formulae, Liouville's formula, geodesics on a surface of revolution. Clairaut's theorem, Bonnet's formula, geodesics on the Liouville surface, Gauss-Bonnet theorem, torsion of a geodesic, geodesic parallel.	4	4
3.	Mapping of surfaces: Mapping, homeomorphism, isometric lines and correspondence, Minding theorem, conformal, isometric and geodesic mapping, Tissot's theorem	4	5

4.	Developable and ruled surface: Envelop, characteristic, edge of regression, developable surface, property of lines of curvature on developable, ruled surface, fundamental coefficients and Gaussian curvature for ruled surface, tangent plane to a ruled surface.	6	3
5.	Differentiable manifolds: Theory of Differentiable functions, coordinate functions, charts and atlases, completeness, compatibility, Differentiable structures, Differentiable manifolds, local representation of a function for charts, induced topology on a manifold.	6	2
6.	Topology of a manifold: Manifold structure on a topological space, properties of induced topology, topological restrictions on manifolds.	6	2
7.	Differentiation on a manifold: Partial differentiations, equivalence relation and class smooth map on manifolds, tangent space, tangent bundles, tensor and exterior bundles, tangent map on manifolds.	6	2, 5
8.	Vector fields on a manifold: C^{∞}- vector fields on manifolds, coordinates of vector fields, set of vector fields, theorem on vector fields and its coordinates, Lie brackets of vector fields and properties of φ related vector fields.	6	4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	♦	–	–	♦	♦	–	–	♦	–	♦
CLO2	–	♦	♦	♦	–	–	–	♦	♦	♦	♦	–
CLO3	♦	♦	♦	–	♦	♦	♦	♦	–	♦	♦	–
CLO4	–	–	♦	♦	♦	–	♦	♦	–	♦	♦	♦
CLO5	–	♦	♦	♦	♦	♦	♦	♦	♦	♦	–	♦

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative)
CLO5	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm & Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Lee, J. M., & Lee, J. M.**, *Smooth manifolds* (pp. 1-29). Springer New York, 2003.
ii.	**Lee, J. M.**, *Manifolds and differential geometry (Vol. 107)*. American Mathematical Society, 2009.
iii.	**Tu, L. W**., *Manifolds. In An Introduction to Manifolds*. New York, NY: Springer New York, 2011.
iv.	**Warner, F. W.**, *Foundations of differentiable manifolds and Lie groups* (Vol. 94). Springer Science & Business Media, 1983.

Supplementary Readings

i.	**Majumdar, M., & Bhattacharyya, A**., *An Introduction to Smooth Manifolds*. Springer, 2023.
ii.	**Struik, D. J.**, *Lectures on classical differential geometry*. Courier Corporation, 2012.

Course Title	**BOUNDARY LAYER THEORY**	**ISCED Code**	0541-5205
		Course Code	MATH 5205
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Differential Geometry, Topological space, Ordinary Differential Equations	**Total Marks**	100

Rationale

The **Boundary Layer Theory** course covers the development of the fundamental equations of laminar and turbulent boundary layer for viscous incompressible fluids and their similarity, as well as approximate solutions for several cases. Topics include the derivation of hydrodynamic and thermal boundary layer equations, similarity, as well as approximate solutions of the laminar boundary layer equations, boundary layer separation, drag and lift force, and natural and forced convection flow. The details of the flow within the boundary layer are important for many problems in aerodynamics, including wing stall, the skin friction drag on an object, and the heat transfer that occurs in high-speed flight.

Course Objectives

The Boundary Layer concept is a cornerstone in the development and application of various fluid mechanics theories. It is of utmost importance in determining the drag forces that act on bodies immersed in a fluid stream. The objectives of this course are to expose the students to the development of the governing equations of boundary layer theory and their similarity, as well as approximate solutions in different geometries.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Understand the concept of slow motion and derive Prandtl's boundary layer equations for the two-dimensional flow of a viscous incompressible fluid.
CLO2	Discuss the similar solutions of two-dimensional laminar boundary layer flow.
CLO3	Discuss the boundary layer separation and the applications of drag and lift forces.
CLO4	Establish the momentum and energy integral equations for two-dimensional Laminar boundary layer flow and derive the boundary layer equation past a horizontal/vertical surface with suction or injection.
CLO5	Derive the thermal boundary layer equation and solve it for natural as well as forced convection flow and explain the concept of turbulence and derive the equation of motion for turbulent flows.

Course Contents

	Course Contents	Hours	CLOs
1.	**Very Slow motion:** Small Reynolds' number flows of very slow motions, Differential equation of very slow motion, Flow past a sphere and a circular cylinder; Sphere and Circle theorems, Stokes law, The Hele-Shaw flow, The Hydrodynamic theory of Lubrication, Slow rotation of a sphere.	10	1, 2
2.	**Boundary Layer Theory**: (i) General concepts and properties of boundary layer, Prandtl's boundary layer theory, point of separation, Wall friction, Displacement, Drag and lift, Plate boundary layer. (ii) Similar solutions of the boundary layer equations, (iii) The Blasius solution, Flow over a wedge, Flow in a convergent channel. (iv) Von Karman's integral equation (or condition),	12	1, 2, 3, 4

	Application of Karman's integral equation to boundary layer (Karman-Pohlhausen methods).		
3.	**Thermal Boundary Layers in Laminar Flow:** The energy equation, Derivation of energy equation and their general properties. Energy integral equation. Thermal boundary layer, Two-dimensional forced convection, natural convection and mixed convection flows, flow past a vertical and inclined flat surface, Flow along a vertical cylinder, Flow past a horizontal cylinder and a sphere, effect of vectored mass flux (suction and injection) on the above flows.	14	3, 4, 5,
4.	**Turbulent Flow:** Stability theory, Orr-Summerfield equation, Turbulent flow, Turbulent boundary layer equations for plane flows, Couette flow.	6	5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	–	–	–	–	–	♦	–	–	–
CLO3	♦	♦	–	♦	–	–	♦	♦	–	–	–	–
CLO4	♦	♦	♦	♦	♦	–	♦	–	♦	–	–	–
CLO5	–	–	♦	♦	♦	–	–	–	♦	♦	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative) & Final exam (Summative)
CLO5	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm & Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Schlichting, H., & Gersten, K.**, *Boundary-layer theory*. Springer, 2016.
ii.	**Raisinghania, M.D.**, *Fluid dynamics with complete hydrodynamics and boundary layer theory*. S. Chand Publishing, 2013.
iii.	**Batchelor, G.K.**, *An introduction to fluid dynamics*. Cambridge University Press, 2000.

Supplementary Readings

i.	**Charlton, F.**, *The textbook of fluid dynamics*. Cambridge University Press, 1967.
ii.	**Pop, I., & Ingham, D.B.**, *Convective heat transfer: mathematical and computational modelling of viscous fluids and porous media*. Elsevier, 2001.
iii.	**Bansal, J.L.**, *Viscous fluid dynamics*. Oxford & IBH Publishing Company, 1977.

Course Title	**MATHEMATICAL COSMOLOGY**	**ISCED Code**	0541-5206
		Course Code	MATH 5206
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Theory of Relativity	**Total Marks**	100

Rationale

It is an excellent introductory combined course on mathematical cosmology. This is a module principally on Einstein's general theory of relativity, a relativistic theory of gravitation which explains gravitational effects as coming from the curvature of space-time. It provides a comprehensive introduction to material which is currently the subject of enthusiastic study from the theoretical and experimental standpoints. In addition, in order to understand the general theory fully, some familiarity with tensor calculus is required. This will involve some self-study material at the start of the module. The rest of the course will be devoted to a detailed investigation of the theory itself together with applications to classical black holes and cosmology.

Course Objectives

The objective of this course is to introduce the concept of space-time, the theory of special relativity and some preliminary ideas from general relativity, cosmology and the mathematical model of the expanding universe. The aim of studying cosmology is to construct mathematical models of the universe.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Have a conceptual knowledge of space-time and how it has evolved, its observational and theoretical basis and major unresolved questions.
CLO2	Understand basic cosmological concepts such as the big bang model and cosmic inflation, dark matter and dark energy, with the ability to discuss them in a non-technical way.
CLO3	Understand the tools with which prove the large-scale structure of the universe.
CLO4	Distinguish and analyze the problems of the classic Big Bang theory.
CLO5	Describe the gross characteristics of evolution of matter and radiation in the Universe, including the formation of the microwave background radiation and of the light elements and identify and describe cosmological current unanswered questions.

Course Contents

	Course Contents	Hours	CLOs
1.	General Relativity: covariant differentiation, Riemannian Geometry, Space-time Curvature, Geodesics, The principle of Equivalence, Action principle and Gravitational Equations.	6	1, 2
2.	From Relativity to cosmology: Historical background, The Schwarzschild solution, the Einstein Universe, the Expanding Universe , Modifying Assumption of cosmology, The Red shifts. Large Scale Structure of the Universe, Astronomy and cosmology, Hubble's law, the background radiation, relativistic cosmology, structural hierarchy, Cosmological constant, The Luminosity of Distance, Angular Size.	8	2, 3, 4
3.	Model: The Friedman Model, The Friedman-Robertson-Walker Metric and Einstein Equations, Derivation of the Robertson Walker Metric, Energy terms, The solution of Friedman Equations. The Hubble constant and the Deceleration parameter, Measurement of Ho, Measurement of Exact solution for zero pressure, solution for pure radiation, Behavior Near zero, the steady state Theory, Motivation for Non-Big-Bang Cosmology.	10	4, 5

4.	The perfect Cosmology: The perfect cosmological Principle, The creation field, Observational parameters of steady state theory, Physical and Astrophysical consideration.	6	4, 5
5.	The very early Universe: History of the Universe, Matter Vs. Radiation dominant Universe, The hot Universe, Big Bang, The Early Universe and Inflation, The successes and problems of Standard Cosmology, Higgs field.	8.	4, 5,
6.	The Space: -Time Singularities on Cosmology and some recent developments.	4	5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	–	–	♦	–	–	–	♦	–	–	–
CLO3	♦	♦	–	♦	–	–	–	♦	♦	–	–	–
CLO4	♦	♦	♦	–	♦	–	♦		–	–	–	–
CLO5	–	–	♦	–	♦	♦	–	–	–	–	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative)
CLO5	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm & Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Martin Rees,** Introduction to Cosmology, Willey, N.Y. 1994.
ii.	**H. Jayant, Narliker,** Introduction to Cosmology, Jores & H. Barle.
iii.	**V. Jayant & Narliker,** Elements of Cosmology.
iv.	**A.K. Rayehaudhuri,** Theoretical Cosmology: The Expanding Universe.

Supplementary Readings

i.	**N. Islam,** An introduction to Mathematical Cosmology.

Course Title	QUANTUM MECHANICS	ISCED Code	0541-5207
		Course Code	MATH 5207
Course Hour	3.0 Hr./Week	Credit Value	3
Prerequisite	Differential Equations, Functional Analysis	Total Marks	100

Rationale

Quantum mechanics is that branch of science which deals with the behaviour of matter and light on the atomic and subatomic scale. It attempts to describe and explain the properties of molecules and atoms and their constituents-electrons, protons, neutrons, and other more obscure particles. These properties include the interactions of the particles with one another and with electromagnetic radiation. It is an important tool to understand at the theoretical level the electronic structure of chemical compounds and the mechanism, thermodynamics, and kinetics of chemical reactions. This course is important because it is the foundation of quantum chemistry, quantum field theory, quantum technology and quantum information science.

Course Objectives

This course aims to provide an introduction to some basic methods for understanding the details of a quantum mechanical system. It is an important tool to understand the basic structures of matter and the mechanisms of formation. It provides a microscopic description of thermodynamics and kinetics of chemical reactions at the theoretical level. It is the most experimentally accurate theory to date. Furthermore, the main effort is to make the students familiar with the advanced concepts of quantum mechanics so that they can apply advanced mathematical techniques in their explanations, analysis and predictions of quantum physical phenomena.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Identify key differences between classical and quantum systems and how those differences affect the operation of quantum technologies.
CLO2	Apply the fundamental principles of quantum theory to formulate and solve technical problems related to quantum technology.
CLO3	Demonstrate proficiency with the mathematics behind modelling and describing the behaviour of quantum systems, as well as quantum algorithms, such as Dirac notation and quantum circuit notation.
CLO4	Identify several different physical platforms used in quantum communication, sensing, and computing technologies and enumerate their pros and cons and Communicate the impact of quantum technologies as a possible solution to emerging societal problems and demonstrate awareness of the ethical, economic, and social implications of their implementation.
CLO5	Demonstrate proficiency with numerical software to simulate quantum systems and/or implement quantum algorithms, for example, by using Python, the IBM Qiskit language for quantum computing, or Computer-Aided-Design (CAD) tools for simulating quantum devices and summarise results of research and/or literature review in oral presentations and written formats to both technical and non-technical audiences from diverse backgrounds.

Course Contents

	Course Contents	Hours	CLOs
1.	**Origin of Quantum theory**: Black body radiation, Photoelectric effect, Compton effect, Bohr model, De Broglie's hypothesis, Wave properties of matter.	07	1, 2
2.	**Wave function**: wave-particle duality, wave packets, Heisenberg uncertainty principle.	08	1, 2, 3

3.	**Schrödinger equation**: Expectation values, Operators, Ehrenfest's theorem, Time-independent Schrödinger equation & its general solution, Schrödinger equation in momentum space.	07	1, 2, 3, 4
4.	**One-dimensional example**: free particle, potential step, the square well, linear harmonic oscillator, periodic potential.	08	1, 5
5.	**Formalism of quantum mechanics**: Dynamical variables, Unitary transformations, Metric representations of wave functions and operators, The Schrödinger and Heisenberg pictures.	06	1, 3, 5
6.	**Schrödinger equations in three dimensions**: Separation of the equation in different coordinates, free particle, square well potential, and the hydrogen atom.	06	1, 3

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	–	♦	–	–	–	–	–	♦	♦	
CLO2	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	–	–
CLO3	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	–
CLO4	♦	♦	♦	–	♦	–	♦	–	–	–	–	–
CLO5	–	♦	♦	♦	–	♦	♦	–	–	–	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative) & Final exam (Summative)
CLO5	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm, Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Griffiths, D. J., & Schroeter, D. F.**, *Introduction to quantum mechanics*. Cambridge University Press, 2018.
ii.	**Bransden, B. H. & Joachin, C.J.**, *Quantum mechanics*. Pearson Education, 2000.
iii.	**Gupta,Kumar, & Sharma**, Quantum Mechanics, Jai Prakash Nath Publications, 2018.
iv.	**Zettili, N.**, *Quantum mechanics: concepts and applications.* John Wiley and Sons, Ltd. Publication, 2009.

Supplementary Readings

i.	**Landau, L. D. & Lifshitz, E. M.**, *Quantum Mechanics: Non-Relativistic Theory*, Pergamon Press, 1991.
ii.	**Powell, J. L. & Crasemann, B.**, *Quantum Mechanics, Addison-Wesley Publishing Company,* 1961.
iii.	**Dirac, P. A. M.**, *The principles of quantum mechanics* (No. 27). Oxford University Press, 1981.

Course Title	FINITE ELEMENT METHOD	ISCED Code	0541-5208
		Course Code	MATH 5208
Course Hour	3.0 Hr./Week	Credit Value	3
Prerequisite	Vibrations and Waves, Electromagnetics and applications, Differential equations.	Total Marks	100

Rationale

Finite Element Method (FEM) is a powerful numerical method used for solving complex engineering and physical problems that are difficult or impossible to solve analytically. It works by dividing a large system into smaller, simpler parts called finite elements, which are interconnected at points known as nodes. These elements are then mathematically modeled and assembled into a larger system of equations that approximates the behavior of the original structure or domain.

Course Objectives

This course serves as an outstanding introduction to the Finite Element Method (FEM). It is designed with two main considerations in mind: the target audience and the teaching methodology. The aim is to ensure that individuals from various engineering and physical science disciplines can comprehend and effectively utilize the method. In terms of pedagogy, the goal is to present technical derivations and explanations in a clear and straightforward manner, while maintaining depth and avoiding oversimplification. FEM is a versatile and robust numerical technique that can be applied to a wide range of mathematical challenges encountered across nearly all scientific and engineering fields. Essentially, FEM transforms ordinary and partial differential equations into a system of algebraic equations.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Explain the basic concepts, mathematical formulation, and theoretical foundation of the finite element method.
CLO2	Derive stiffness matrices and load vectors for various types of elements (1D, 2D, and simple 3D elements) using shape functions and interpolation techniques.
CLO3	Formulate and solve structural, thermal, and other physical problems using finite element models under different boundary and loading conditions and Visualize and interpret simulation results (e.g., stress distribution, deformation, temperature profile) and communicate findings effectively through technical reports and presentations.
CLO4	Assess the accuracy, convergence, and stability of finite element solutions through mesh refinement, error estimation, and validation techniques and Identify the assumptions, limitations, and potential sources of error in finite element models and make informed judgments in their application.
CLO5	Apply FEM to solve complex engineering problems and support decision-making in the design and optimization of structures and systems.

Course Contents

	Course Contents	Hours	CLOs
1.	**Sobolev Spaces**: Vector spaces and inner product space, Hilbert spaces, linear functional, Lebeague spaces, compact set, compact Support, distributions, locally integrable functions, weak derivatives, Sobolev spaces, Holder’s inequality, Cauchy-Schwarz inequality, Young’s Inequality, Poincare inequality, duality and negative norms, Reisz representation theorem, Lax-Milgram theorem.	4	1, 2, 4
2.	**Some Model PDEs:** Laplace's equation, elliptic BVPs, physical experiments modeled by Laplace's equation, the equations of isotropic elasticity, general linear elasticity	4	1, 2, 3, 5
3.	**The weak form of BVPs:** The divergence theorem, Green's identity, the weak form of a BVP, minimization of energy, relaxing the PDE, the weak form of the	6	2, 3, 4, 5

	Dirichlet condition, Neumann condition, mixed boundary conditions, inhomogeneous boundary conditions for the elliptic PDEs, weak derivative for elasticity equation, equivalence between strong from and week form, existence and uniqueness for the weak form of BVPs.		
4.	**The Galerkin method:** The projection theorem, the Galerkin method for the variational problems, the Galerkin method for the nonsymmetric problems.	7	4, 5
5.	**Piecewise polynomials and the finite element method:** Piecewise linear functions defined on a triangular mesh,quadratic Lagrange triangles**,** Continuous piecewise quadratic functions, the sparsity of the stiffness matrix.	7	4, 5
6.	**Applications:** Finite element methods forone dimensional model problem for stationary and non-stationary cases with different boundary conditions (elliptic and parabolic equations), finite element methods for the two dimensional model problem for steady and transient cases with different boundary conditions (elliptic and parabolic equations).	6	4, 5
7.	**Convergence of the finite element methods**: Approximating smooth functions by continuous piecewise linear functions, approximation by higher-order piecewise polynomials, convergence in the energy norm, convergence in the *L2*-norm.	6	4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	-	♦	-	♦	-	-	-	♦	-	-	-
CLO2	♦		♦	-	-	-	-	-	-	-	-	-
CLO3	♦	-	-	-	-	-	-	-	-	-	-	-
CLO4	-	-	-	♦	-	♦	♦	-	-	-	-	-
CLO5	-	-	♦	-	-	♦	-	-	-	♦	♦	-

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Quiz/ Homework (Formative)
CLO2	Lecturing and Discussion	Midterm (Summative)
CLO3	Lecturing and Visual Presentation	Assignment (Formative) and Midterm (Summative)
CLO4	Lecturing, Student Activity and Discussion	Midterm (Summative)
CLO5	Lecturing and Discussion	Final Exam (Summative)

Learning Materials

Recommended Readings

i.	**Brenner S. C. and Scott L. R.,** The Mathematical Theory of Finite Element Methods, *Springer, New York,* 2008.
ii.	**Gockenbach M. S.,** Understating and Implementation of Finite Element Method, *SIAM, USA,* 1987.

Supplementary Readings

i.	**Chen Z.,** Finite Element Methods and Their Applications, *Springer-Verlog, Germany*, 2005.
ii.	**Lewis P. E. and Ward J. P.,** The finite element method: Principles and Application, *Addison Wesley,* 1991.

Course Title	**MATHEMATICAL BIOLOGY**	**ISCED Code**	0541-5209
		Course Code	MATH 5209
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Basic Algebra, Ordinary differential Equations, Partial Differential equations	**Total Marks**	100

Rationale

To equip students with the mathematical tools necessary for the analysis and resolution of a diverse range of biological problems at various scales, **Mathematical Biology** stands out as one of the most rapidly growing and thrilling domains within Applied Mathematics. This surge in growth is primarily attributed to the advent of advanced experimental techniques in the biological sciences, which have led to the generation of an unprecedented volume of quantitative data.

Course Objectives

Upon completion of the module, students should possess the following abilities:

1. Evaluate basic models of biological phenomena through mathematical analysis.
2. Replicate models and essential findings related to biological systems.
3. Familiarise students with advanced mathematical modelling in the Life Sciences.
4. Apply module methods to address novel problems within the realm of Mathematical Biology.
5. Investigate techniques for solving models and engage in discussions about the implications of predictions.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Understand the applications of Ordinary Differential Equation (ODE) models in various biological systems.
CLO2	Gain awareness of selecting and utilising diverse modelling techniques across different areas.
CLO3	Learn about reaction-diffusion equations and their relevance in biological applications.
CLO4	Establish connections between biological questions and mathematical concepts.
CLO5	Develop proficiency in mathematical tools such as dynamical systems, linear algebra, differential equations, and difference equations through the modeling of biological systems and explore the utility of using mathematical tools to comprehend the properties and behaviour of biological systems.

Course Contents

	Course Contents	Hours	CLOs
1.	Population Dynamics: Simple continuous and discrete models, Stability theory, classification of stability and its definition, graphical and stability theory of linear and nonlinear differential equations.	3	1, 3
2.	Method of Liapunov, Stochastic Model: Stochastic linear and nonlinear models of population, spatial model, and optimal control of population model.	4	1, 2, 3
3.	Single-species population models: Exponential model, Logistic model, and model with carrying capacity.	3	1, 2, 5
4.	Two species population models: Predator-prey models, competition models, models of mutualism, Kolmogorov model.	4	1, 2, 3, 5
5.	Fundamental matrix solutions of two and three-species population models.	3	1, 4
6.	Microbial Population Models: Microbial population, Chemostat, growth of microbial populations, stability of the models.	5	2, 5,

7.	Virus dynamics: virus, immunity, cells, epidemic models, dynamics of infection, diseases, AIDS/HIV models, dynamics of hepatitis B virus, age-dependent epidemic model, Stochastic epidemic model.	5	3, 4, 5
8.	Anti-Virus drug therapy: Control of an epidemic model, drug therapy, vaccination effects, treatment of HIV, CTL response, immune responses eliminate infected cells, and the simplest models of immune response dynamics.	4	3, 4, 5
9.	Dynamics with Diffusion: Diffusion equation, single and multi-species diffusion models, competition model with diffusion, epidemic model with diffusion, diffusion in artificial kidney.	5	4, 5
10.	Applications: Blood pressure and its measurements, glucose concentration in blood, Heart function test and optimisation models for blood testing.	5	3, 4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	–	♦	–	–	–	–	–	–	–	–
CLO2	–	–	♦	–	–	♦	♦	♦	–	♦	–	–
CLO3	♦	♦	♦	♦	–	–	–	–	–	♦	♦	–
CLO4	–	–	–	♦	♦	♦	♦	♦	–	–	–	♦
CLO5	–	–	♦	♦	–	♦	–	–	–	♦	–	♦

♦Aligned –Not-aligned

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Quiz/Homework (Formative) and Midterm (Summative)
CLO2	Lecturing and Group Discussion	Presentations (Formative), Midterm&Final exam(Summative)
CLO3	Lecturing and Visual Presentation	Assignment & Presentations (Formative), Midterm & Final exam(Summative)
CLO4	Lecturing and Slide Presentation	Homework (Formative) and Final exam(Summative)
CLO5	Lecturing and Student Activity	Final exam (Summative)

Learning Materials

Recommended Readings

i.	**J. D. Murry**, *Mathematical Biology*, Springer, 1993.
ii.	**N. Kapur**, *Mathematical Models in Biology and Medicine*, East-West Press, 2008.
iii.	**Edward Beltrami**, *Mathematics for Dynamic Modeling*, Academic Press,2nd edition, 1997.

Supplementary Readings

i.	**Leah Edelstein-Keshet** ,*Mathematical Models in Biology*, McGraw-Hill College,8th edition , 1988.
ii.	**M.A. Nowak, R.M. May**,*Virus Dynamics, Mathematical principles of Immunology and Virology*, Oxford University Press,1st editioon, 2001.

Course Title	**COMPUTATIONAL FLUID DYNAMICS**	**ISCED Code**	0541-5210
		Course Code	MATH 5210
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Hydrodynamics and Fluid Dynamics	**Total Marks**	100

Rationale

Computational Fluid Dynamics (CFD) is an essentially interdisciplinary field with a wide range of applications. CFD has become an indispensable instrument in the study and design of thermal and fluid flow systems across a broad spectrum of industries. Fluid dynamics uses numerical tools and algorithms to resolve and examine issues related to fluid flows. Notable applications of CFD encompass meteorology, transportation systems (aerospace, automotive, high-speed rail), energy systems, environmental studies, electronics, and biomedical engineering (design of life-support and drug delivery systems). There has been significant advancement in the development and utilisation of CFD across all facets of fluid dynamics. CFD has emerged as a standard modelling instrument extensively employed in the business. The proper application of CFD as a design analysis or diagnostic instrument necessitates a comprehensive grasp of fundamental physics, mathematical modelling, and numerical methods.

Course Objectives

This course intends to deliver these specific insights into CFD. The finite difference and finite volume methods will be examined as distinct approaches to discretising the equations of fluid dynamics. A requisite theoretical foundation for the accuracy, convergence, consistency, and stability of the numerical systems will be presented.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Understand how partial differential equations are categorised and how they behave physically in scientific and engineering applications.
CLO2	Utilise iterative and elimination techniques to solve systems of linear algebraic equations.
CLO3	Reduce mistakes in approximations of differential equation solutions by applying the principles of error minimization.
CLO4	Use discretization techniques (finite difference, finite element, and finite volume) to evaluate the accuracy and stability of numerical schemes.
CLO5	Determine the mathematical characteristics of the governing Navier-Stokes equations and the flow in physics, then establish appropriate boundary conditions for the solution and Learn about conservation equations, governing equation solution techniques in turbulence modeling, and computational fluid dynamics for real-world applications.

Course Contents

	Course Contents	Hours	CLOs
1.	Classification of Partial Differential Equations, Boundary and Initial Conditions, Derivation of Finite Difference equations: simple method, general method, higher order derivatives, multidimensional finite difference formulas, higher order accuracy schemes. Analysis and Application of Numerical Schemes: Consistency; Stability; Convergence; Fourier or von Neumann stability analysis. Application of FDM to model equations: wave, Heat, Laplace and Burgers equations.	10	1, 2, 3, 4
2.	Grid generation: Introduction, Coordinate Transformation, differential equation methods, algebraic methods, transfinite interpolation methods, unstructured grid generation, mesh adaptation.	6	3, 4
3.	Finite Volume Method: Basic Technique, Model Equations in Integral Form, Finite Volume Discretisation of Equations, Finite Volume Method for One-Dimensional and Two-Dimensional problems.	7	3, 4

4.	Finite volume method for convection-diffusion problems: steady one-dimensional convection-diffusion, discretisation schemes, central differencing scheme, upwind differencing scheme, hybrid differencing scheme, higher order differencing scheme (QUICK, TVD)	6	3, 4
5.	Navier-Stokes equations: Stream function - vorticity formulation; Primitive variable formulation; Pressure correction techniques like SIMPLE, MAC, Fractional Step. Application of pressure correction methods in Lid-driven cavity flow.	8	5
6.	Introduction to Turbulence Modelling: Important features of turbulent flow, General Properties of turbulent quantities, Reynolds average Navier-Stokes (RANS) equation, Closure problem in turbulence: Necessity of turbulence modelling and applications.	5	5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	♦	–	–	♦	♦	–	–	♦	–	♦
CLO2	–	♦	♦	♦	–	–	–	♦	♦	♦	♦	–
CLO3	♦	♦	♦	–	♦	♦	♦	♦	–	♦	♦	–
CLO4	–	–	♦	♦	♦	–	♦	♦	–	♦	♦	♦
CLO5	–	♦	♦	♦	♦	♦	♦	♦	♦	♦	–	♦

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Quiz/Homework (Formative) and Midterm (Summative)
CLO2	Lecturing and Group Discussion	Presentations (Formative), Midterm&Final exam(Summative)
CLO3	Lecturing and Visual Presentation	Assignment & Presentations (Formative), Midterm & Final exam(Summative)
CLO4	Lecturing and Slide Presentation	Homework (Formative) and Final exam(Summative)
CLO5	Lecturing and Student Activity	Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Chung, T. J.**, *Computational fluid dynamics*. Cambridge University Press, 2002.
ii.	**Versteeg, H. K.**, *An introduction to computational fluid dynamics: the finite volume method, 2/E*. Pearson Education India, 2007.
iii.	**Anderson, D., Tannehill, J. C., Pletcher, R. H., Munipalli, R., & Shankar, V.,** *Computational fluid mechanics and heat transfer*. CRC Press, 2020.

Supplementary Readings

i.	**Hirsch, C.**, Numerical computation of internal and external flows. Vol. 2-Computational Methods for Inviscid and Viscous Flows. *Chichester*, 1990.
ii.	**Ferziger, J. H., Perić, M., & Street, R. L.**, *Computational methods for fluid dynamics*. Springer, 2019.

Course Title	INFORMATION THEORY	ISCED Code	0541-5211
		Course Code	MATH 5211
Course Hour	3.0 Hr./Week	Credit Value	3
Prerequisite	Basic mathematics, probability, and statistics	Total Marks	100

Rationale

In today's data-driven world, understanding and interpretation of information flow is important in the fields from communication technology to neuroscience and biological systems. Information theory offers mathematical tools to analyze uncertainty, detect network structure, and understand relationships between individuals. This course is designed to introduce students to the key concepts and tools of information theory, enabling them to analyze information flow and dependencies in various real-world systems.

Course Objectives

1. To provide the basic concepts of 'Information'.
2. To quantify the information of an event.
3. To determine the dependency of two events.
4. To understand the process of information flow.
5. To learn the shortcomings of information measure schemes.
6. To know the real-life applications of information measure.

Course Learning Outcomes (CLOs

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Describe the concepts of 'information'.
CLO2	Explain the elementary information-theoretic quantities both analytically and graphically.
CLO3	Determine the dependency of two events and Elucidate the direction of information flow.
CLO4	Clarify the causality between two processes and assess limitations of different information-theoretical schemes
CLO5	Apply information theory concepts to practical problems (e.g., neural network, complex systems).

Course Contents

	Course Contents	Hours	CLOs
1.	**Statistical Preliminaries:** Set theory. Discrete probabilities. Conditional, Independent, and Joint Probabilities. Statistical Expectations, Moments, and Correlations. Probability Distributions: Binomial Distribution, Poisson Distribution, Continuous Probabilities, Gaussian Distribution, Multivariate Gaussian Distribution.	6	1, 2
2.	**Concepts of Information**: Basic Ideas. Uncertainty, Definition of information. Properties of information.	4	1, 2
3.	**Fundamental information-theoretical quantities:** Entropy and its properties. Joint entropy and its properties. Conditional entropy. Applications of the above-mentioned schemes.	6	2, 3
4.	**Relative Entropy and Mutual Information:** Kullback–Leibler Divergence. Relative Entropy. Mutual information. Relationship Between Entropy and Mutual Information. Chain Rules for Entropy, Relative Entropy, and Mutual Information. Mutual Information and Phase Transitions. Time-delayed mutual information and its application.	6	3, 4

5.	**Inequalities and their Consequences:** Jensen's Inequality and Its Consequences. Log Sum Inequality and Its Applications. Data-Processing Inequality. Sufficient Statistics. Fano's Inequality.	4	2, 3
6.	**Rate Distortion Theory:** Quantization,definition and calculation of rate distortion function, converse to the rate distortion theorem, Achievability of the rate distortion function, strongly typical sequences and rate distortion, Characterization of the rate distortion function.	4	2, 4
7.	**Transfer Entropy:** Definition of Transfer Entropy. Determination of History Lengths. Computational Interpretation as Information Transfer. Conditional Transfer Entropy. Source–Target Lag.	6	4, 5
8.	**Applications of Transfer Entropy:** Real-world use in neuroscience, social media, biology, transportation, financial market, etc.	6	5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	–	–	–	–	–	–	–	–	–
CLO3	♦	–	♦	–	–	–	–	–	–	–	–	–
CLO4	–	–	–	♦	–	–	–	–	–	–	–	–
CLO5	–	–	–	–	–	–	♦	–	–	–	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

Mapping of Course Learning Outcomes (CLOs) with the Teaching-Learning & Assessment Strategy

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Quiz/Homework (Formative) and Midterm (Summative
CLO2	Lecturing, Questioning and Answer questioning	Homework (Formative) and Final exam(Summative)
CLO3	Lecturing and Group discussion	Presentations (Formative) Midterm,Final exam (Summative)
CLO4	Lecturing and Visual Presentation	Final exam (Summative)
CLO5	Lecturing, Questioning and Answer questioning	Assignment and Presentations (Formative) Midterm and Final exam (Summative)

Learning Materials

Recommended Readings

i.	Bossomaier, T., Barnett, L., Harré, M., & Lizier, J. T. *An Introduction to Transfer Entropy*.
ii.	Cover, T. M., & Thomas, J. A. *Elements of Information Theory*.

Supplementary Readings

i.	Mc. Eliece, R. J. *The Theory of Information and Coding*.
ii.	Bose, R. *Information Theory, Coding and Cryptography*.
iii.	Togneri, R., & DeSilva, C. J. S. *Fundamentals of Information Theory and Coding Design*.

Course Title	**PERTURBATION THEORY**	**ISCED Code**	0541-5212
		Course Code	MATH 5212
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Ordinary Differential Equation, Partial Differential Equation	**Total Marks**	100

Rationale

The course Perturbation Theory provides students with a thorough grasp of the many strategies and procedures utilized to approximate complicated mathematical problems in practical applications. It focuses on providing students with the tools they need to properly assess, evaluate, and utilize approximation approaches in real-world circumstances. Students develop the capacity to address complicated situations where exact solutions are difficult or computationally expensive by taking this course.

Course Objectives

A Perturbation Theory course aims to teach students how to solve complex quantum mechanical problems by approximating solutions based on simpler, solvable problems. The course focuses on developing the ability to break down complex systems into solvable and perturbative parts, allowing for the application of systematic approximations to energy levels and wave functions. Ultimately, the goal is to equip students with a powerful tool for analyzing physical phenomena where exact solutions are not readily available.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Use local analysis techniques to approximate solutions for linear differential equations (LDE).
CLO2	Solve nonlinear differential equations (NDE) using approximate methods.
CLO3	Utilize perturbation theory for linear eigenvalue problems.
CLO4	Comprehending and applying boundary layer theory to complex differential equations.
CLO5	Employ the WKB approximation for inhomogeneous linear equations.

Course Contents

	Course Contents	Hours	CLOs
1.	**Local analysis:** Approximate solution of the linear differential equation (LDE); Classification of singularities in homogenous LDE; asymptotic solution at irregular singular points in homogenous and non-homogenous LDE; irregular singularities at infinity; asymptotic solution of LDE for large values of the independent variable;	6	1, 2
2.	**Approximate solution of nonlinear differential equation (NDE):** Spontaneous singularity, approximate solutions of 1st order NDE, approximate solution of higher order NDE;	12	1, 2, 5
3.	**Perturbation methods:** Perturbation theory, regular and singular perturbation theory, perturbation methods for linear eigenvalue problems;	7	1, 2, 4
4.	**Global analysis:** Boundary layer theory: Introduction to BL theory, mathematical structure of BL, higher order BL theory, distinguished limits and BLS of thickness $\varepsilon \neq 0$;	9	2, 5
5.	**WKB theory:** The exponential approximation for dissipative and dispersive phenomena, conditions for validity of WKB approximation, WKB solution of inhomogeneous linear equations.	8	4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	♦	♦	–	–	–	–	–	–	–
CLO3	♦	♦	–	♦	♦	♦	♦	–	–	–	–	–
CLO4	♦	–	♦	♦	–	♦	♦	♦	♦	–	–	–
CLO5	♦	♦	♦	♦	♦	♦	–	♦	♦	♦	♦	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Homework/Quiz (Formative), Midterm (Summative)
CLO2	Lecturing and Slide Presentation	Homework (Formative), Final exam (Summative)
CLO3	Lecturing, Multimedia presentation and Video presentation	Midterm & Final exam (Summative)
CLO4	Lecturing, Slide Presentation and Student Activity	Presentation, Assignment (Formative) & Final exam (Summative)
CLO5	Lecturing and Student Activity	Midterm & Final exam (Summative)

Learning Materials

Recommended Readings

i.	**Murdock, J. A.** (1999). *Perturbations: theory and methods*. Society for Industrial and Applied Mathematics.
ii.	**Media.Bender, C. M., & Orszag, S. A.**, *Advanced mathematical methods for scientists and engineers I: Asymptotic methods and perturbation theory*. Springer Science & Business Media, 2013.
iii.	Kevorkian, J., & Cole, J. D., *Perturbation methods in applied mathematics* (Vol. 34). Springer Science & Business, 2013.

Supplementary Readings

i.	**Simmonds, J. G., & Mann Jr, J. E.**, *A first look at perturbation theory*. Courier Corporation, 1998.

Course Title	VIVA VOCE	ISCED Code	0541-5219
		Course Code	MATH 5219
Course Hour		Credit Value	2
Prerequisite	Recommended Books and Lecture Materials	Total Marks	50

Rationale

The viva gives students the chance to show that they have a thorough comprehension of the material and to respond to inquiries about the specifics of their project, thesis, or several first-semester courses. On this stage, they can demonstrate their intelligence and short-term social concerns.

Course Objectives

This is a platform to practice and show their smartness and confidence, as well as to address immediate issues in the society.

The main focus of the assessment is on the advanced mathematics courses designed for graduate program.

Mathematics is a fundamental subject, and job-seeking students ought to explore it in many institutions of the job market. Viva voce is vital for making mathematics acceptable in the business and research realms.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Develop crucial communication skills through oral examinations that promote self-realization and self-expression.
CLO2	Stimulate interactive interaction between candidates and assessors, allowing examinees to demonstrate their abilities and examiners to distinguish between superficial and profound knowledge through extensive questions.
CLO3	Exhibit the ability to tailor questions to the specific needs and abilities of individual students.
CLO4	Conduct real-time tests, which have traditionally been used in job market evaluations, to measure proficiency in several areas.
CLO5	Effectively evaluate top students by using in-depth questions to determine their degree of proficiency and gauge their higher-order cognitive skills.

Course Contents

	Course Contents	Hours	CLOs
1.	Students respond orally to questions during the comprehensive viva examination. These tests frequently draw from both the first and second semesters' worth of coursework. A vital component of academic programs, viva exams are frequently administered at the end of each academic year.	Second Semester	1, 2, 3, 4, 5
2.	These Viva examinations formed part of the theory component of the final summative examination in the second semester of the first year. Since the Viva Voce is conducted for all students irrespective of their passing status in theory, the exercise is time consuming. To determine the impact of viva voce examinations on summative examination performance, this study has been conducted.		

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	-	♦	-	♦	-	♦	-	-	-	-
CLO2	♦	♦	♦	♦	-	-	-	-	-	-	-	-
CLO3	-	♦	-	♦	-	♦	♦	♦	♦	-	♦	-
CLO4	-	-	♦	-	♦	♦	♦	-	♦	♦	♦	♦
CLO5	-	-	♦	-	-	-	-	-	♦	♦	♦	-

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1-CLO5	Student Activity	Presentation, concept and understanding on the taught courses, communication skills, Smartness and Confidence.

Learning Materials

Recommended Readings

i.	All recommended books of MS Year Second Semester.

GED Courses

Course Title	**OPERATIONS MANAGEMENT**	**ISCED Code**	0413-5213
		Course Code	MGT 5213
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Probability and Statistics, Introductory Business Administration, Linear Programming	**Total Marks**	100

Rationale

Operations activities, such as forecasting, choosing a location for an office or plant, allocating resources, designing products and services, scheduling activities, and assuring and improving quality are core activities and often strategic issues in business organizations. Production Management or Operations Management is the management of systems or processes that create goods and/or services. The material in this course is intended as an introduction to the field of operations management. The field of operations management is dynamic, and very much a part of the good things that are happening in business organizations. Much of what the students learn will have practical application.

Course Objectives

Operations Management aims to focus on efficiently producing goods and services while meeting customer needs and expectations. Key objectives include improving efficiency, reducing costs, enhancing quality, and ensuring flexibility and dependability. Ultimately, operations management objectives are to deliver products and services that satisfy customers and contribute to organizational probability.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Be an expert in product and service design.
CLO2	Process selection, technology selection.
CLO3	Design of work systems, location planning, and facility planning and Quality improvement of goods and services.
CLO4	Forecasting and Capacity planning.
CLO5	Scheduling, managing inventory and manage large-scale projects

Course Contents

	Course Contents	Hours	CLOs
1.	**Introduction:** Introduction to Operations Management. The scope of OM. OM and decision-making Productivity, Product mix, Strategy. Competitiveness.	6	1, 2
2.	**Capacity Planning:** Strategic capacity decision, Strategy formulation, Defining and measuring capacity, Evaluating capacity alternatives. Quality Control: Management of quality, Statistical process control, Variations and control, Control Charts, Process capability, Improving process capability, Capability analysis. Forecasting: Features common to all forecasts, Elements of good forecasts, Steps in the forecasting process, Accuracy and control of forecasting, and Applications forecasting models. Process selection and facility layout.	10	1, 2, 3, 4, 5
3.	**Inventory Control:** Nature and importance of inventories, Introduction to basic inventory models (Economics order quantity (*EOQ) model, EPQ model, Fixed order interval model, Single period model).	8	1, 4,
4.	**Scheduling:** Scheduling in high-volume systems, intermediate–volume systems, low-volume systems, Scheduling methods of linear Programming, Scheduling jobs through two work centres, Minimizing Scheduling difficulties, and scheduling the workforce.	9	1, 4

5.	**Project management:** Behavioral aspect of Project management, Key decisions in Project management, PERT (program evaluation and review technique), CPM (critical path method), Deterministic time estimates, Probabilistic time estimates, Applications.	9	1, 3, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	–	♦	♦	♦	♦	–	–	–	–
CLO3	♦	♦	–	♦	♦	♦	♦	♦	♦	♦	–	–
CLO4	♦	♦	♦	♦	♦	♦	–	♦	♦	♦	–	–
CLO5	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Quiz/ Homework (Formative)
CLO2	Lecturing and Discussion	Midterm (Summative)
CLO3	Lecturing and Visual Presentation	Assignment (Formative) and Midterm (Summative)
CLO4	Lecturing and Visual Presentation	Assignment (Formative) and Midterm (Summative)
CLO5	Lecturing and Visual Presentation	Final Exam (Summative)

Learning Materials

Recommended Readings

i.	**Stevenson, W. J.,** Operations Management, McGraw Hill, 2017.
ii.	**Hillier,F. S.**, Introduction to Operations Research, McGraw Hill, 2002.
iii.	**Winston,W. L.**, Operations Research, Cengage Learning, 2003.

Supplementary Readings

i.	**Griffin**,**R. W.**, Fundamentals to Operations Management, Cengage Learning, 2015.

Course Title	QUANTITATIVE RISK MANAGEMENT	ISCED Code	0413-5214
		Course Code	MGT 5214
Course Hour	3.0 Hr./Week	**Credit Value**	3
Prerequisite	Hydrodynamics and Fluid Dynamics	**Total Marks**	100

Rationale

Within the realm of risk management, **quantitative risk management** analysis provides an objective and data-driven tool to comprehend, prioritize, and handle risks. Utilizing this approach allows you to enhance your understanding of the risk landscape, make decisions based on more informed insights, and ultimately bolster your resilience in the face of uncertainty.

Course Objectives

It is a follow-up course with prerequisites of "Stochastic Calculus" and "Introduction to Mathematical Finance". The idea and concept of risk management in Banks, Insurance and other financial institutions are covered from stochastic modelling perspectives. Stock market volatility modeling and stock derivative price modelling are a good part of the course. Back-testing risk measures for stock return and other risk measures for derivative investments are covered.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Apply various aspects of the theory and practice of risk modeling for financial institutions
CLO2	Gain an understanding of different types of financial risks, including market, credit, and operational risks and Prepare for research degrees in Mathematical Finance and advanced Actuarial Science
CLO3	Estimate various risk measures such as Value-at-Risk (VaR) and Expected Shortfall for different types of risks within a financial institution, understand concepts of implied volatility in derivative markets and implied volatility models for derivative pricing, facilitating engagement in quantitative research groups of Banks and Insurance companies dealing with derivatives.
CLO4	Construct and estimate volatility processes, such as ARCH and GARCH and Understand the concept of tail risk and quantify it using either heavy-tail distributions or extreme value theory.
CLO5	Construct a multivariate model and calibrate its parameters to real financial data, either through a multivariate distribution (top-down approach) or copula (bottom-up approach) and Use GARCH models for financial econometrics with non-stationary distributions in stock return modeling and implement risk management through Value-at-Risk (VaR) and Expected Shortfall (ES).

Course Contents

	Course Contents	Hours	CLOs
1.	**Volatility Modelling:** Simple Variance Forecasting, The GARCH Variance Model, Extensions to the GARCH Model.	3	2, 3,
2.	**Volatility Modelling:** Maximum Likelihood Estimation, Variance Model Evaluation, Using Intraday Information, Empirical Exercises, Chapter References for further reading	3	2, 3, 4
3.	**Correlation Modelling in Finance:**Value at Risk (VaR) for Simple Portfolios, Portfolio Variance, Modelling Conditional Covariances, Modelling Conditional Correlations, Quasi-Maximum Likelihood Estimation,	4	1, 2, 3
4.	**Correlation Modelling in Finance:** Realised and Range-Based Covariance, VaR from Logarithmic versus Arithmetic Returns, Empirical Exercises, Chapter References for further reading.	4	1, 2, 3
5.	**Modelling the Conditional Distribution in Finance:** Visualising Non-Normality, The Standardised t(d) Distribution, The Cornish-Fisher Approximation to VaR, Extreme Value Theory (EVT), The Expected Shortfall (ES) Risk Measure, Empirical Exercises, Chapter References for further reading.	5	2, 3, 5
6.	**Simulation-Based Methods:** Historical Simulation (HS), Weighted Historical Simulation (WHS), Multi-Period Risk Calculations, Monte Carlo Simulation (MCS), Filtered Historical Simulation (FHS), Empirical Exercises, estimating VaR and ES for ARCH/GARCH processes.	3	2, 3, 5
7.	**Simulation-Based Methods:** Jump-diffusion processes; fattailed levy processes; mean reverting processes. Review of Vasicek Model, exponential Vasicek model, CIR model, mean reversion +CIR combined model to apply risk measures. Chapter	3	4, 5

	References for further reading		
8.	**Option Pricing:** Basic Definitions, Option Pricing under the Normal Distribution, Allowing for Skewness and Kurtosis, GARCH Option Pricing Models, Implied Volatility Function (IVF) Models, The CFG Option Pricing Formula, Empirical Exercises, Chapter References for further reading.	4	2, 3, 5
9.	**Modeling Option Risk:** The Option Delta, Portfolio Risk Using Delta, The Option Gamma, Portfolio Risk Using Gamma.	3	3, 4
10.	**Modeling Option Risk:** Portfolio Risk Using Full Valuation, A Simple Example, Pitfall in the Delta and Gamma Approaches, Empirical Exercises, Chapter References for further reading	4	3, 4
11.	**Backtesting Risk Models:** Backtesting VaRs, Increasing the Information Set, Conditional coverage test, Unconditional coverage test, Independence test.	3	4, 5
12.	**Backtesting Risk Models:** Application of backtesting to simulation based models of section 5; Empirical Exercises, Chapter References for further reading.	3	4, 5

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	–	–	–	–	–	♦	–	♦	–	–	–
CLO2	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO3	–	–	♦	–	–	♦	♦	♦	♦	–	–	–
CLO4	–	–	♦	♦	♦	♦	–	–	–	♦	–	–
CLO5	–	–	–	–	–	–	♦	–	–	♦	♦	–

♦Aligned –Not-aligned

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CLO1	Lecturing and Student Activity	Quiz/Homework (Formative) and Midterm (Summative
CLO2	Lecturing, Questioning and Answer questioning	Homework (Formative) and Final exam(Summative)
CLO3	Lecturing and Group discussion	Presentations (Formative) Midterm,Final exam (Summative)
CLO4	Lecturing and Visual Presentation	Final exam (Summative)
CLO5	Lecturing, Questioning and Answer questioning	Assignment and Presentations (Formative) Midterm and Final exam (Summative)

Learning Materials

Recommended Readings

i.	**McNeil, A.,** *Quantitative Risk Management: Concepts, techniques and tools*, Princeton University Press, 2015.
ii.	**Christoffersen, P.,** *Elements of Financial Risk Management*, Academic Press, 2016.

Supplementary Readings

i.	**Dowd, K.**, *Measuring Market Risk*, Wiley,Second edition, 2005.

MS 3rd Semester

Course Title	MS THESIS	ISCED Code	0541-5301
		Course Code	MATH 5301
Course Hour	Sessional	**Credit Value**	12
Prerequisite	CGPA 3.5 in B.Sc.	**Total Marks**	100

Rationale

This course aims to provide graduates with advanced knowledge, understanding, capacities, and attitudes in the context of their degree of study. Graduates can handle unstructured real-life problems mathematically and propose various solution strategies based on their knowledge of problem descriptions and literature reviews. Indeed, it is a research platform for students to demonstrate their knowledge and talents in numerous fields of mathematical application.

Course Objectives

Each student of the MS thesis group is required to work on a project focusing on a specific topic in mathematics. Students develop a skill in analyzing and formulating mathematical concepts that enables them to acquire more comprehensive specialized skills and more advanced knowledge. They gain a broad understanding of the basic concepts and methods of mathematics that develop essential skills in interpreting formulas and solving mathematical problems. Students adapt to independent scientific work by submitting a Dissertation in MS word and PowerPoint Presentation. Furthermore, the Thesis Dissertation makes them ready to face presentations and oral examinations in front of a panel of experts.

Course Learning Outcomes (CLOs)

On satisfying the requirements and successful completion of this course, students will have the knowledge and skills to

CLO1	Explain different problems related to time-demanding mathematical research.
CLO2	Pursue extensive research on real-world problems employing mathematical methodologies.
CLO3	Develop and write a Thesis based on research findings and be able to continue further research work.

Course Contents

	Course Contents	Hours	CLOs
1.	A particular research topic in Mathematics is given by the concerned thesis supervisor.	Sessional	1, 2, 3

Alignment of CLOs VS PLOs

Mapping of CLOs to PLOs

PLOs/ CLOs	PLO1	PL02	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11	PLO12
CLO1	♦	♦	–	–	–	–	–	–	–	–	–	–
CLO2	♦	♦	♦	♦	♦	–	–	–	–	–	–	–
CLO3	♦	♦	–	♦	♦	♦	♦	–	–	–	–	–

♦*Aligned* –*Not-aligned*

Teaching-Learning VS **Assessment Strategy**

CLOs	Teaching-Learning Strategy	Assessment Strategy
CO1-CO2	Lectures for Team Teaching	Presentation and Viva Voce
CO3	Group Discussion and Inquiry-based Instruction	Report Writing and Presentation

Learning Materials

Recommended Readings

i.	All courses recommended by supervisor of the respective research area.