University of Dhaka (Affiliated Colleges)
Department of Mathematics
Curriculum for 1 (one) Year M. Sc. Program
(Effective Academic Year 2022-2023)

The M. S. program has duration of one academic year. Each student of the program has to take **seven** courses (each of 4 credits).

Credit Requirement **32 Credits**

7 Courses, 28 Credits
Viva Voce 4 Credits

List of Courses for M. S. Program

Course No.	Course Title	Credits
	Group A	
370501	THEORY OF GROUPS	4
370502	THEORY OF RINGS AND MODULES	4
370503	ADVANCED NUMBER THEORY	4
370504	REAL FUNCTION THEORY	4
370505	GENERAL TOPOLOGY	4
	Group B	
370506	DIFFERENTIAL AND INTEGRAL EQUATIONS	4
370507	OPERATIONS RESEARCH	4
370508	NUMERICAL METHODS FOR DIFFERENTIAL EQUATIONS	4
370509	GEOMETRY OF DIFFERENTIAL MANIFOLDS	4
370510	DYNAMICAL SYSTEMS	4
370511	MATHEMATICAL BIOLOGY	4
370512	OPERATIONS MANAGEMENT	4
370513	THEORY OF RELATIVITY	4
370514	FLUID DYNAMICS	4
370515	QUANTUM MECHANICS	4
370599	Viva-Voce	4

Note: The students will choose seven courses at least two courses from each Group

Course Code: 370501	**Credit Hours: 4.00 Hrs /Week**	**Year: MS**	**Semester:**
Course Title: THEORY OF GROUPS	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

Theory of groups and representations is key to many branches of sciences and mathematics such as studying symmetries in geometry, Conservation laws of physics are related to the symmetry of physical laws under various transformations, group theory predicted the existence of many elementary particles before they were found experimentally. The structure and behavior of molecules and crystals depends on their different symmetries. Group theory shows up in many other areas of geometry and Topology. Examples include different kinds of groups, such as the fundamentalgroup of a space. Classical problems in algebra have been resolved with group theory. Cryptography uses a lot of group theory. Different cryptosystems use different groups. This a course that may be studied for its own sake or from view point of applications.

Course Objectives:

By the end of the module, students should be familiar with the topics listed in the Course Contents. In particular, students will be able to prove the Class Equation for finite Groups, learn the techniques to prove Sylow Theorems and their applications for analyzing the structures of Finite Groups of given orders. They should be able to find Extensions and Split Extensions of groups; find Representation using Matrix; prove Schur's Lemma, Maschke's Theorems; find Group Characters.

Course Content:

1. **Finite Abelian group and Free Group:** Fundamental theorem of finite Abelian group, Free products of groups and Free groups.
2. **Group action:** Conjugation, Class equation if finite group, Orbit Stabilizer theorem.
3. **Sylow Theory:** Finite p-groups, classification of Groups of order p, p^2, pq, p^3
4. **Group Extensions**: Direct Products, Cyclic Extentions, Split Extentions, Semi-direct Product, Wreath Products, and Tensor product.
5. **Series of Groups:** Solvable, Super solvable, Nilpotent Groups and their subgroups; Commutator Group, Composition series, Normal series, Factor Groups; Upper and Lower Central Series
6. **Group Representation:** Permutational and Matrix Representation of Groups, Reducibility, Schur's Lemma, Maschk's Theorem
7. **Group Character:** Group Characters, Reducible, Irreducible, Faithful Characters; Orthogonality of First and Second Kind.

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- To understand basic ideas and applications of Groups
- To get introduced to different terminologies and properties of Finite Groups
- To get familiar with different classes of Groups, such as Symmetry Groups, Permutation Groups, Dihedral Groups, Klein4 Groups
- To find and prove the Class Equation for Finite Groups
- To learn the techniques of proofs of Sylow Theorems in the module
- To learn to apply Representation Theory of Groups and decomposition into irreducible representations to find Group Characters of Finite Groups
- to find Group Characters of Finite Groups

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. David S. Dummit, Richard M. Foote, **Abstract Algebra**,John Wiley and Sons Inc.
2. Joseph A. Gallian, **Contemporary Abstract Algebra**,Cengage Learning.
3. W. Ledermann. **Introduction to Group Characters**, Cambridge University Press
4. I. D. Macdonald, **The Theory of Groups**, Oxford University Press
5. Thomas W. Judson, **Abstract Algebra: Theory and Application**, Orthogonal Publishing

Course Code: 370502	**Credit Hours: 4.00 Hrs /Week**	**Year: MS**	**Semester:**
Course Title: THEORY OF RINGS AND MODULES	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

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 vector space over a field. The study of modules over a ring $\boldsymbol{R}$ provides us with an insight into the structure of $\boldsymbol{R}$. In this course we shall develop ring and module theory leading to the fundamental theorems of Wedderburn and some of its applications.

Course Objectives:

By the end of the course the student should understand:

1. The importance of rings and modules as central objects in algebra and some of its applications.
2. The basic structure and theory of rings and modules.
3. How to develop this theory to investigate important classes of integral domains.
4. The concept of a module as a generalization of a vector space and an Abelian group.
5. The classification of any finitely generated module as a homomorphic image of a free module.
6. Simple modules, Schur's lemma. Radical, simple and semi simple artinian rings. Examples.
7. Semi-simple modules, artinian modules, their endomorphism. Examples.
8. The Wedderburn-Artin theorem.

Course Content:

1. **Topics in the Theory of Rings:** Polynomial rings over Unique Factorization Domain (UFD), Wedderburn's and Jacobson's Theorems, the Radical, Semisimple and Simple rings.
2. **Rings of Fractions:** Rings of fractions and embedding theorems, local rings and Noetherian rings, Rings with Ore conditions and related theorems.

3. **Field Theory:** Irreducible Polynomials and Eisenstein criterion, Algebraic extensions of fields, Splitting fields and Finite fields.

4. **Modules and vector spaces:** Definition and examples, submodules and direct sums, R-homomorphisms and quotient modules, completely reducible and free modules, projective and injective modules, Noetherian and Artinian rings and modules. Wedderburn-Artin theorem.

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- See the relations between algebra and its applications in and outside mathematics.
- To get introduced to different terminologies and properties of Finite Groups
- Become familiar with rings and fields, and understand the structure theory of modules over a Euclidean domain along with its implications
- Write precise and accurate mathematical definitions of objects in ring theory.
- Use mathematical definitions to identify and construct examples and to distinguish examples from non-examples
- Validate and critically assess a mathematical proof.
- To understand how every finitely generated module is a homomorphic image of a free module.
- Use a combination of theoretical knowledge and independent mathematical thinking to investigate questions in ring theory and to construct proofs.
- Write about ring theory in a coherent, grammatically correct and technically accurate manner.

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. Hiram Paley and Paul M. Weichsel. **A First Course in Abstract Algebra**, Holt, Rinehart and Winston

2. S Lang, **Algebra**, Springer

3. Thomas W Hungerford, **Algebra**, Springer

4. P.B. Bhattarcharya, S.K. Jain & S.R. Nagpaul, **Basic Abstract Algebra**, Cambridge University Press

5. David S. Dummit, Richard M. Foote, **Abstract Algebra**, John Wiley & Sons, Inc.

Course Code: 370503	**Credit Hours: 4.00 Hrs /Week**	**Year: MS**	**Semester:**
Course Title: ADVANCED NUMBER THEORY	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

Number theory is a broad subject with many strong connections with other branches of mathematics. The idea of the course is to give a solid introduction to quadratic fired and algebraic number theory. It will be bridging the gap between elementary number theory and the systematic study of advanced topics.

Course Objectives:

By the end of the course the student should understand:

- Learn quadratic field specially, Euclidian quadratic fields
- Get idea on quadratic residues, and law of quadratic reciprocity.
- Learn the distribution of prime numbers. An extended idea on prime number theory and several arithmetical functions related to prime number theory.
- Get an idea on Algebraic Number theory.

Course Content:

1. **Quadratic Fields:** Arithmetic of quadratic fields, Euclidean quadratic fields.
2. **Quadratic Residuacity:** Quadratic residues and nonresidues, Euler criterion, Legendre symbol, Gauss's lemma, law of quadratic reciprocity, Jacobi' s symbol.
3. **Average orders of Arithmetic Functions:** Lim sup, Lim inf, average orders of arithmetical functions.
4. **Distribution of Prime Numbers:** Bertrand's postulate, Chebyshev's theorem, the function $\theta(x)$ and $\psi(x)$. The prime number theory; elementary proof via Selbdrg's lemma, complex analytical proof.
5. **Primes in Arithmetic Progressions:** Characters of an abelian group, L-functions, Dirichlet's proof of infinitude of primes in arithmetic progressions.
6. **Algebraic Number Theory:** Noetherian ring and Dedekind domains, ideal classes and the unit theorem, units in real quadratic field.

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- Arithmetic of Euclidian quadratic field. quadratic residues, Jacobi's symbol, gauss lemma, and law of quadratic reciprocity. They can extend their idea on Quadratic residuacity for further ideas.
- Arithmetic functions and average orders of arithmetic functions
- The distribution of prime numbers. An extended idea on prime number theory and several arithmetical functions related to prime number theory, the function $\theta(x)$and $\psi(x)$. They will see the elementary proof as well as complex analytical proof of prime number theorem.
- Get an idea on Algebraic Number theory and get direction for future study on this area.

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. G.H. Hardy and E M Wright. **An introduction to the theory of numbers**, Oxford University Press
2. Kenneth Ireland, Michael Rosen, **A Classical Introduction to Modern Number Theory**, Springer New York
3. Ivan Niven, H. S. Zuckerman, H. L. Montgomery, **An Introduction to The Theory of Numbers**, John Wiley and sons
4. S. Rose. **A course in number theory**, Oxford University Press
5. P. Samuel, **Algebraic Theory of Numbers**, Dover Publication

Course Code: 370504	**Credit Hours: 4.00 Hrs /Week**	**Year: MS**	**Semester:**
Course Title: REAL FUNCTION THEORY	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

This is a continuation of a course on introduction to measure theory in n −dimensional Euclidian space offered in the senior year of the undergraduate program. The general abstract theory of measure, integration, and their applications is in order for a complete knowledge of the subject.

Course Objectives:

The course's objectives include introducing students to the ideas of abstract measure and its properties, integration of real function on an abstract measure space and its properties, and finally their applications in modern analysis.

Course Content:

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

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- Students will learn the abstract theory of measures,
- Students will learn the abstract theory integrations,
- Students will learn the abstract theory applications in modern analysis
- Students will learn the abstract theory of measure space
- Students will learn the abstract theory of Topology

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. H.L. Royden, P.M. Fitzpatrick. Real Analysis, PHI
2. Gerald B. Folland, Real Analysis Modern Techniques and their applications. John Wiley & Sons Inc.

Course Code: 370505 Course Title: GENERAL TOPOLOGY	Credit Hours: 4.00 Hrs /Week Total Marks: 100	Year: MS	Semester:
Course Teacher:	Course Type: Theory	Pre-requisite:	Academic Session: 2022-2023

Rationale:

Geometry has grown out of efforts to understand the world around us, and has been a central part of mathematics from the ancient times to the present. Topology has been designed to describe, quantify, and compare shapes of complex objects. Together, geometry and topology provide a very powerful set of mathematical tools that is of great importance in mathematics and its applications. This module will introduce the students to the mathematical foundation of modern geometry based on the notion of distance. We will study metric spaces and their transformations. Through examples, we will demonstrate how a choice of distance determines shapes, and will discuss the main types of geometries. An important part of the course will be the study of continuous maps of spaces. A proper context for the general discussion of continuity is the topological space, and the students will be guided through the foundations of topology. Geometry and topology are actively researched by mathematicians and we shall indicate the most exciting areas for further study

Course Objectives:

The main objective of this topic is to compare several notions that describe convergence in topological spaces.

The objectives of this course are to:

1. discussion of product topologies and introduce quotient spaces
2. introduce convergence of nets and filters in a topological space
3. demonstrate concepts of countability and separation axioms, notion of Lindel öf space, proof of Urysohm's Lemma. To give the idea how a topological space depends upon the distribution of open sets in the space and introduce the connection between different spaces such as regular spaces, completely regular spaces, and normal spaces, Urysohnmetrization theorem (Statement) and Tietze Extention theorem(Statement).
4. introduce student the concept of compactness by describing generalization of finiteness and Heine-Borel theorem to demonstrate notions of compactness and compactification constructions. Introduce the notion of different types of connected spaces and the relation between pathwise and local connectedness, components, path components, locally path connectedness.
5. introduce to the concept of uniform topological space and metrizable space, and their relation.
6. introduce to the concept of Functional spaces and establish a relation between point-wise and uniform convergences
7. introduce students to the notion of Commutative Topological Groups, Bases, Subgroups and Quotient groups, completion of topological groups, continuous homomorphisms, Groups of functions
8. develop the student's ability to handle abstract ideas in topology to understand real world applications

Course Content:

1. **Product and quotient topological spaces:** Constructing continuous functions, Pasting lemma, Maps into products, Product topology, Uniform topology on $\mathbb{R}^J$, Uniform limit theorem, Quotient topology.

2. **Convergence:** Convergence of nets and filters.

3. **Countability and Separationproperties:** Lindelöf space, Regular spaces, Completely regular spaces, Normal spaces, Characterization of Normality, Urysohn lemma, Statements of Urysohnmetrization theorem and TietzeExtention theorem.

4. **Compactness and Connectedness:** Compact and locally compact spaces, Uniform continuity theorem, Compactification, Path connectedness, locally connectedness, components, Path components, Locally path connectedness

5. **Uniform spaces:** Uniformisability and uniform metrisability.

6. **Function spaces:** Topology of pointwise convergence, Topology of uniform convergence, Compact open topology.

7. **Topological Groups:** Topological group, Elementary properties, Bases, Subgroups and Quotients of topoloical groups, completion of topological groups, Continuous homomorphisms, Groups of functions, Uniformities and metrisation.

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- learn the idea of different product topologies.
- learn the notation of quotient spaces.
- understand to work with various notions of compactness and be familiar with various compactification constructions.
- learn about connected spaces. They will also understand the relation between Pathwise and local connectedness, and components, path components, locally path connectedness.
- gain knowledge of Functional spaces and establish a relation between point-wise and uniform convergences. They will able to distinguish uniform and point-wise convergences
- study the important relation: "If a uniformity is metrizable, so is the uniform topology it generates. In the opposite direction, metrizability of the uniform topology does not imply that the uniformity itself is metrizable".
- learn the notion of different properties of commutative topological groups.

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. Munkres. James, Topology. Pearson
2. J. Kelly, General Topology.
3. G.F. Simmons, Introduction to Topology and Modern Analysis
4. James Dugundji. Topology, William C Brown Pub, 1966.
5. K. D. Joshi, Introduction to General Topology, Wiley Eastern Limited.

Course Code: 370506 **Course Title: Differential and Integral Equations**	**Credit Hours: 4.00 Hrs/Week** **Total Marks: 100**	**Year: MS**	**Semester:**
Course Teacher:	**Course Type: Theory**	**Pre-requisite:** **MTH-303**	**Academic Session: 2022-2023**

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 equation 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 analyze 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:

The main objective of the course is for students to

1. give knowledge on some basic mathematical analysis of solutions of differential euqations
2. learn to classify integral equations.
3. Analyze stability and time long dynamics of solutions of DEs.
4. discuss existence and uniqueness of solutions of Integral equations of Volterra and fredholm type.
5. know how to interpret the solutions of DIE.
6. learn about the application DIE to model and analyze real-life problems.
7. use integro-differential equations with real life exaples
8. numerical methods of integral equations.
9. detail Symmetric kernels and eigenpair analysis.

Course Content:

1. **Existence and Uniqueness Theorem of Differential Equations:** Review of existence and uniqueness theorem with some examples, fixed point methods, and existence theorem for vector valued IVP (higher dimensional cases), boundedness of solutions
2. **Periodic Solutions:** Periodic solutions of linear and non-linear differential and integral equations, Asymptotic behavior of solutions of linear differential equations.
3. **Stability Analysis:** Stability analysis of linear and nonlinear differential equations, Lyapunov stability analysis.

4. **Integral Equations:** Conversions of IVP's to integral equations, existence, uniqueness and general properties of solutions of Volterra integral equations, linear and non-linear systems of VIE's resolving kernels, Fredholm theory of IE's, semi-analytic solutions of a class of integral equations of Volterra and Fredholm types, singular Integral equations, Integro-Differential equations.
5. **Numerical Solutions of Integral Equations:** Degenerate kernel methods, Projection Methods, Quadrature Methods, Rainer Kress Methods.
6. **Hilbert- Schmidt theory:** Symmetric kernels, Complex Hilbert space, orthogonal system of functions, fundamental properties of eigenvalues and eigenfunction for symmetric kernels, Hilbert-Schmidt theorem with applications.

Course Learning Outcomes:

After the successful completion of the course, students will be able to:

- explain the concept of existence and uniqueness of solutions of differential equations
- explains stability and longtime dynamics of solutions of DE.
- Analyze stability and time long dynamics of solutions of DEs.
- Classify and expresses the existence-uniqueness theorem of integral equations
- Obtain analytic and semi-analytic solutions of a class of integral equations.
- symmetric kernels and relevant theorems
- Quadrature approximations solutions of integral equations using various schemes.
- Projections methods of IEs.
- Applications of Integral equations and Intrgro-differential equations in various branches science and engineering.

Evaluation: Incourse Assessment 30 Marks. Final examination (Theory, 4 hours): 70 Marks. **Eight** questions of equal value will be set, of which any **five** are to be answered.

References:

1. *Ravi P. Agrawal and Donal O' Regan, An Introduction to Ordinary Differential Equations, Springer*
2. *Fred Brauer and John A. Nohel, Ordinary differential equations*
3. *Masujima, M., Weinheim, Applied Mathematical Methods of Theoretical Physics: Integral Equations and Calculus of Variations, Germany, Wiley*
4. *D. E. Atkinson, Numerical solutions of integral equations.*
5. M. Rahman, Integral Equations and their Applications, WITpress.

Course Code: 370507	**Credit Hours: 4.00 Hrs /Week**	**Year: MS**	**Semester:**
Course Title: OPERATIONS RESEARCH	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

Operations Research (OR), also called Management Science, is the study of scientific approaches to decision-making problems. Through mathematical modeling, it seeks to design, improve and operate complex systems in the best possible way. This is a comprehensive course covering several areas of OR. The module covers topics that include: linear programming, bounded variable simplex algorithm, transportation and assignment problem, job sequencing, network model, dynamic programming, integer programming, game theory and nonlinear programming. Analytic techniques and computer packages will be used to solve problems facing different real life application oriented decision making problems.

Course Objectives:

The objectives of this course are to:

1. formulate a real-world problem as a mathematical programming model.

2. implement and solve the model using various software packages.

3. solve specialized linear programming problems like the transportation and assignment problems.

4. solve network models like the shortest path, minimum spanning tree, and maximum flow problems.

5. understand the applications of, basic methods for, and challenges in integer programming.

6. understand how to model and solve problems using dynamic programming.

7. learn optimality conditions for single- and multiple-variable unconstrained and constrained nonlinear optimization problems, and corresponding solution methodologies

Course Content:

1. **Basics of Operations Research:** Introduction, Definition, Characteristic, Necessity, Scope, Classification of problems, Types of mathematical models, Review of Linear Programming, Bounded Variable Simplex Algorithm.
2. **Transportation and Assignment Problem**: Introduction, Formulation, Relationship with LP, Solution procedure, Travelling Salesman Problem, Applications.
3. **Network Models:** Network definitions, Shortest Route problem, Minimal Spanning Tree problem, Maximal-Flow problem.

4. **Integer Programming:** Introduction, Pure integer and Mixed integer programming problem, Solution of IP using Branch and Bound Algorithm, Cutting-plane Algorithm, Applications.
5. **Sequencing Problem:** Sequencing problem processing n jobs through two machines, n jobs through three machines, two jobs through m machines, n jobs through m machines and approaches to more complex sequencing problems.
6. **Game Theory:** Introduction, Zero-sum game and Non-zero-sum game, Minimax-maximin pure strategies, Mixed strategies and Expected payoff, solution of $(2 \times 2), (2 \times n)$ and $(m \times 2)$ games, solution of $(m \times n)$ games by linear programming and Brown's algorithm. Evolutionary games: Basic concepts of evolutionary games; Scope of evolutionary games; Estimation of Nash equilibrium of several 2×2 games (Prisoner's dilemma, Chicken/snowdrift, stag-hunt, harmony/trivial, etc. using replicator dynamics.
7. **Dynamic Programming:** introduction, Resource allocation problem, investment Problem, Production scheduling problem, Stagecoach problem, Equipment replacement problem.

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- Students will be able to model and solve some real life oriented problems such as, transportation and assignment problem. Also they will be able to connect these problems with the network models.
- They will be familiarized with job scheduling problems along with their solution procedures.
- Application of bounded variable Linear program will be understood in modeling several network models.
- They will learn modeling with integer program along with the solution techniques
- Students will get some basic backgrounds on Dynamic programming and Game theory.
- They will be able to solve constrained and unconstrained nonlinear optimization problems
- Students will be able to develop applications using the familiar software tools (EXCEL/SOLVER, LINDO, MATLAB, MATHEMATICA, etc.) to solve problems.

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. **Operations Research, Applications and Algorithms**- *Wayne L. Winstion,* Thomson Learning.
2. **Operations Research, An Introduction**- *Hamdy A. Taha*, Pearson Prentice Hall.
3. **Operations Research**- *A. Ravindran, D.T. Philips, J.J. Solberg*, John Wiley and Sons.
4. **Introduction to Operations Research**, *F. Hiller, G. Lieberman*, Mc Graw-Hill.
5. **Evolutionary dynamics: Exploring the equations of life,** Martin Nowak, Harvard University Press.

Course Code: 370508	**Credit Hours: 4.00 Hrs /Week**	**Year: MS**	**Semester:**
Course Title: NUMERICAL METHODS FOR DIFFERENTIAL EQUATIONS	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

There are a lot of naturally occurred processes which can be described using ordinary and partial differential equations (ODEs and PDEs). A thorough knowledge of these processes are acquired solving the relevant equations. This course deals with numerical methods of various types of ordinary and partial differential equations. In particular, finite difference methods (FDMs) for linear and nonlinear ordinary differential equations as well as for elliptic, parabolic, hyperbolic partial differential equations will be discussed. Moreover, students will learn finite element methods (FEMs) in details.

Course Objectives:

1. To learn FDM for linear and nonlinear ODEs.
2. To know how to solve PDEs using FDMs.
3. To find numerical integration using FEM.
4. To provide a detailed knowledge about FEM to solve PDEs.
5. To learn how to solve eigenvalue problem using FEM.

Course Content:

Finite Element Method

1. **Introduction to FEM:** Discretization, Construction of basis functions, Numerical integration; coordinate transformation, local and global derivatives, mesh generation, h-p convergence.
2. **Galerkin Method:** BVP for Ordinary Differential Equations, 2D Poisson's and Laplace's equations, one space dimensional heat and Wave equations.
3. **Weighted Residuals Method:** Subdomain, Matrix formulation, Modified Galerkin method to solve 1-D linear and nonlinear BVP.
4. **Finite Element Solution of BVP:** Outline of FE procedures for Poisson's and Laplace's equations, Matrix formulation, Element concept, Triangular, Rectangular and Quadrilateral elements (linear and quadratic elements).
5. **Variational Formulation of ODEs (BVP):** Variational Functional and Construction of functionals, Rayleigh-Ritz method and finite elements.

Finite Difference Method

6. **Elliptic PDEs:** Review the solution of 2-space variables Poisson's and Laplace's equations, matrix formulation of the model, Stability, and error analysis of methods.
7. **Parabolic PDEs**: Review of 1D problems, Heat equation in 2-space variables, Matrix formulation, Forward, Backward and Crank-Nicolson methods, ADI method, Von Neumann Stability and error analysis of methods.
8. **Hyperbolic PDEs**: Wave equation in 1-space variables, Different types of explicit and implicit methods, Convergence and stability analysis, Wave equation in 2-space variables, Lax-Wendroff and Courant-Friedrichs-Lewy explicit methods, Wendroff implicit method, Wave equation in time-dependent and

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- Ability to solve linear and nonlinear ODEs employing FDM
- Analyze PDEs using relevant FDMs.
- Find numerical integration using FEM.
- Apply FEM in solving PDEs.
- Solve eigenvalue problem utilizing FEM.

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. P. E. Lewis and J. P Ward, The finite element method: Principles and Application, Addison Wesley
2. M. A. Celia and W. G. Gray, Numerical Methods for Differential Equations, Prentice-Hall Int. Inc.
3. G. D. Smith, Numerical solution of Partial differential equations, Clarendon press, Oxford
4. A. R. Mitchell and R. Wait, Finite Element Method in Partial Differential Equations, John Wiley & Sons Ltd
5. S. C. Brenner and L. R. Scott, The Mathematical Theory of Finite Element Methods, third edition, springer, 2000

Course Code: 370509	**Credit Hours: 4.00 Hrs/Week**	**Year: MS**	**Semester:**
Course Title: Geometry of Differential Manifolds	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rational:

Geometry of Differential Manifolds is based on three dimensional basic vector geometry of curves and surfaces with calculus. Understanding of this course students will precede 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 able to apply the concepts of surfaces to find which surface are minimal surfaces and also to know Weingarten, Gauss and Codazzi equations, Theorema Egreegium, fundamental theorem of surface theory etc. Students will know the concepts of developable surfaces, ruled surfaces, Gaussian curvature, Geodesics, Geodesic curvature, Liouvilles formula, Clairaut's theorem, Bonnet's formula and Gauss-Bonnet theorem. Students will learn about Conformal, isometric and geodesic mapping, Tissot's theorem. Theory of differential functions, charts, atlases, differentiable manifolds, smooth map on Manifolds, Tangent space, Tangent bundles, C^{∞}- vector fields and Lie brackets of vector fields on Manifolds, φ - related vectorfields.

Course Objectives:

The objectives of this course are:

- To give knowledge on mathematical concepts of space curve and surfaces, this course is very much useful.
- Students will know the concepts of geodesic curvature κ_g and its formulae, Liouville's formula, geodesic on a surface of revolution, Clairaut's theorem, Bonnet's formula, geodesics on Liouville surface, Gauss-Bonnet theorem.
- Students will learn about Manifolds structure on a topological space, C^{∞} - vector fields on manifolds etc.

Course Content:

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, Theoema Egreegium, fundamental theorem of surface theory.
2. **Developable and Ruled Surfaces:** 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.
3. **Geodesics on a Surface:** Geodesics, differential equation of geodesics, geodesics

on plane, surface, sphere, right circular cone, right helicoid, cylinder, torus etc., geodesic curvature κ_g and its formulae, Liouville's formula, geodesic on a surface of revolution. Clairaut's theorem, Bonnet's formula, geodesics on Liouville surface, Gauss-Bonnet theorem, torsion of a geodesic, geodesic parallel.

4. **Mapping of Surfaces:** Mapping, homeomorphism, isometric lines and correspondence, Minding theorem, conformal, isometric and geodesic mapping, Tissot's theorem.
5. **Differentiable Manifolds:** Theory of differentiable functions, coordinate functions, charts and atlases, complete, compatiablity, differentiable structures, differentiable manifolds, local representation of a function between two manifolds for their charts, induced topology on a manifolds.
6. **Topology of a Manifolds:** Manifold structure on a topological space, properties of induced topology, topological restrictions on manifolds.
7. **Differentiation on a Manifolds:** Partial differentiations, equivalence relation and class, smooth map on manifolds, derivation of smooth function and tangent vector, structure of tangent space, independent of tangency relation, tangent space, tangent bundles, tensor and exterior bundles, tangent map on manifolds.
8. **Vector Fields on a Manifolds:** 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.

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be able to:

- Apply Gauss and Weingarten equations to find out Theorema Egreegium and Codazzi's equations.
- Have to know about minimal surface, Riccati equation and its solution with some problem.
- Know how to check developable surface and how to find Gaussian Curvature and which surface is ruled surface or skew.
- How to find the geodesics for surfaces of plane, sphere, right circular cone, right helicoid, cylinder and torus and so on and to know geodesic curvature and its theorem.
- Illustrate different types of mapping and their properties and proof Tissot's theorem by using non-conformal mapping.
- Know about manifolds, charts, atlases and compatiability by using composite of two charts, local representation.
- Illustrate the differential structure of manifold with C^{∞} - function and topology.
- Gather Knowledge about smooth map, tangent space, tangent bundles, structure of tangent space map on manifolds.
- Earn knowledge about the conception of φ - related vector fields, to know a lemma and its applications into proposition of Lie brackets of vector fields.

Evaluation: Incourse Assessment: **30** Marks. Final examination (Theory, 4 hours): **Full marks: 70**. **Eight** questions of equal value will be set, of which any **Five** are to be answered.

References:

1. C. E. Weatherburn, Differential Geometry of Three Dimensions, Cambridge University Press, London.
2. F.W. Warner, Foundations of Differentiable Manifolds and Lie groups, Scott, Foresman and Company, Glenview, Illiniois, London
3. S.C. Mital and D.C. Agarwal, Differential Geometry, Krishna Prakashan Mandir, India.
4. D. J. Struik, Lectures on Classical Differential Geometry, Addison-Wesley Publishing Company, Inc. USA.
5. F. Brickell and R.S. Clark, Differentiable Manifolds: AnIntroduction, Van Nostrand Reinhold Company, London.

Course Code: 370510	**Credit Hours: 4.00 Hrs/Week**	**Year: MS**	**Semester:**
Course Title: DYNAMICAL SYSTEMS	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

Dynamics deals with change which evolve in time. Whether the system in question settles down to equilibrium, keep repeating in cycles, or does something more complicated, it is the dynamics that we use to analyze the behavior in various places of science.

Course Objectives:

At the end of the year students should be able to know:

1. The qualitative properties of dynamics and to understand asymptotic behavior
2. To classify equilibria by their stability, invariant manifolds and topological types
3. Identify fundamental differences between linear and nonlinear dynamical systems
4. Construct and interpret phase portraits of maps and flows
5. Identify fixed points and periodic points and determine their stability
6. How qualitative structure of the flow can change as parameters are varied
7. Unpredictable long-term behavior in a deterministic dynamical system
8. Characterization and measurements of chaos such as sensitive dependence on initial conditions and Lyapunov exponents
9. Use fractals to predict or analyze various biological processes or phenomena.

Course Content:

1. **Discrete Dynamical Systems**: One parameter family of maps, contraction and expanding map, fixed and periodic points, family of logistic maps, tent map, linear map, iterative maps, quadratic maps, Smale horseshoe map, and their stability analysis.
2. **Chaotic Dynamical systems**: Definitions of chaos, sensitive dependence on initial conditions, orbit structure, Cantor set, basin of attractor and repeller, strange attractors, Li-Yorke chaos and Lyapunov exponents.
3. **Differential Dynamical Systems**: One and two dimensional linear and nonlinear differential equations, sink, source and saddle points, hyperbolic fixed point, and their stability; population models; Henon map, Lorenz map; manifold and sub-manifold, stable and unstable manifold, center manifold theorem, Hartman-Grobman theorem, Hadamard-Perron theorem, Smale theorem.

4. **Bifurcations**: Bifurcations, bifurcation points, Saddle-node bifurcation, period-doubling bifurcation, pitchfork bifurcation, trancritical bifurcation, Hopf bifurcation, backward bifurcation.

5. **Symbolic Dynamical Systems**: Sequence spaces, shift map, symbolic dynamics, sub-shift of finite type.

6. **Fractal and Multi-fractal**: Basic concept of fractals, self-similarity, fractal dimension, chaos game, fractals in nature, Koch curve, Sierpinski triangle, Sierpinski carpet, Multi-fractal.

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- extend their knowledge of calculus to solve problems in difference (and maybe differential) equations
- students improve problem solving skills.
- understand the concepts of dynamical systems and to learn how to function in a work group.
- graphical analysis of dynamical systems and understand phase portraits.
- recognize when a dynamical system exhibits chaotic behavior
- generate fractals and find the topological dimension and fractal dimensions.

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. S H Strogatz, Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, And Engineering, Westview press, 2000.
2. R.L. Devaney. A First course in chaotic dynamical systems, Westview Press, 1992.
3. R.A. Holmgren. A first course in discrete dynamical systems, Springer, 2001.
4. S. Banerjee, M K Hassan, S. Mukherjee & A Gowrisankar, Fractal Patterns in Nonlinear Dynamics and Application, CRC press.
5. A. Katok and B. Hasselblatt. Introduction to modern theory of dynamical systems, CUP, Cambridge, 1995.

Course Code: 370511	**Credit Hours: 4.00 Hrs/Week**	**Year: MS**	**Semester:**
Course Title: MATHEMATICAL BIOLOGY	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

To provide students with the mathematical tools used to study and solve a variety of problems in biology at different scales. Mathematical Biology is one of the most rapidly growing and exciting areas of Applied Mathematics. This is because recently developed experimental techniques in the biological sciences, are generating an unprecedented amount of quantitative data.

Course Objectives:

By the end of the module the student should be able to:

1. to analyze simple models of biological phenomena using mathematics
2. to reproduce models and fundamental results of biological systems
3. introduce the student to advanced mathematical modeling in the Life Sciences
4. apply methods in the module to new problems inside the scope of Mathematical Biology
5. explore methods for solving the models and discuss the implications of the predictions.

Course Content:

1. **Single Species Continuous Models:** Introduction to linear and nonlinear population models, Sharpe-Lotka age-dependent population model, Gurtin-MaCamy age-dependent population model.
2. **Multi Species Continuous Models:** Two species linear and nonlinear population models, multi-species models, stability. Migration Modeling.
3. **Microbial Population Models**: Microbial population, dynamics of microbial competition, chemostat model and stability of equilibrium points.
4. **Dynamics of Infectious Diseases:** Virus dynamics, Dynamics of infectious diseases, AIDS/HIV models, dynamics of hepatitis B virus, age-dependent epidemic model, drug therapy, vaccination effects, Immunization and other public health intervention strategies, Modeling vector-borne diseases.

5. **Dynamics with Diffusion**: Reaction-Diffusion models, single and multi-species diffusion models, competition model with diffusion, epidemic model with diffusion, Pattern formations in systems of reaction-diffusion equations.
6. **Stochastic Model**: Concepts in probability, stochastic Processes, Brownian motion, martingales, stochastic linear and nonlinear models of population. Continuous and discrete time Markov Chain.

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- the applications of ODE models in a variety of biological systems
- making the student aware how to choose and use different modeling techniques in different areas
- reaction-diffusion equations and their applications in biology
- introduce the connections between biological questions and mathematical concepts
- develop the mathematics of dynamical systems, linear algebra, differential equations and difference equations through modeling biological systems
- explore the utility of using mathematical tools to understand the properties and behavior of biological systems.

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. F Brauer & C Castillo-Chavez, Mathematical models in population biology and epidemiology, Springer-Verlag, New York, 2001.
2. Maia Martcheva, An Introduction to Mathematical Epidemiology, Texts in Applied Mathematics, Springer, 2015.
3. J.D. Murray, Mathematical Biology, Springer, 1993.
4. H. L. Smith & P. Waltman, Theory of Chemostat, CUP, 1995.
5. M. A. Nowak & R. M. May, Virus Dynamics, Mathematical Principles of Immunology and Virology, 2000.

Course Code: 370512	**Credit Hours: 4.00 Hrs/Week**	**Year: MS**	**Semester:**
Course Title: OPERATIONS MANAGEMENT	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

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:

1. To give knowledge on the ways to manage the business organization efficiently.

2. Students will be able to learn the formulating procedure of different types of management tools.

3. It will help the students to apply the knowledge gather from this course in real life problems.

Course Content:

Chapter 1: Strategic Capacity Planning

Introduction to Operations Management (OM), the scope of OM, Productivity, Strategy, Competitiveness. Strategic capacity decision, Defining and measuring capacity, Evaluating capacity alternatives.

Chapter 2: Quality Control

Management of quality, Statistical process control, Variations and control, Control charts, Process capability, Improving process capability, Capability analysis.

Chapter 3: Forecasting

Elements of good forecast, Accuracy and control of forecasting, Applications of Forecasting, Judgmental Forecasting Methods, Time Series, Forecasting Methods for a Constant-Level Model, Incorporating Seasonal Effects into Forecasting Methods, An Exponential Smoothing Method for a Linear Trend Model, Holt's method, Winter's method, Box-Jenkins Method, Causal Forecasting with Linear Regression.

Chapter 4: Inventory Control

Components of Inventory Models, basic inventory models (Economic order quantity (EOQ) model, EPQ model, fixed order interval model, Single period model, Deterministic Continuous-Review Models, Deterministic Periodic-Review Model, Stochastic Continuous-Review Model, Stochastic Single-Period Model for Perishable Products, Stochastic Periodic-Review Models, Larger Inventory Systems in Practice.

Chapter 5: Planning and Scheduling

Scheduling in high-volume systems, intermediate-volume systems, low-volume systems, Scheduling methods of Linear Programming, Scheduling jobs through two work centers, Minimizing scheduling difficulties, scheduling the work force.

Chapter 6: Supply Chain Management

Value chains, supply chains, demand chains, need for supply chain management, benefits of supply chain management, managing supply chain, evaluating shipping alternatives, Global supply chain, e-commerce, effective supply chain, optimizing the supply chain.

Chapter 7: Waiting line and Simulation

Goal of Waiting line, Measuring system performance, Queuing models, The Essence of Simulation, Advantage and limitations of using simulations, applications of Simulation, Generation of Random Numbers, Generation of Random Observations from a Probability Distribution, Variance-Reducing Techniques, Regenerative Method of Statistical Analysis, Monte-Carlo simulation.

Chapter 8: 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.

Course Learning Outcomes (CLOs):

After the successful completion of the course, students will be an able to:

- be an expert in product and service design
- process selection, technology selection.
- design of work systems, location planning, facility planning.
- quality improvement of goods and services;
- forecasting,
- capacity planning;
- scheduling.
- managing inventory
- manage large scale projects.

Evaluation: Incourse Assessment **30** Marks. Final examination (Theory, 3 hours) **70** Marks. **Eight** questions will be set of which any **five** are to be answered.

References:

1. Operations Management by William J. Stevenson, 7th Edition, McGrew-Hill Higher education.
2. Operations Research by Wayne L. Winston,
3. Introduction to OR by Hillier and Lieberman, 10th Edition, McGrew-Hill Higher education
4. Fundamentals of Management Science by Turban & Merideth

Course Code: 370513	**Credit Hours: 4.00 Hrs/Week**	**Year: MS**	**Semester:**
Course Title: THEORY OF RELATIVITY	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

This course 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. The aim of studying this course is to construct mathematical models of the universe.

Course Learning Outcomes (CLOs):

After the completion of the course students will be able to:

- understand the physical principles which guided Einstein theory of relativity
- solve Einstein's equations in a variety of simple situations
- investigate the geodesic structure of the most important solutions of the theory
- understand the key properties of black holes
- understand the new world view of 4 dimensional Lorentzian space-time that replaced the Newtonian view of space and universal time
- understand that gravitational phenomena are manifestations of the geometry of space-time
- understand how geometry is encoded in a metric tensor, understand how Newtonian gravitation can be recovered in a limit from General Relativity
- understand how a black hole is described by the Schwarzschild metric
- understand how the whole universe can be modeled approximately by the Friedman metric

Course Contents:

1. Inertial frame, Galilean transformations, Michelson-Morley experiment, Absolute motion and historical survey.
2. Lorentz transformations, postulates of the special theory of relativity, Lorentz transformation equation, Consequences of Lorentz transformations, relativistic formulae for velocity and acceleration.
3. Minkowski's space and its properties.
4. **Relativistic mechanics:** Mass and momentum, Newton's laws of motion, equivalence of mass and energy, transformation formulae for momentum, energy, force and density.
5. Relativistic optics, relativistic electrodynamics and relativistic fluid mechanics.

6. Principle of covariance and principle of equivalence.
7. Relativistic field equations: Energy-momentum tensor, Principle of Mach and Einstein's law of gravitation, Schwrzschild's solution of Einstein's equation, Newton's law as first approximation.
8. The three crucial tests of the general theory of relativity.
9. Cosmology: Cosmology models: (a) Robertson-Walker model (b) Friedmann Model (c) Einstein's model (d) de Sitter model.
10. Introduction to unified field theory. String cosmology

References:

1. Goyal J.K., Gupta K.P. Theory of Relativity.
2. Steven Weinberg. Gravitation and Cosmology Principles and applications of the General Theory of Relativity.
3. Rashid H., Islam N. Theory of Relativity (in Bengali).

Course Code: 370514	**Credit Hours: 4.00 Hrs/Week**	**Year: MS**	**Semester:**
Course Title: FLUID DYNAMICS	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

The course deals with theoretical and practical aspects of hydrodynamics and fluid dynamics. The various topics covered are: Reynolds Transport Theorem, conservation of mass, momentum and energy, the development of the Navier-Stokes' equation, ideal and potential flows, vorticity, hydrodynamic forces in potential flow. Some of the vital topics covered are boundary layer concept, governing equations, incompressible flows, compressible flows, high speed flows, internal flow, external flow, dimensional analysis, and introduction to computational fluid dynamics.

Course Objectives:

1. To understand about the Navier-Stokes equation, steady and unsteady laminar flow.
2. To understand the concept of fluid and to be able to explain the properties of fluid.
3. To understand the hydrostatic forces acting on a solid surface immersed in liquid and to be able to calculate them in a specific situation.
4. To understand the basic equations of the conservation laws (continuity equation, Euler's equation and Bernoulli's theorem, momentum theorem) and to be able to apply them in a specific problem.
5. To understand the concept of dimensional analysis and to be able to apply it in a specific situation.
6. To understand about the Navier-Stokes equation, steady and unsteady laminar flow.

Course Learning Outcomes (CLOs):

Upon completion of this course, students will explore the followings:

- To learn the basic knowledge on fluid properties (continuity, density, viscosity, and surface tension).
- Describe the fundamental principles of the motion of ideal (inviscid) and real (viscous) fluid flows.
- Apply analytical concepts to analyze a range of two-dimensional fluid flows, with appropriate choice of simplifying assumptions and boundary conditions.
- To learn the dimensional analysis (basic/derived quantities, Buckingham's pi-theorem, similarity parameters).
- To learn the fundamentals of fluid dynamics.
- Investigate the physics/dynamics of a particular fluid flow giving a critical evaluation of the effect of significant flow and geometric parameters applying both hydrodynamic theory and knowledge from other disciples relevant to the problem.

Course Contents:

1. **Introduction and General Properties of Navier-Stokes equations:** Dimensional analysis and Similitude, Newton's law of viscosity, Newtonian and Non-Newtonian fluids, body and surface forces, stress vector and components, Relation between the stress and rate of strain, Derivation of the Navier-Stokes equations of motion and its general properties.
2. **(a) Steady Laminar flows:** Parallel flow through a straight channel, Plane and generalized Couette flows, Plane Poiseuille flow. Flow through a circular pipe-the Hagen-Poiseuille flow, Flow between two coaxial circular cylinders, Flow between two concentric rotating cylinders.

   (b) Unsteady flows: Flow between two parallel plates, Flow over a suddenly accelerated flat plate, Flow over an oscillation plate (Determination of maximum and average velocities, the shearing stress, skin-friction and the coefficient of skin-friction).
3. **Small Reynolds number flows or very slow motion:** Differential equation of very slow motion, Slow motion over a sphere (Stokes' solutions), Hydrodynamic theory of lubrication.
4. **Laminar boundary layer theory:** General concepts and properties of boundary layer, Prandtl's boundary layer equations, Separation of boundary layer, Similarity concept and similarity solutions of the boundary layer equations, Flow in convergent and divergent channel, Flow past a wedge, Boundary layer on a flat plate an zero incidences.
5. **Karman's integral equation (or condition):** Application of Karman's integral equation to boundary layer (Karman-Pohlhausen method), Determination of shearing stress and boundary layer thickness.
6. **Suction and injection in boundary layer:** General concepts, Steady flow between two porous parallel plates, suction/injection through horizontal or vertical plates (some specific problems).
7. **Thermal boundary layers in laminar flows:** Derivation of the energy equation, Theory of similarity in heat transfer, Thermal boundary analogy between heat transfers and skin-friction. Parallel forced flow past a flat plate at zero incidences, Natural flow past horizontal or vertical plates (some specific problems).

Evaluation: Incourse Assessment: 30 Marks. Final examination (Theory, 4 hours): Full marks: 70 **Eight** questions of equal value will be set, of which any **Five** are to be answered.

References:

1. **H. Schlichting:** Boundary Layer Theory
2. **M.D. Raisinghania:** Fluid dynamics with complete hydrodynamics and boundary layer theory
3. **F. Chorlton:** A Text Book of Fluid Dynamics
4. **D. E. Rutherford:** Fluid Dynamics
5. **Shanti Swarup:** Fluid Dynamics

Course Code: 370515	**Credit Hours: 4.00 Hrs/Week**	**Year: MS**	**Semester:**
Course Title: QUANTUM MECHANICS	**Total Marks: 100**		
Course Teacher:	**Course Type: Theory**	**Pre-requisite:**	**Academic Session: 2022-2023**

Rationale:

The course concerns origin of quantum theory, Heisenberg uncertainty principle, Schrödinger equation, many-particle systems and many other topics.

Course Objectives:

1. To know who invented Quantum theory and what quantum theory.
2. To know why the wave equation is so important and application of wave equation.
3. To learn what Schrodinger equation represents and to know that Schrödinger equation is used for.
4. To practice one dimensional examples.
5. To know the purpose of formalism, advantages of formalism and the main idea of formalism.
6. To know what the three –dimensional Schrodinger equation and the properties of Schrödinger equation.
7. To know what the angular momentum and how it is calculated.

Course Learning Outcomes (CLOs):

Upon completion of this course, students will explore the followings:

- To know the purposes of quantum theory and about black body radiation, photoelectric effect, Bohr model.
- It describes not only the moment of strings and wires, but also the movement of fluid surfaces, limitations of wave function,wave particle duality Heisenberg uncertainty principle etc.
- It gives us a detailed account of the form of the wave functions or probability waves that control the motion of some smaller particles, also learn about expectation values Ehrenfest's theorem, time independent Schrodinger equation etc.
- To know about free particle, potential step, periodic potential, linear harmonic oscillator etc.
- The formalism of quantum mechanics is built upon two fundamental concepts. Learning dynamical variables, the Schrodinger and Heisenberg pictures etc.
- To illustrate the solution of the time-independent Schrodinger equation in three-dimension, learn the separation of the equations in different co-ordinates and the hydrogen atom etc.
- Learning orbital angular momentum, eigenvalues and eigenfunctions of L^2 *and* L_z etc.

Course Contents:

1. **Origin of Quantum theory:** Black body radiation, Photoelectric effect, Compton effect, Bohr model, De Broglie's hypothesis, Wave properties of matter.
2. **Wave function:** wave-particle duality, wave packets, Heisenberg uncertainty principle.
3. **Schrödinger equation:** Expectation values, Operators, Ehrenfest's theorem, Time-independent Schrödinger equation & its general solution, Schrödinger equation in momentum space.
4. **One dimensional examples:** free particle, potential step, the square well, linear harmonic oscillator, periodic potential.
5. **Formalism of quantum mechanics:** Dynamical variables, Unitary transformations, Metric representations of wave functions and operators, The Schrödinger and Heisenberg pictures.
6. **Schrödinger equations in three dimensions:** Separation of the equation in different co-ordinates, free particle, square well potential, the hydrogen atom.
7. **Angular momentum:** Orbital angular momentum, the eigenvalues and eigenfunctions of L^2 and L_z, Spin angular momentum, Total angular momentum, addition of angular momenta.
8. **Many-particle systems:** System of identical particles, Bosons and Fermions, Two-electron atoms.

Evaluation: Incourse Assessment: 30 Marks. Final examination (Theory, 4 hours): Full marks: 70 **Eight** questions of equal value will be set, of which any **Five** are to be answered.

References:

1. B.H. Bransden& C.J. Joachain. Introduction to Quantum Mechanics.
2. L. I. Schiff . Quantum Mechanics.
3. David J. Griffiths. Introduction to Quantum Mechanics.

Course Code: 370599	**VIVA VOCE**	**Credits: 4**
Viva Voce on courses taught in the M. S. program.		