

# Indira Gandhi University, Meerpur (Rewari)

(A State University Established under Haryana Act No. 29 of 2013)  
(Recognized u/s 12(B) & 2(f) of UGC Act, 1956 )



**Scheme of Examination and Syllabi**

**for**

**Ph.D. Coursework (Mathematics)**

**with effect from session 2025-26**

**Indira Gandhi University, Meerpur (Rewari)**  
**Scheme of Examination**  
**Ph.D. Coursework (Mathematics)**  
**w.e.f. session 2025-26**

Course Type	Course Code	Title of the Course	Theory Marks	Internal Marks	Total Marks	Credits
CC	25L8.0-MAT-101	Research Methodology	70	30	100	4
<b>Subject Elective (Any One)</b>	25L8.0-MAT-102(A)	Advanced Solid Mechanics	70	30	100	4
	25L8.0-MAT-102(B)	Riemannian Geometry	70	30	100	4
	25L8.0-MAT-102(C)	Differential Manifolds	70	30	100	4
	25L8.0-MAT-102(D)	Inventory Management	70	30	100	4
	25L8.0-MAT-102(E)	Quantum Mechanics	70	30	100	4
CC	25L8.0-RPE-103	Research & Publication Ethics	40	10	50	2
CC	25L8.0-MAT-104	Review of Literature & Seminar	-	50	50	2

**Total Credits : 12**

- Note: 1.** The courses having an internal assessment of 30 marks will comprise of one written test (10 marks), one written assignment (10 marks) and one presentation (10 marks).
- 2.** The internal assessment of **Research & Publication Ethics** will comprise of one written assignment of 10 marks.
- 3.** Subject Elective Courses will be offered subject to availability of requisite resources/faculty.



## 25L8.0-MAT-101: Research Methodology

Time : 3 hours

Total Marks : 100  
Theory Marks : 70  
Internal Marks : 30  
Credits : 4

**Course Objectives:** The aim of this course is to get the students familiar with the steps involved in the research process, data collection, computer software knowledge and writing skill of research papers.

**Course Outcomes:** After studying this course, the student will be able to:

- CO1. Understand how to start a good research
- CO2. Get familiar with the computer software's
- CO3. Analyse the data and charts.
- CO4. Understand the layout of the research.

**Course Contents:**

### Unit-I(Three Questions)

**Introduction:** Meaning, objectives and types of research.

**Research Process:** Steps involved in research process, Problems encountered by researchers in India.

**Research Design:** Meaning and need for research design, Different research designs. Data collection through experimental techniques and theoretical calculations, Types of data and various methods of data collection and compilation.

### Unit-II(Three Questions)

**Introduction to Computers:** Functions, Operating systems, Windows- Working with files and folders, Internet Explorer, knowledge of Microsoft Word, Excel, Power Point.

**Processing and analysis of data:** Coding, editing, classification and tabulation of data, Elements of analysis, various kinds of charts and diagrams used in data analysis.

### Unit-III(Two Questions)

Use of Excel for analysing the data applying various statistical techniques.

**Preparation of Dissertation:** Types and layout of research, Precautions in preparing the research dissertations. Bibliography and annexure, discussion of results, Drawing conclusions, giving suggestions and recommendations to the concerned persons.

**Note:** The question paper will contain three sections and eight questions in all. Students will be required to attempt five questions in all selecting at least one from each section. All questions will carry equal marks.



## Books recommended

1. Bill Taylor, Research Methodology: A Guide for Researchers in Management and Social Sciences, PHI.
2. R. P. Mishra, Research Methodology, Concept Publishing Company(P) Ltd., New Delhi.
3. G.V. Shenoy and Madan Pant, Statistical Methods in Business and Social Sciences, McMillan Indian Ltd., New Delhi.
4. Suresh C. Sinha and Anil K. Dhiman, Research Methodology, Ess Ess Publications, New Delhi, 2002
5. ITL Education Solutions Ltd., Introduction to Information Technology, Pearson Education.
6. C. R. Kothari, Research Methodology, New Age International Publishers, 2004.
7. S. J. Chapman, MATLAB Programming for Engineers, CL-Engineering.

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## 25L8.0-MAT-102(A): Advanced Solid Mechanics

Time : 3 hours

Max. Marks : 100  
Theory Marks : 70  
Internal Marks : 30  
Credits : 4

**Course Objectives:** The aim of the course is to get the students familiar with the concept of Tensor, Strain, Stress and waves in the elastic media as well as the importance of these waves in the real world problems.

**Course Outcomes:** After studying this course, the student will be able to:

- CO1. Understand the concept of tensor and properties of the tensor.
- CO2. Understand the concept of strain and stress for the infinitesimal transformation.
- CO3. Get familiar with the Hooke's law and equation of motion in isotropic media.
- CO4. Understand the basic knowledge of the waves in elastic solids and their importance in the real world problems.

**Course Contents:**

### Unit-I(Three Questions)

Contribution of Indian Mathematicians/Physicist in classical/non-classical theory of elasticity, Cartesian tensors of different orders, contraction, multiplication and quotients laws for tensors, Isotropic tensors.

Affine transformation, Infinitesimal affine deformation, Pure deformation. Components of strain tensor and their geometrical meanings, Strain quadric of Cauchy, principal strains, Strain invariants, General infinitesimal deformation, Saint-Venant conditions of compatibility, Finite deformation. Stress vector, Normal stress, Shear stress, Stress components, Cauchy equation of equilibrium, Stress tensor of order two, Symmetry of stress tensor, Stress quadric of Cauchy, Principal stresses, Stress invariants, Maximum normal and shear stresses, Mohr diagram.

### Unit-II(Three Questions)

Generalized Hook's law, Hook's law in an elastic media with one plane of symmetry, Orthotropic and transversely isotropic symmetries. Homogeneous isotropic elastic media. Elastic moduli for an isotropic media, Equilibrium and dynamical equations for an isotropic elastic media, Beltrami-Michell compatibility conditions. Principle of conservation of mass-equation of continuity. Principles of balance of linear and angular momentum. Equations of motion in spatial coordinates. Principle of conservation of energy.

### Unit-III(Two Questions)

Transverse and longitudinal disturbance, P wave, S wave and SH wave. Reflection and refraction phenomenon in the elastic solids, liquid/liquid, liquid/solid, solid/liquid. Energy partition. Rayleigh wave in a elastic half-space. Love waves. Phase and group velocities.

**Note:** The question paper will contain three sections and eight questions in all. Students will be required to attempt five questions in all selecting at least one from each section. All questions will carry equal marks.



## Books recommended

1. I.S. Sokolnikoff, Mathematical Theory and Elasticity, Tata McGraw Hill, New Delhi, 1977
2. A. Udias, Principles of Seismology, Cambridge University Press, 1999.
3. D. S. Chandrasekhariah and L. Debnath, Continuum Mechanics, Academic Press, 1994.
4. A. S. Saada, Elasticity Theory and Applications, Pergamon Press, New York
5. A.E.H. Love, A Treatise on the Mathematical Theory of Elasticity, Cambridge University Press, 1959.

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## 25L8.0-MAT-102(B): Riemannian Geometry

Time : 3 hours

Max. Marks : 100  
Theory Marks : 70  
Internal Marks : 30  
Credits : 4

**Course Objectives:** The primary objective of this course is to study calculus over differentiable manifolds equipped with an inner product at each point that smoothly varies point to point.

**Course Outcomes:** After studying this course, the student will be able to:

- CO1. Work with manifolds, tangent spaces, vector fields, and Riemannian metric as a generalization of intrinsic surface geometry
- CO2. Understand covariant derivatives, parallel transport, Christoffel symbols, Riemannian curvature tensor, Ricci curvature and scalar curvature tensor.
- CO3. Understand geodesics as length minimizing curves exponential map, and properties of complete manifolds.
- CO4. Implement the concept of Riemannian geometry in research.

**Course Contents:**

### Unit-I(Two Questions)

Review of differentiable manifolds and vector fields, Covariant differentiation of vector fields and affine connection, Riemannian metric, Riemannian manifolds, Riemannian connection, Fundamental theorem of Riemannian geometry via Koszul's formula.

### Unit-II(Three Questions)

Tensors and tensor fields (Riemannian metric as the most significant example), Tensorial property, Covariant differentiation of tensor fields, Riemann curvature tensor, Ricci tensor, Sectional, Ricci and scalar curvatures, Isometries, Notion of covering spaces, Pull-back metrics via diffeomorphisms.

### Unit-III(Three Questions)

Covariant differentiation of a vector field along a curve with specific examples, Arc length and energy of a piecewise smooth curve, Geodesics as length minimizing curves, First variation of arc length, Geodesics as a critical point of the arc length functional, First variation formula, Exponential map, Geodesic completeness, Geodesic normal coordinates, Hopf-Rinow theorem (statement only), Geodesic variations, Jacobi fields and Gauss lemma. Second variation formula, The index form (Jacobi fields as minimizers of the index form)

**Note:** The question paper will contain three sections and eight questions in all. Students will be required to attempt five questions in all selecting at least one from each section. All questions will carry equal marks.

## Books recommended

1. M. Berger, A Panoramic View of Riemannian Geometry, Springer; 1st Edition, 2003. Corr. 2nd printing, 2011.
2. W. M. Boothby, An Introduction to Differentiable Manifolds and Riemannian Geometry, Second Edition, Academic Press, New York, 2007.
3. S. S. Chern, W. H. Chen and K. S. Lam, Lectures on Differential Geometry, World Scientific Publishing, 2022.
4. Manfredo P. Do Carmo and Francis Flaherty, Riemannian Geometry: Theory and Applications, Birkhauser Boston, 2011.
5. S. Kumaresan, A Course in Differential Geometry and Lie Groups (Texts and Readings in Mathematics), Hindustan Book Agency, 2002.
6. J. M. Lee, Introduction to Riemannian Manifolds-176, GTM, Springer, 2021.
7. B. O' Neill, Semi-Riemannian Geometry with Applications to Relativity, Academic Press, New York, 1983.

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## 25L8.0-MAT-102(C): Differential Manifolds

Time : 3 hours

Max. Marks : 100  
Theory Marks : 70  
Internal Marks : 30  
Credits : 4

**Course Objectives:** The primary objective of this course is to introduce the fundamental theory and concepts of smooth manifolds and enable students to apply differential calculus on smooth manifolds.

**Course Outcomes:** After studying this course, the student will be able :

- CO1.** To demonstrate an understanding of the basic theory of smooth manifolds, including their definition, properties and variety of examples.
- CO2.** To define and work with essential tools of differential geometry such as tangent spaces, tangent bundle and various types of maps on manifolds.
- CO3.** To perform calculations on smooth manifolds, including computing the Lie bracket, exterior derivatives and integrals.
- CO4.** To gain the necessary background and skills for advanced study and research in differential geometry, Riemannian Geometry or related fields.

**Course Contents:**

### Unit-I(Three Questions)

Topological manifolds, Charts, Atlases, Smooth manifolds, Examples of smooth manifolds, Manifolds with boundary, Smooth functions on a manifold, Smooth maps between manifolds, Diffeomorphism, Smoothness in terms of components, Examples of smooth maps, Smooth covering maps, Partition of unity and Bump functions.

### Unit-II(Three Questions)

Tangent vectors, Tangent space and Tangent bundle, The Differential of a map, Computations in coordinates, Velocity vectors of curves, Maps of constant rank, Embeddings, Submersions and Immersions, Embedded submanifolds, Immersed submanifolds, Restricting maps to submanifolds, Tangent space to submanifolds. Sard's theorem(Statement only), The Whitney embedding theorem (statement only).

### Unit-III(Two Questions)

Topological groups, Lie groups, Lie group homomorphisms, Lie subgroups, Group actions and Equivariant maps, Vector fields, Vector fields and smooth maps, Integral curves of vector fields, Lie brackets, The Lie algebra of a Lie group. Differential forms on Euclidean n-space, Differential forms on manifolds, The Exterior algebra, Exterior product, Exterior derivative, Pullback of a map, Interior product and Lie derivative, The Cartan formula and properties of Lie derivatives.

**Note:** The question paper will contain three sections and eight questions in all. Students will be required to attempt five questions in all selecting at least one from each section. All questions will carry equal marks.

## Books recommended

1. W. M. Boothby, An Introduction to Differentiable Manifolds and Riemannian Geometry, Second Edition, Academic Press, New York, 2007.
2. S. S. Chern, W. H. Chen and K. S. Lam, Lectures on Differential Geometry, World Scientific Publishing, 2022.
3. L. Conlon, Differentiable Manifolds, 2nd edition, Birkhauser Boston, Cambridge, MA, 2011.
4. N. J. Hicks, Notes of Differential Geometry, D. Van Nostrand Reinhold Company, New York, 1965.
5. S. Kumaresan, A Course in Differential Geometry and Lie Groups (Texts and Readings in Mathematics), Hindustan Book Agency, 2002.
6. J. M. Lee, Introduction to Smooth Manifolds, GTM, Vol. 218, Springer, New York, 2021.
7. L. W. Tu, An Introduction to Manifolds, Second edition, Springer, 2011.
8. F. Warner, Foundations of Differentiable Manifolds and Lie Groups, GTM, 94, Springer, New York, 1983

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## 25L8.0-MAT-102(D): Inventory Management

Time : 3 hours

Max. Marks : 100  
Theory Marks : 70  
Internal Marks : 30  
Credits : 4

**Course Objectives:** The aim of the course is to get the students familiar with the ways that inventory can be classified, to discuss inventory costs and the trade-offs that exist among them, to identify when to order and how much to order, with a particular emphasis on the economic order quantity, to differentiate the various inventory flow patterns, to discuss special concerns with inventory management and to identify several contemporary approaches to managing inventory.

**Course Outcomes:** After studying this course, the student will be able to:

- CO1. Learn how to maintain the right amount of inventory to meet demand without excessive overstocking or costly shortages.
- CO2. Minimize holding costs and ordering costs.
- CO3. Ensure products are available for timely delivery, improving satisfaction and loyalty and free up capital tied in excess inventory for other investments.
- CO4. Streamline warehouse operations, reduce errors, and speed up order fulfillment.

**Course Contents:**

### Unit-I(Two Questions)

Introduction: The Historical Development, Nature and Meaning of Operations Research and its Management Applications. Modelling in Operations Research and its Principles. Approximations and Main Characteristics of Operations Research. General Methods for solving Operations Research Models, Main Phases of Operations Research Study. Scope of Operations Research, Role of Operations Research in Decision-Making, Brief outlines of Operations Research Models, Quantitative Techniques, Development of Operations Research in India, Role of Computers in Operations Research.

### Unit-II(Three Questions)

Inventory/Production Management-I (Deterministic Inventory Models): Inventory - Definition, Decisions, Types of Inventory Models and their Development. Cost involved and variables in Inventory Problems. Deterministic Elementary Inventory Models: Static Demand Models, Dynamic or Fluctuating Demand Models and Deterministic Models with Price-Breaks.

### Unit-III(Three Questions)

Inventory/Production Management-II (Probabilistic Inventory Models and ABC Analysis) : Probabilistic Inventory Models, Selective Inventory Management, Replacement and Reliability Models.

**Note:** The question paper will contain three sections and eight questions in all. Students will be required to attempt five questions in all selecting at least one from each section. All questions will carry equal marks.

## Books recommended

1. H. A. Taha, Operations Research-An Introduction, Prentice Hall, 2010.
2. P. K. Gupta and D.S. Hira, Operations Research, S. Chand and Co. Ltd., 2014.
3. S. D. Sharma, Operations Research, Kedar Nath Ram Nath Publications, 2012.
4. J. K. Sharma, Mathematical Models in Operations Research, Tata McGraw-Hill Publishing Company Ltd., 1989.
5. Kanti Swarup, P. K. Gupta and ManMohan, Operations Research, Sultan Chand and Sons, New Delhi, 2014.

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## 25L8.0-MAT-102(E): Quantum Mechanics

Time : 3 hours

Max. Marks : 100  
Theory Marks : 70  
Internal Marks : 30  
Credits : 4

**Course Objectives:** The objective of this course is to focus on grasping foundational concepts like wave-particle duality, the Schrödinger equation, and operators, then applying them to solve problems in 1D and 3D potentials (e.g., wells, hydrogen atom), understanding quantum phenomena (like spin, tunneling), and exploring advanced topics such as perturbation theory, scattering, and relativistic quantum mechanics, ultimately connecting theory to real-world applications like quantum computing.

**Course Outcomes:** After studying this course, the student will have understanding of

- CO1. Difference between classical and quantum mechanical theory and approach
- CO2. Various techniques to solve time dependent and time independent Schrodinger equations using different Coordinate systems.
- CO3. Connection between symmetry and conservation laws, commutation relations, tools to calculate components and total angular momentum.
- CO4. Various approximation methods utilized in Quantum Mechanics.

**Course Contents:**

### Unit-I(Three Questions)

Introduction, Vector spaces, Matrix Representations, Similarity transformation, Inner Product space, Spectral decomposition, Schmidt decomposition (Singular Value decomposition), Infinite dimensions and Hilbert spaces, Symmetric operator, Self-Adjoint operator, Positive operator, Tensor product of vector spaces, Partial Trace, Partial Transpose

Stern-Gerlach experiment, Postulates of Quantum Mechanics Postulates, Bloch sphere, Projective Measurement, Positive Operator Valued measure (POVM), Discriminating the states, Commutators, the expectation value and the uncertainty, Heisenberg uncertainty relations, Self- adjoint extension, von-Neumann's prescription.

### Unit-II(Three Questions)

General properties of the Schrodinger Equation, Complete set of commuting operators, Evolution operator, Schrodinger, Heisenberg, and Interaction pictures, Two state system, Rabi- Oscillation, Density Operator, Quantum entanglement, Entanglement entropy.

Schrodinger wave equation, operator methods, symmetry and angular momentum, approximate methods, quantum mechanics for a system of particles, Dirac equation.

Infinite potential well, Particle moving on a ring, Particle moving on a ring enclosing a magnetic flux, Aharonov- Bohm effect, Charged particle in a magnetic field, Landau levels, Periodic potential, Bloch's Condition, Kronig-Penney model.



### Unit-III(Two Questions)

Relativistic quantum mechanics, Quantization of non-relativistic Schrodinger equation, Dirac  $\gamma$ -Matrices and their properties, Charge and current densities, Covariant form of Dirac equation, Dirac equation for a central field-H-atom, Negative energy states.

**Note: The question paper will contain three sections and eight questions in all. Students will be required to attempt five questions in all selecting at least one from each section. All questions will carry equal marks.**

### Books recommended

1. J.J. Sakurai, Advanced Quantum Mechanics-Addison Wesley, 1967
2. J.J. Sakurai and Jim Napolitano, Modern Quantum Mechanics, Cambridge University Press, 2025.
3. D.J. Griffiths, Introduction to Quantum Mechanics, Springer Link, 2001.
4. L.H. Ryder, Quantum field theory, Cambridge University Press, 1996.
5. Steven L. Weinberg, Lectures On Quantum Mechanics, Cambridge University Press, 2015.
6. R. R. Puri, Non-Relativistic Quantum Mechanics, Cambridge University Press; First edition, 2017.
7. R. Shankar, Principle of Quantum Mechanics, Springer, 2014.
8. Claude Cohen-Tannoudji, Bernard Diu, and Franck Laloë, Quantum Mechanics, Vol. 1, 2 & 3.
9. W. Greiner, Relativistic Quantum Mechanics, 2nd Edition, 2001.



## 25L8.0-MAT-104: Review of Literature & Seminar

Total Marks : 50  
Internal Marks : 50  
Credits : 2

**Note:** Students shall review 15 to 20 research papers in their area of interest. Seminar in thrust area/Research Assignment/Literature/Survey etc. will be evaluated by DRC.

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