MAJOR COURSE- MJ 9	Mathematical Physics-III	(Theory Credit -03) (Total Marks=60+15)

Course Objective:

The objective of this course is to introduce students to advanced mathematical techniques essential for understanding complex physical systems. Topics covered will include the fundamentals of complex analysis, matrix theory, tensor analysis, and group theory. Emphasis will be placed on the application of these mathematical tools to solve real-world physics problems, including the evaluation of integrals, matrix diagonalization, the use of tensors in physical contexts, and the symmetry operations of physical systems.

Course Outcomes:

By the end of this course, students will be able to:

1. Understand and apply the principles of complex analysis, including the use of Cauchy's theorem, Cauchy's integral formula, and residue calculus to solve physical problems.
2. Perform matrix operations and apply matrix theory in physical contexts, including solving eigenvalue problems and diagonalization.
3. Grasp the concept of tensors and apply tensor operations in various physical situations, particularly in the context of Cartesian and covariant tensors.
4. Use group theory to analyze the symmetry properties of physical systems, construct character tables, and understand the significance of group representations in physics.
5. Solve problems involving branch cuts and principal value integrals, and use dispersion relations to extract physical insights.

These objectives and outcomes are designed to ensure that students gain both a theoretical understanding and practical skills for applying advanced mathematical methods in physics.

Course Contents:

Complex Analysis (12 HRS): Functions of complex variables, analytic functions, and Cauchy-Riemann conditions. Introduction to multivalued functions. Cauchy's Theorem and Cauchy's Integral Formula. Derivatives of analytic functions. Liouville's Theorem. Power series expansions: Taylor's theorem and Laurent's theorem. Calculus of residues and its applications to evaluate real definite integrals. Handling integrals involving branch cuts and using complex integration for summation of series. Principal value integrals and dispersion relations.

Matrices (10 HRS): Introduction to matrices through rotation of coordinate systems. Properties of Hermitian, orthogonal, and unitary matrices. Understanding null and unit matrices, singular and non-singular matrices. Inverse of a matrix and similarity transformations. Eigenvalue problems and diagonalization of matrices.

Tensor Analysis (12 HRS): Introduction to tensors: Cartesian, covariant, and contravariant tensors. Operations on tensors: contractions and direct products. Examples of special tensors: pseudo, dual, isotropic, symmetric, and anti-symmetric tensors.

Group Theory (11 HRS): Definition and examples of physically important finite groups, Basic symmetry operations and their matrix representations, Multiplication table, Cyclic groups and subgroups, Classes. Reducible and Irreducible representation, Schur's lemma, Orthogonality theorem, Character of a representation, Construction character tables.

References:

1. Mathematical Methods for Physicists, G. B Arfken, H. J. Waber, E.E. Harris,2013,7thEdn., Elsevier.
2. Boas, M.L., Mathematical Methods in Physical Sciences, Wiley International Editions.
3. Group Theory and Quantum Mechanics, M. Timkham.
4. Matrices and Tensors: A.W.Joshi
5. Mathematical Physics: Das and Sharma.
6. Mathematical Physics: A. K. Ghatak, I. C. Goya l&S.J.Chua.
7. Mathematical Methods for Physicist & Engineers: Pipes & Harvel.
8. Mathematical Tools for Physics, James Nearing, 2010, Dover Publications.
9. Mathematical Methods for Scientists and Engineers: D. A. McQuarrie,2003, Viva Book.
10. Mathematical Physics, H. K. Dass, S Chand
11. Mathematical Physics, B.S. Rajput, Pragati Prakashan Meerut

MAJOR COURSE- MJ 9	Mathematical Physics-III	(Practical Credit -01) (Total Marks=25)

1. Plot $f(z)=e^{iz}$, on the complex plane. Show the real and imaginary parts, magnitude |f(z)|, and argument arg(f(z)) over a grid of complex numbers.
2. Write a program to check if a function satisfies the Cauchy-Riemann conditions. Given a function $f(z) = u(x, y) + iv(x, y)$ implement the conditions for analyticity and plot the real and imaginary parts of u(x,y) and v(x,y).
3. Write a program that numerically verifies Cauchy's Theorem by calculating the integral of an analytic function along different contours. Use the Cauchy Integral Formula to evaluate integrals of functions over simple closed contours and compare with direct integration.
4. Implement the Taylor series expansion of a complex function and compare the numerical results with the exact value. Write a program to compute the Laurent series of a function around a singularity and visualize the expansion.
5. Consider a 3x3 matrix, Check if its orthogonality. Compute numerically its eigenvalues, diagonalisation and inverse.
6. Write a program to perform the rotation of coordinate systems using rotation matrices. Visualize how a point in 2D or 3D space is transformed when the coordinate system is rotated by a given angle (using appropriate rotation matrices).
7. Consider two 2x2 matrix A=((1,2),(3,4)) and B=((5,6),(7,8)), Vector V =(2,3) and Transformation matrix T=((1,0), (0, -1)), calculate the following
    a. compute the **contraction**$A_{ij}B^{ij}$.
    b. Find its **covariant** and **contravariant** components of V under T
    c. compute the **symmetric** and **antisymmetric** parts of A and B.
8. Given a 2D vector V= (3,4) and a rotation matrix R= ((cos θ, −sin θ), (sin θ, cos θ)), where $\theta = 30°$, calculate the following:
9. Compute the new vector V′ after applying the rotation matrix R.
    a. Compute the covariant and contravariant components of the transformed vector.
    b. Verify the orthogonality of R, i.e., $R^TR=I$.
10. Let V be a vector space and G be a finite group. Let ρ be a representation of G on V.
    a. State and explain Schur's Lemma.
    b. Use Schur's Lemma to prove that if ρ is an irreducible representation and T is a linear operator on V that commutes with all elements of G, then T must be a scalar multiple of the identity operator.
    c. Apply Schur's Lemma to a specific example, such as the representation of S_3 on a 2D vector space.

11. Understand how symmetry operations (like rotations) can be represented by matrices, and verify the basic group rules.

Reference book

1. Computational Physics **–** Mark Newman (Python-based)
2. Computational Complex Analysis **–** Richard S. Palais
3. Numerical Linear Algebra **–** Lloyd N. Trefethen and David Bau III
4. Computational Group Theory and Applications **– Ákos Seress**
5. A Student's Guide to Python for Physical Modeling **–** Jesse M. Kinder and Philip Nelson

MAJOR COURSE- MJ 10	Solid State Physics-I	(Theory Credit -03) (Total Marks=60+15)

Course Objective:

1. To introduce students to the fundamental concepts of crystallography, the structure of solids, and the types of crystal bonds that govern the physical properties of materials.
2. To explain the role of lattice vibrations and their effect on the heat capacity of solids, and provide a quantum mechanical description of phonons.
3. To introduce the free electron theory and band theory to understand the electrical properties of materials, including conductors, semiconductors, and insulators.
4. To explore the dielectric properties of materials, including polarization, electric susceptibility, and ferroelectric and piezoelectric effects.

Course Outcomes:

Upon completion of the course, students will be able to:

1. **Understand the basics of crystallography**, including the distinction between crystalline and amorphous materials, unit cells, Miller indices, and X-ray diffraction techniques for structure determination.
2. **Analyze crystal bonding** in materials, including ionic, covalent, and weak bonding, and calculate cohesive energy and compressibility of solids.
3. **Describe lattice vibrations** and their quantum mechanical properties, including the concept of phonons, and apply models such as Dulong-Petit, Einstein, and Debye for the heat capacity of solids.
4. **Apply free electron and band theory models** to understand the electrical properties of solids, specifically the conduction behavior of metals, semiconductors, and insulators.
5. **Examine dielectric properties**, including the concepts of polarization, electric susceptibility, and the classical theory of electric polarizability, as well as ferroelectric and piezoelectric behaviors.

These objectives and outcomes will ensure that students gain a thorough understanding of the physical principles that govern the properties of solid materials, both at a theoretical and practical level.

Course Contents:

Crystallography and Structure of Solids (10 HRS): Structure of solids: crystalline vs. amorphous materials, lattice translation and symmetry, unit cell and simple crystal structures, Miller indices and their significance, diffraction of X-rays by crystals, Bragg's Law and structure factor, methods for structure determination, point defects in crystals, dislocations and their role in crystal plasticity.

Crystal Binding and Cohesive Energy (08 HRS): ionic, covalent, and weak bonding, cohesive energy of solids, compressibility and its relationship with bonding, ionic and covalent bonding in solids, atomic interactions in crystals, bonding forces and their implications on crystal structures, lattice energy and its computation, elastic properties of solids, calculation of the bulk modulus.

Lattice Vibrations and Heat Capacity (10 HRS): Vibration of lattice: mono- and diatomic chains, periodic lattice and its implications, phonons and their quantum mechanical description, phonon spectrum and the density of states, heat capacity of solids: Dulong-Petit law, Einstein and Debye models of specific heat, T3 law and its significance in low temperatures, thermal expansion and resistivity, anharmonic effects in lattice vibrations.

Free Electron Theory and Band Theory (08 HRS): Free electron theory: assumptions and limitations, Drude's model and Sommerfeld model of conduction, concept of density of states, periodic potentials in one dimension, electrons in weak periodic potential, tight-binding approximation and its applications, band theory of solids: conductors, semiconductors, and insulators, Brillouin zone and its significance, motion of electrons in magnetic fields.

Dielectric Properties of Materials (09 HRS: Polarization, Local Electric Field at an Atom. Depolarization Field. Electric Susceptibility. Polarizability. Clausius Mosotti Equation. Classical Theory of Electric Polarizability. Normal and Anomalous Dispersion. Cauchy and Sellmeir relations. Langevin-Debye equation. Complex Dielectric Constant. Ferroelectricity and Piezo electricity.

Reference Books:

1. Introduction to Solid State Physics, Charles Kittel, 8th Edition, 2004, Wiley India Pvt. Ltd.
2. Introduction to Solid State Physics, Arun Kumar, PHI
3. Elements of Solid-State Physics, J.P. Srivastava, 4th Edition, 2015, Prentice-Hall of India
4. Introduction to Solids, Leonid V. Azaroff, 2004, Tata Mc-Graw Hill
5. Solid State Physics, M.A. Wahab, 2011, Narosa Publications
6. Solid-state Physics, H. Ibach and H. Luth, 2009, Springer
7. Solid State Physics, Rita John, 2014, McGraw Hill
8. Elementary Solid State Physics, 1/e M. Ali Omar, 1999, Pearson India.
9. Solid State Physics, Neil W. Ashcroft and N. David Mermin
10. Solid State Physics – S.O. Pillai
11. Solid State Physics, Dekker

MAJOR COURSE- MJ 10	Solid State Physics-I	(Practical Credit-01) (Total Marks=25)

1. X-ray Diffraction and Bragg's Law – Verification of Bragg's law using X-ray diffraction data.
2. Crystal Structure Determination – Analysis of simple cubic, FCC, and BCC structures using X-ray or optical diffraction methods.
3. Determination of Lattice Parameters – Measurement of lattice constants using X-ray diffraction patterns.
4. Study of Crystal Defects – Examination of point defects and dislocations using optical microscopy or simulations.
5. Measurement of Specific Heat – Verification of Dulong-Petit's law using calorimetry.
6. Phonon Dispersion Relation – Computational modeling of phonon dispersion in monoatomic and diatomic chains.
7. Thermal Expansion Coefficient – Measurement of linear thermal expansion of a metal rod.
8. Hall Effect in Conductors – Determination of carrier concentration and Hall coefficient in metals.
9. Resistivity of Materials – Measurement of temperature dependence of electrical resistivity in metals and semiconductors.
10. Magnetic Susceptibility – Determination of magnetic susceptibility of paramagnetic salts using Gouy's balance.
11. Hysteresis Loop – Study of B-H curve in ferromagnetic materials.
12. Curie Temperature Measurement – Determination of Curie temperature in a ferromagnetic material.
13. Free Electron Theory Verification – Study of the temperature dependence of resistivity in metals.
14. Tight Binding Approximation – Simulation of electronic band structure using computational tools.
15. Magnetoresistance in Metals – Measurement of resistance change under an applied magnetic field.

Reference books

1. Practical Physics – G.L. Squires
2. Advanced Practical Physics for Students – B.L. Worsnop & H.T. Flint
3. Experimental Solid State Physics – R. Srivastava

MAJOR COURSE- MJ 11	Classical Mechanics	(Theory Credit -03) (Total Marks=60+15)

Course Objective:

1. **Understand the Lagrangian formulation**: To provide students with a solid foundation in Lagrangian mechanics, focusing on the concept of generalized coordinates, constraints, and the principle of virtual work.
2. **Study the dynamics of systems under central forces**: To familiarize students with the theory of central force motion, including the two-body problem, effective potential, and Kepler's laws.
3. **Analyze rigid body motion**: To enable students to study the motion of rigid bodies, understanding concepts like moment of inertia, Euler’s equations, precession, and nutation.
4. **Learn the Hamiltonian formalism**: To introduce students to Hamiltonian mechanics, including generalized momenta, Hamilton’s equations, phase space, and cyclic coordinates.
5. **Explore canonical transformations**: To introduce and apply the theory of canonical transformations, Poisson brackets, and their relationship with conservation laws.
6. **Study the Hamilton-Jacobi theory**: To familiarize students with the Hamilton-Jacobi equation (HJE), action-angle variables, and its application in integrable systems.

Course Outcomes:

By the end of this course, students should be able to:

1. **Apply the Lagrangian formulation**: Derive and solve Lagrange’s equations for simple mechanical systems, including systems with constraints and forces expressed in generalized coordinates.
2. **Solve central force problems**: Analyze and solve problems related to central forces, including the two-body problem, energy conservation, and the Rutherford scattering problem.
3. **Understand rigid body dynamics**: Solve problems involving rigid bodies, calculate the moment of inertia tensor, and analyze rotational motion, including precession and gyroscopic effects.
4. **Use the Hamiltonian formalism**: Understand and apply Hamilton’s equations of motion, identify conserved quantities using cyclic coordinates, and work in phase space.
5. **Perform canonical transformations**: Identify and perform canonical transformations, use generating functions, and apply Poisson brackets to simplify complex systems.
6. **Analyze the Hamilton-Jacobi equation**: Apply the Hamilton-Jacobi equation and action-angle variables to solve problems in integrable systems and understand their significance in classical mechanics.

These objectives and outcomes should help guide students through key concepts in classical mechanics and develop the problem-solving skills necessary for advanced physics applications.

Course Contents:

Lagrangian Mechanics (12 HRS): Degrees of freedom, generalized coordinates, constraints, principle of virtual work, D'Alembert's principle, Lagrange’s equation, Hamilton's variational principle, Euler-Lagrange equation. Simple applications of the Lagrangian formulation: 1) Single free particle in a) Cartesian and b) plane polar coordinates 2) Atwood’s machine 3) Bead sliding on a uniformly rotating wire in a force-free space 4) Motion of a block attached to a spring 5) Simple pendulum. Symmetry and conservation laws.

Central Force Motion (10 HRS): Two-body problem, reduced mass, equation of motion under a central force, conservation of angular momentum and energy, effective potential, classification of orbits, Kepler's laws and their derivation, Virial theorem, scattering in a central force field, Rutherford scattering.

Rigid Body Dynamics (08 HRS): Definition of a rigid body, degrees of freedom, moment of inertia tensor, principal moments and principal axes, Euler's equations of motion. Torque-free motion, motion of a symmetric top, precession, nutation, and gyroscopic motion. Coriolis and centrifugal forces, stability of rotational motion.

Hamiltonian Mechanics (08 HRS): Generalized momenta and the Legendre transformation, Hamilton's equations of motion, applications of the Hamiltonian formulation, cyclic coordinates and conservation laws, phase space and Liouville's theorem. Velocity-dependent potentials (e.g., magnetic forces) and their modifications to Lagrange's and Hamilton's equations for velocity-dependent potentials.

Canonical Transformations (07 HRS): Definition and conditions for a transformation to be canonical, generating functions and their types, Poisson brackets and their invariance under canonical transformations, infinitesimal canonical transformations, relation to symmetries and conservation laws. Hamilton-Jacobi equation (HJE), action-angle variables.

Reference Books:

1. Classical Mechanics, H.Goldstein, C.P. Poole, J.L. Safko, 3rd Edn. 2002, Pearson Education.
2. Intoduction to Classical mechanics, Nikhil Ranjan Roy, 2016, Vikash Publishing House Pvt. Ltd.
3. Mechanics, L. D. Landau and E. M. Lifshitz, 1976, Pergamon.
4. Classical Electrodynamics, J.D. Jackson, 3rd Edn., 1998, Wiley.
5. The Classical Theory of Fields, L.D Landau, E.M Lifshitz, 4th Edn., 2003, Elsevier.
6. Introduction to Electrodynamics, D.J. Griffiths, 2012, Pearson Education.
7. Classical Mechanics, J. C. Upadhyaya, Himalay Publishing House
8. Classical Mechanics, P.S. Joag, N.C. Rana, 1st Edn., McGraw Hall.
9. Classical Mechanics, R. Douglas Gregory, 2015, Cambridge University Press.
10. Classical Mechanics: An introduction, Dieter Strauch, 2009, Springer.
11. Solved Problems in classical Mechanics, O.L. Delange and J. Pierrus, 2010, Oxford
12. Classical mechanics, Gupta and Kumar

MAJOR COURSE- MJ 11	Classical Mechanics	(Practical Credit-01) (Total Marks=25)

4. To determine the coupling coefficient of coupled pendulums
5. To determine the coupling and damping coefficient of damped coupled oscillator.
6. To study population models e.g. exponential growth and decay, logistic growth, species, competition, predator-prey dynamics, simple genetic circuits.
7. Computational visualization of trajectories in the Sinai Billiard
8. Write a program to verify that Kepler's first law.
9. Write a program to verify Kepler's second law
10. Write a program to verify Kepler's Third law
11. Write a program to view cannon shell trajectory neglect air friction.
12. Write a program to find the trajectory of base ball
13. To calculate Poisson brackets for various mechanical systems and study their properties.

Reference books

1. Advanced Physics Experiments – I.S. Grant and W.R. Phillips
2. Experimental Physics: Principles and Practice for the Laboratory" – Walter F. Smith
3. Python Libraries: NumPy (numerical solutions), Matplotlib (visualization), SciPy (ODE solvers), SymPy (Poisson brackets)
4. Scilab/Xcos: Modeling population dynamics and coupled oscillators
5. VPython: For visualizing projectile motion, billiard dynamics, and planetary orbits