Program Name: **B.Sc. (Physics)**

Major in Physics

4 years Program following NEP Guidelines

Program Code: **PHY3403**

Offered by Department of Physics, School of Basic and Applied Sciences, Adamas University

Duration: 4 Years

Academic Year: 2024-25

Program Outcome for B.Sc. Physics

PO1	**Mastery of Core Physics Principles**	Attain a comprehensive understanding of core Physics principles, encompassing Classical Physics, Quantum Physics, Statistical Physics, Electrodynamics, and Relativity, applicable in higher education and professional contexts.
PO2	**Experimental Proficiency**	Develop proficiency in applying Physics concepts through hands-on experimentation, precise data analysis, and correlation of experimental results with theoretical models.
PO3	**Computational Simulation Expertise**	Leverage computational tools and programming languages (e.g., Mathematica, Matlab, Python, C) to simulate and validate theoretical models in Physics.
PO4	**Applied Physics Solutions**	Apply knowledge from the domain of Applied Physics to address real-world challenges, particularly in the development of electronic devices, sensors, and instrumentation systems.
PO5	**Analytical Problem-Solving**	Utilize mathematical techniques to critically analyze and solve complex Physics problems, contributing to the formulation and refinement of theoretical models.
PO6	**Material Science and Technology Integration**	Implement knowledge of material properties and Solid-State Physics in developing innovative technologies to enhance modern lifestyles and societal development.
PO7	**Addressing Emerging Challenges**	Engage in research-driven exploration of new scientific questions and design solutions to meet contemporary societal and scientific needs.
PO8	**Ethical Leadership in Science**	Exhibit ethical responsibility and dedication as an academic professional, contributing positively to the global scientific community with integrity and diligence.
PO9	**Advanced Communication Skills**	Demonstrate advanced proficiency in communicating complex scientific ideas effectively to both specialized and general audiences, through written and oral formats.
PO10	**Expertise in Scientific Reporting**	Showcase the ability to lead independent Physics projects and present results through detailed scientific reports, presentations, and public discussions.

Paper Name: Mathematical Methods I

Paper Code: PHY100

L T P – 3-0-1

Course Objectives:

1. To understand the mathematical principles and physical significance of ordinary and partial differential equations in modeling physical systems.
2. To explore vector calculus and matrix operations for solving complex problems in Physics, with applications in advanced topics.
3. To analyze Fourier series for representing periodic functions and their use in solving Physics-related problems.
4. To investigate special integrals, including Beta and Gamma functions, and their relevance in higher-level Physics contexts.
5. To develop programming skills in Python for solving numerical Physics problems and conducting simulations in laboratory settings.

Course Outcome:

On completion of this course, the students will be able to:

CO1: Recall and identify fundamental concepts of differential equations, partial differential equations, vector algebra, matrices, and special integrals.

CO2: **Explain** the principles of solving ordinary and partial differential equations, vector calculus operations, and Fourier series expansion techniques.

CO3: **Apply** methods like separation of variables, undetermined coefficients, or variation of parameters to solve specific mathematical problems in differential equations and Fourier series.

CO4: **Analyze** vector fields and matrix transformations to derive properties like divergence, curl, eigenvalues, and eigenvectors.

CO5: **Evaluate** the convergence of Fourier series, properties of special integrals, and the accuracy of numerical results obtained from matrix operations or least square fitting.

CO6: **Develop** computational algorithms using Python to perform tasks like matrix operations, error analysis, and data fitting, demonstrating the integration of mathematical methods and programming.

Course Content:

Module I: Differential Equations

Differential equations of first order, Linear Differential equation, Bernoulli's equation, Exact differential equation, integrating factor, second order differential equation, homogeneous and inhomogeneous equations, Complete solution = C.F + P.I. Different methods of finding Particular Integral. Wronskian and general solution. Statement of existence and Uniqueness Theorem for Initial Value Problems. Cauchy-Euler Equations, Legendre's equations, Method of variation of parameters, Method of undetermined coefficient.

Module II: Partial Differential Equations

Solutions to partial differential equations, using separation of variables: Laplace's Equation in problems of rectangular, cylindrical and spherical symmetry. Wave equation and its solution for vibrational modes of a stretched string, rectangular and circular membranes.

Module III: Vectors

Vector algebra: Scalar product and Vector product, Scalar triple product and their interpretation in terms of area and volume respectively. Scalar and Vector fields. Vector Calculus: Directional derivatives and normal derivative. Gradient of a scalar field and its geometrical interpretation. Divergence and curl of a vector field. Del and Laplacian operators. Vector identities, Vector Integration, Ordinary Integrals of Vectors. Line, surface and volume integrals of Vector fields. Gauss' divergence theorem, Green's and Stokes Theorems and their applications.

Theory of Orthogonal Curvilinear Coordinates: Derivation of Gradient, Divergence, Curl and Laplacian in Cartesian, Spherical and Cylindrical Coordinate Systems.

Linear Vector Space: Vectors in function space, Axiomatic definition, linear independence, bases, dimensionality, inner product, Gram-Schmidt orthogonalization, Operators, self-Adjoint and Unitary Operators, Transformation of Operators

Module IV: Matrices

Definition, Various types of matrices, addition, subtraction and multiplication of matrices, Adjoint and Inverse of a matrix, Solution of simultaneous equations, Determination of Eigen Value and Eigen Vectors, Diagonalization of a real, symmetric matrix, Functions of a Matrix, Cayley-Hamilton's Theorem. commuting matrices with degenerate eigenvalues, Orthonormality of eigenvectors.

Module V: Fourier Series

Periodic functions. Dirichlet's Conditions (Statement only). Expansion of periodic functions in a series of sine and cosine functions. Complex representation of Fourier series. Expansion of functions with arbitrary period. Expansion of non-periodic functions over an interval. Even and odd functions and their Fourier expansions. Application. Summing of Infinite Series. Term-by-Term differentiation and integration of Fourier Series. Parseval Identity.

Module VI: Some Special Integrals

Beta and Gamma Functions and Relation between them. Expression of Integrals in terms of Gamma Functions. Error Function (Probability Integral).

Mathematical Physics I Lab (Hands on Training)

- **Introduction to Errors**

Systematic and Random Errors, Propagation of Errors, Standard and Probable Errors, Floating Point Numbers, Single and Double Precision Arithmetic, Underflow and Overflow

- **Introduction to Programming (Python)**

Constants, Variable, Statement, Intrinsic functions, Conditional Execution, Functions, Iterations, Strings, Files, Lists, Introduction to Numpy, Scipy and Matplotlib, 2D graphs using both functions and data files

- **Matrix Operations**

Matrix addition, Matrix multiplication, Transpose of Matrix, Solution of Simultaneous Equations, Estimation of Eigen value and Eigen vector

- **Least Square Fitting Method**

Linear Least Square method, Nonlinear Least Square method – Exponential Form, Hyperbolic Form, Power Method

- **Sorting Method**

Selection Sort, Bubble Sort

Reference Books:

1. ***Mathematical Methods for Physicists***, G.B.Arfken, H.J.Weber, F.E.Harris, 2013, 7thEdn., Elsevier.
2. ***Mathematical Methods in Physical Sciences***, Mary L. Boas, 2006, 3rdEdn., Wiley.
3. ***Mathematical Physics***, H K Dass, 2014, 6thEdn., S. Chand Publisher.
4. ***An introduction to Ordinary Differential Equations***, E.A. Coddington, 2009, PHI learning.
5. ***Differential Equations***, George F. Simmons, 2007, McGraw Hill.
6. ***Mathematical Tools for Physics***, James Nearing, 2010, Dover Publications.
7. ***Advanced Engineering Mathematics***, Erwin Kreyszig, 2008, Wiley India.
8. ***Mathematical Methods for Physics and Engineering***, K. F. Riley, M. P. Hobson, S. J. Bence, Cambridge University Press.

9. ***Differential and Integral Calculus***, N. Piskunov, Mir Publisher.
10. ***Calculus***, Apostol, Wiley.
11. ***Vector Analysis***, Murry R. Spiegel, Schuam Series

Paper Name: Mechanics and Waves

Paper Code: PHY101

L-T-P: 3-0-1

Course Objectives:

1. To understand the dynamics of particles and systems, including central forces, collisions, and motion in non-inertial frames.
2. To explore gravitational principles and their application in analyzing central force motion, satellite orbits, and potential fields.
3. To analyze the rotational dynamics of rigid bodies, focusing on angular momentum, torque, and moments of inertia.
4. To investigate fluid dynamics, including the continuity equation and Bernoulli's principle, and their role in understanding fluid motion.
5. To develop practical skills for performing experiments on rigidity modulus, Young's modulus, viscosity, surface tension, and oscillations using laboratory techniques.

Course Outcome:

Upon successful completion of this course, students will be able to:

CO1: **Recall** the fundamental concepts of dynamics, gravitation, rotational motion, fluid mechanics, oscillations, and waves.

CO2: **Explain** the principles behind the dynamics of particles, central forces, gravitation, fluid motion, and wave behavior, including applications like GPS and Bernoulli's theorem.

CO3: **Apply** the laws of motion, conservation principles, and equations like Poiseuille's law and Bernoulli's equation to solve practical problems in mechanics and fluid dynamics.

CO4: **Analyze** the motion of systems under central forces, rotational dynamics, and oscillatory systems to evaluate energy, angular momentum, and wave characteristics.

CO5: **Evaluate** experimental data from mechanics lab experiments to determine physical constants such as rigidity modulus, viscosity, and frequency of oscillations, ensuring precision and accuracy.

CO6: **Design and conduct** experiments using mechanics lab apparatus to investigate concepts such as surface tension, rotational dynamics, and wave motion, demonstrating practical understanding and innovation.

Course Content:

Module I: Fundamentals of Dynamics

Velocity and Acceleration in Polar coordinates, Analysis of Central forces, Equation of motion of trajectory of a particle moving under central force, Elastic and inelastic collisions between particles. Centre of Mass. Determination of centre of mass for different geometrically symmetric objects, Principle of conservation of momentum. Impulse. Momentum of variable-mass system: Motion of rocket. Dynamics of a system of particles. Inertial and Non-inertial frames and fictitious forces. Uniformly rotating frame. Centrifugal force. Coriolis force and its applications.

Module II: Gravitation and Central Force Motion:

Gravitational potential, potential energy and field. Potential and field due to disc, spherical shell, solid sphere cylinder, conic etc. The energy equation and energy diagram. Kepler's Laws. Satellite in circular orbit and applications. Geosynchronous orbits. Weightlessness. Basic idea of global positioning system (GPS).

Module III: Rotational Dynamics of rigid bodies

Angular momentum of a particle and system of particles. Torque. Principle of conservation of angular momentum. Rotation about a fixed axis. Moment of Inertia. Calculation of moment of inertia for rectangular, cylindrical and spherical bodies. Kinetic energy of rotation. Motion involving both translation and rotation. Calculation of moment of inertia for simple symmetric systems; Ellipsoid of inertia and inertia tensor; Setting up of principal axes in simple symmetric cases.

Unit IV: Fluid Motion:

Kinematics of Moving Fluids, Equation of Continuity, Euler's equation, Bernoulli's Theorem, Poiseuille's Equation for Flow of a Liquid through a Capillary Tube. Navier-Stokes equation and its applications.

Unit V: Oscillations and Waves

Simple Harmonic Oscillations. Differential equation of SHM and its solution. Damped oscillation, Forced oscillations, power dissipation and Quality Factor, Wave Motion, Concept of Progressive and Standing waves, energy transport.

Unit VI: Hands on Training through Mechanics Lab Experiments: (Any 5 at least)

- Determination of Rigidity modulus by Dynamic method.
- Determination of Young's Modulus by Flexure method.

- Determination of coefficient of viscosity by Poiseuille's capillary flow method.
- Determination of Surface Tension of a given liquid by Jurin's Law.
- To determine the value of 'g' using Compound Pendulum.
- Determination of frequency of a tuning fork by using a Sonometer.
- To study Lissajous Figures along with Phase and Frequency determination.

Reference Books

1. ***An introduction to mechanics***, D. Kleppner, R.J. Kolenkow, 1973, McGraw-Hill.
2. ***Introduction to Classical Mechanics***, David Morin, Cambridge University Press
3. ***Classical Mechanics***, Douglas Gregory, Cambridge University Press.
4. ***Mechanics***, Berkeley Physics, vol.1, C.Kittel, W.Knight, et.al. 2007, Tata McGraw-Hill.
5. ***Physics***, Resnick, Halliday and Walker 8/e. 2008, Wiley.
6. ***Theoretical Mechanics***, M.R. Spiegel, 2006, Tata McGraw Hill.

Paper Name: Electromagnetic Theory I

Paper Code: PHY102

L T P – 3-0-1

Course Objectives:

1. To understand the principles of electric fields, potentials, and energy, and apply Gauss's Law and Laplace's equation to electrostatic problems.
2. To explore the Method of Electrical Images and boundary value techniques for solving electrostatic problems in various coordinate systems.
3. To analyze the behavior of dielectric materials in electric fields and understand the energy storage in dielectric systems.
4. To evaluate DC circuits using network theorems, including Thevenin, Norton, and Maximum Power Transfer, for solving practical electrical problems.
5. To develop experimental skills in investigating magnetostatics and magnetic materials, focusing on current distributions and hysteresis losses.

Course Outcome:

At the end of the course, students will be able to

CO1: **Define** and **describe** fundamental concepts such as electrostatic fields, Gauss's law, magnetic fields, and dielectric properties, including key laws and theorems (e.g., Biot-Savart law, Laplace's equation).

CO2**: Explain** the principles of boundary value problems, the method of electrical images, and the relationship between polarization, susceptibility, and dielectric constants in various scenarios.

CO3: **Solve** problems related to electrostatics, steady currents, and magnetostatics by applying Gauss's law, Ohm's law, and Ampere's law to practical situations and simple systems.

CO4: **Analyze** electrical and magnetic circuit systems using network theorems (e.g., Thevenin's, Norton's, and Superposition theorems) and evaluate experimental results to verify these principles.

CO5: **Design** and **conduct** experiments, such as determining unknown resistances, measuring the B-H curve, or verifying circuit theorems, and critically assess experimental data for validity and accuracy.

CO6: **Formulate** solutions to advanced scenarios involving non-uniform magnetization, energy loss in ferromagnetic materials, or the behavior of dielectric-filled capacitors, integrating theoretical concepts and experimental evidence.

Course Content:

Module I: Electric field and Potential

Electrostatic Field, Potential and Energy, Gauss' Law with applications, Laplace's and Poisson equations. The Uniqueness Theorem. Superposition theorem (statement only). Field potential and related properties of an electric dipole.

Module II: Boundary Value Problems and Method of Electrical Images

Application of Laplace's equation in 1D, 2D and 3D for Cartesian, Spherical Polar and Cylindrical Polar coordinates. Method of Electrical Images and its application to: (1) Plane Infinite Sheet and (2) Sphere.

Module III: Dielectric Properties and Electrostatic energy

Electric Field in matter. Concept of Polarization, Electrical Susceptibility and Dielectric Constant. Capacitor (parallel plate, spherical, cylindrical) filled with dielectric. Displacement vector D. Relations between E, P and D. Gauss' Law in dielectrics, Electrostatic energy of a charged sphere. Gauss' Law in presence of dielectrics, free charge and bound charge, Electrostatic energy density in presence of a dielectric.

Module IV: Steady current

Ohm's law – Differential form, Kirchhoff's Law, Wheatstone bridge – its sensitivity (qualitative discussion only), Network Theorems: Ideal Constant-voltage and Constant-current Sources. Thevenin theorem, Norton theorem, Superposition theorem, Reciprocity theorem, Maximum Power Transfer theorem. Applications to dc circuits.T and π networks.

Module V: Magnetostatics

Lorentz force and concept of magnetic field; Force and Torque on current element; Biot-Savart's law, magnetic vector potential; calculation of vector potential and magnetic induction in simple cases. $\vec{\nabla}\times\vec{B}=\mu_0\vec{J}$. Ampere's Law,

Module VI: Theory of Magnetism and Magnetic materials

Free current and bound current; surface and volume density of current distribution; magnetisation; non-uniform magnetisation of matter; $\vec{\nabla}\times\vec{M}=J_b$; introduction of H; line integral of H in terms of free current; boundary conditions for B and H; hysteresis and energy loss in ferromagnetic material; magnetic circuit; energy stored in magnetic field.

Hands on Training through Experiments:

Experiment 1: Use a Multimeter for measuring (a) Resistances, (b) AC and DC Voltages, (c) DC Current, (d) Capacitances and (e) Checking electrical fuses

Experiment 2: To measure the resistance per unit length of the wire of a bridge and to determine an unknown resistance by Carey Fosters bridge.

Experiment 3: To verify the Thevenin and Norton theorems.

Experiment 4: To verify the Superposition, and Maximum power transfer theorems.

Experiment 5: To draw the B-H curve of Fe using Solenoid & determine energy loss from Hysteresis curve.

Experiment 6: To study the nature of dependence of dipolar field of a short bar magnet on distance with the help of a deflection and Oscillation magnetometer and determine the horizontal component of the Earth's magnetic field.

Reference Books

1. ***Electricity and Magnetism***, Rakshit and Chattopadhyay, New Age Publisher
2. ***Foundations of Electricity and Magnetism***, B. Ghosh
3. ***Electricity and Magnetism***, D. C. Tayal, S. Chand Publisher
4. ***Electricity and Magnetism***, Edward M. Purcell, 1986 McGraw-Hill Education
5. ***Introduction to Electrodynamics***, D.J. Griffiths, 3rd Edn., 1998, Benjamin Cummings.
6. ***Feynman Lectures Vol.2***, R. P. Feynman, R. B. Leighton, M. Sands, 2008, Pearson Education

Paper Name: Thermal Physics

Paper Code: PHY103

L T P – 3-0-1

Course Objectives:

1. To understand the Kinetic Theory of gases, including the Maxwell-Boltzmann distribution, mean free path, and transport phenomena in gases.
2. To explore the equation of state for real gases and analyze deviations from ideal gas behavior using Van der Waal's equation.
3. To evaluate the 1st and 2nd laws of thermodynamics, with a focus on assessing the efficiency of heat engines and refrigerators.
4. To investigate thermodynamic systems using Maxwell's relations and analyze phase transitions.
5. To develop experimental skills by conducting experiments related to thermal conductivity and the mechanical equivalent of heat.

Course Outcome:

On completion of this course, the students will be able to

CO1: **Define** fundamental concepts and laws of thermodynamics, kinetic theory, and thermal conductivity, including Maxwell-Boltzmann distribution and the Joule-Thomson effect.

CO2: **Explain** the behavior of real and ideal gases, the principles of phase transitions, and the implications of the zeroth, first, second, and third laws of thermodynamics.

CO3: **Apply** thermodynamic principles to solve problems related to heat engines, refrigeration cycles, and entropy changes in thermodynamic systems.

CO4: **Analyze** the deviations of real gases from ideal gas behavior using Van der Waals equations, and interpret thermodynamic processes using Maxwell's relations and the Clausius-Clapeyron equation.

CO5: **Design and conduct** experiments, such as determining thermal conductivity, thermoelectric power, and temperature coefficients, to validate theoretical models and laws in thermal physics.

CO6: **Integrate** theoretical principles with experimental data to formulate new approaches for measuring and improving energy efficiency, such as enhancing the performance of heat engines and refrigeration systems.

Course Content:

Module I: Kinetic Theory of Gases:

Distribution of Velocities: Maxwell-Boltzmann Law of Distribution of Velocities in an Ideal Gas and its Experimental Verification. Mean, RMS and Most Probable Speeds. Specific heat of Gases, Mean Free Path, Estimation of Mean Free Path. Transport Phenomenon in Ideal Gases: (1) Viscosity, (2) Thermal Conductivity and (3) Diffusion. Brownian Motion and its Significance.

Module II: Real Gases

Behavior of Real Gases- Deviations from the Ideal Gas Equation, Van der Waal's Equation of State for Real gases. Joule-Thomson Effect for Real and van der Waal Gases

Module III: Laws of Thermodynamics

Zeroth Law of Thermodynamics & Concept of Temperature, Concept of Work & Heat, State Functions, First Law of Thermodynamics and its differential form, Applications of First Law. Heat Engines. Carnot's Cycle, Carnot engine & efficiency. Refrigerator & coefficient of performance, 2nd Law of Thermodynamics: Kelvin-Planck and Clausius Statements and their Equivalence. Carnot's Theorem. Applications of Second Law of Thermodynamics, Concept of Entropy, Third Law of Thermodynamics. Unattainability of Absolute Zero.

Module IV: Maxwell's relations and Phase Transition

Derivations and applications of Maxwell's Relations, Maxwell's Relations, First and second order Phase Transitions with examples, Clausius-Clapeyron Equation and Ehrenfest equations, Helmoltz Free energy and Gibb's Free energy

Thermal Physics Lab

List of Experiments: (Any Five)

1. To estimate the temperature of a torch bulb filament from resistance measurement and to verify Stefan's law
2. Determination of Thermal Conductivity of a bad conductor of heat by Lee's and Charlton's method.
3. To determine the Temperature Coefficient of Resistance by Platinum Resistance Thermometer (PRT).
4. Determination of thermoelectric power at a certain temperature of the given thermocouple.
5. Determine Mechanical Equivalent of Heat, J, by Callender and Barne's constant flow method.
6. Determine the Coefficient of Thermal Conductivity of Cu by Searle's Apparatus.

7. Calibrate a thermocouple to measure temperature in a specified range using (1) Null Method, (2)Direct measurement using Op-Amp difference amplifier and to determine Neutral Temperature.

Reference Books:

1. ***Thermal Physics***, Roy and Gupta.
2. ***Heat and Thermodynamics***, M.W. Zemansky, Richard Dittman, 1981, McGraw-Hill.
3. ***A Treatise on Heat***, Meghnad Saha, and B.N.Srivastava, 1958, Indian Press
4. ***Thermal Physics***, S. Garg, R. Bansal and Ghosh, 2nd Edition, 1993, Tata McGraw-Hill
5. ***Modern Thermodynamics with Statistical Mechanics***, Carl S. Helrich, 2009, Springer
6. ***Thermodynamics, Kinetic Theory & Statistical Thermodynamics***, Sears & Salinger. 1988, Narosa.
7. ***Concepts in Thermal Physics***, S.J. Blundell and K.M. Blundell, 2nd Ed., 2012, OxfordUniversity Press

Paper Name: Mathematical Methods II

Paper Code: PHY200

L T P – 3-0-1

Course Objectives:

1. To understand and apply Dirac Delta functions and their properties for solving physical problems and interpreting experimental results.
2. To explore the Frobenius method for solving differential equations and gain proficiency in using special functions such as Legendre, Bessel, Hermite, and Laguerre in physics applications.
3. To analyze physical experiments using probability and statistical methods for performing calculations and data interpretation.
4. To investigate physical systems by performing integral transforms (Fourier and Laplace) and solving differential equations both analytically and numerically.
5. To develop practical skills in executing numerical methods, including root finding, interpolation, differentiation, integration, and solving ordinary differential equations using algorithms and techniques.

Course Outcome:

On completion of this course, the students will be able to

CO1: Recall and describe the properties of the Dirac delta function, concepts of probability distributions, and integral transforms, including their definitions and fundamental principles.

CO2: Explain the Frobenius method and its applications to special functions (e.g., Legendre, Bessel, Hermite), as well as the importance of orthogonality and recurrence relations in these functions.

CO3: **Use** mathematical tools such as Fourier and Laplace transforms, and numerical methods (e.g., interpolation, root finding) to solve ordinary differential equations and real-world problems in physics and engineering.

CO4: **Analyze** the behavior of complex variables and singularities through Cauchy-Riemann equations, Taylor and Laurent expansions, and **apply** Cauchy's residue theorem to evaluate real integrals.

CO5: Develop solutions to second-order linear differential equations using Frobenius methods and synthesize solutions using expansions in series of Legendre and Bessel functions for physical phenomena.

CO6: Design algorithms using numerical techniques (e.g., Runge-Kutta, Simpson's rule) for solving complex problems, integrating these approaches with analytical methods to optimize computational efficiency and accuracy.

Course Content:

Module I: Dirac Delta function and its properties

Definition of Dirac delta function. Representation as limit of a Gaussian function and rectangular function. Properties of Dirac delta function.

Module II: Frobenius Method and Special Functions

Singular Points of Second Order Linear Differential Equations and their importance. Frobenius method and its applications to differential equations. Legendre, Bessel, Hermite and Laguerre Differential Equations. Properties of Legendre Polynomials: Rodrigues Formula, Generating Function, Orthogonality. Simple recurrence relations. Expansion of function in a series of Legendre Polynomials. Bessel Functions of the First Kind: Generating Function, simple recurrence relations. Zeros of Bessel Functions and Orthogonality. Bessel function of 2nd kind, Generating functions, Spherical Bessel Functions, Legendre polynomials, Orthogonality, Physical interpretation of Generating functions, Associated Legendre's Equation, Spherical Harmonics, Hermite functions, Laguerre Functions.

Module III: Concept of Probability

Basic concepts of probability distribution. Permutations and Combinations, Conditional Probability, Conditional Probability, Binomial distribution, Poisson's distributions, Multinomial distributions. Problems on probability calculation.

Module IV: Integral Transform

Fourier and Laplace transform and their inverse transforms, Application of Laplace transform, Bromwich integral [use of partial fractions in calculating inverse Laplace transforms], Discrete Fourier Transform, Transform of derivative and integral of a function, Solution of differential equations using integral transforms.

Module V: Complex Variables

Recapitulation of Complex numbers, triangular inequalities, Schwarz inequality. Function of a complex variable, single and multiple-valued function, limit and continuity, Differentiation, Cauchy-Riemann equations and their applications, Analytic and harmonic function, Complex integrals, Cauchy's theorem (elementary proof only), converse of Cauchy's theorem, Cauchy's Integral Formula and its corollaries, Series: Taylor and Laurent expansion, Classification of singularities, Branch point and branch cut, Cauchy's Residue theorem and evaluation of some typical real integrals using this theorem.

Module VI: Mathematical Physics II Lab

Root Finding for a Single Variable

Bisection Method, Newton-Raphson Method

Interpolation

Lagrange Interpolation, Newton Forward and Backward Interpolation

Numerical Differentiation and Integration

Numerical Differentiation, Integration: Trapezoidal rule, Simpson's 1/3 method, Simpson's composite method, n-point Gaussian Quadrature method

Solution of Ordinary Differential Equation

Solution of 1st order and 2nd ordinary differential equation – Euler algorithm, Runge Kutta algorithm (2nd Order and 4th Order)

Reference Books:

1. ***Mathematical Methods for Physicists***, G.B. Arfken, H.J. Weber, F.E. Harris, 2013, 7th Edn., Elsevier.
2. ***An introduction to Ordinary Differential Equations***, E.A. Coddington, 2009, PHI learning
3. ***Differential Equations***, George F. Simmons, 2007, McGraw Hill.
4. ***Mathematical Tools for Physics***, James Nearing, 2010, Dover Publications.
5. ***Advanced Engineering Mathematics***, D.G. Zill and W.S. Wright, 5 Ed., 2012, Jones and Bartlett Learning
6. ***Advanced Engineering Mathematics***, Erwin Kreyszig, 2008, Wiley India.
7. ***Mathematical Methods in Physical Sciences***, Mary L. Boas, Wiley
8. ***Mathematical Methods for Physics and Engineering***, K. F. Riley, M. P. Hobson, S. J. Bence, Cambridge University Press
9. ***Differential and Integral Calculus***, N. Piskunov, Mir Publisher
10. ***Vector Analysis***, Murry R. Spiegel, Schuam Series.
11. ***Mathematical Physics***, H K Dass, S Chand Publisher
12. ***Differential Equations***, S. L. Ross, Wiley

Paper Name: Electronics I

Paper Code: PHY201

L T P – 3-0-1

Course Objectives:

1. To understand the operation of PN junction diodes, including drift and diffusion processes, rectification, and their applications in voltage regulation using Zener, Schottky, and tunnel diodes.
2. To explore the behavior and characteristics of transistors (PNP, NPN) in different configurations (CB, CC, CE) and perform load line analysis to determine the Q-point.
3. To design and analyze transistor biasing circuits and amplifiers (CE, RC-coupled), focusing on their stability, efficiency, and frequency response using h-parameters and equivalent circuits.
4. To simplify and optimize logic circuits using Boolean algebra and Karnaugh maps, and apply digital logic gates in practical applications such as parity checking and binary addition.
5. To develop practical skills in constructing basic data processing circuits like multiplexers, demultiplexers, encoders, decoders, and arithmetic circuits to perform simple data manipulation tasks.

Course Outcome:

On completion of this course, the students will be able to

CO1: **Recall** the fundamental principles of semiconductor devices, including conduction mechanisms, PN junctions, and diode applications.

CO2: **Explain** the working principles and characteristics of three-terminal devices, such as bipolar junction transistors (BJTs) in different configurations.

CO3: **Apply** transistor biasing techniques to design stable amplifier circuits and analyze their performance using hybrid models.

CO4: **Analyze** digital logic circuits using Boolean algebra and Karnaugh Maps to simplify logic expressions and design optimized circuits.

CO5**: Evaluate** the performance of rectifier circuits, amplifiers, and data processing systems by calculating key parameters like ripple factor, efficiency, and gain.

CO6: **Design and implement** logic gates, arithmetic circuits, and rectifiers to solve real-world problems, integrating analog and digital components.

Course Content:

Module I: Revisions of fundamentals

Conduction mechanisms: Drift and Diffusion, Basics of PN junction, Derivation for Barrier Potential, Depletion region, Diode rectification: Half-wave, Full-wave Rectifiers, Calculation of Ripple Factor and Rectification Efficiency, Clipper and Clamper circuits. Application of diodes: Zener Diode and Voltage Regulation. Silicon Controlled rectifier (SCR, Thyristor), Schottky and Tunnel diode and Solar Cell.

Module II: Three terminal devices

Transistor fundamentals: PNP and NPN Types and CB, CC and CE Configurations, Current gains α, β, g, and their Relations, Load Line analysis Q-point of Transistors. Transistor behaves as switch.

Module III: Amplifiers

Transistor Biasing and Stabilization, Thermal runaway, Fixed Bias, Collector to base bias and Voltage Divider Bias, Cascaded amplifiers, Transistor as 2-port Network. H-parameter Equivalent Circuit. Analysis of a single-stage CE amplifier using Hybrid Model. Input and Output Impedance. Current, Voltage and Power Gains. Darlington pair, RC-coupled amplifier and its frequency response.

Module IV: Digital Electronics

Fundamentals, Difference between Analogue and Digital electronics. Binary Numbers, Conversion: Decimal, Binary, Octal and Hexadecimal numbers. Logic gates: Basic and Universal Gates. XOR and XNOR Gates and application as Parity Checkers.

Boolean algebra: De Morgan's Theorems. Boolean Laws. Simplification of Logic Circuit using Boolean Algebra. Idea of Minterms and Maxterms. Conversion of a Truth table into Equivalent Logic Circuit by (1) Sum of Products Method and (2) Karnaugh Map.

Module V: Data Processing Circuits

Data processing circuits: Basic idea of Multiplexers, De-multiplexers, Decoders, and Encoders. Arithmetic Circuits: Binary Addition. Binary Subtraction using 2's Complement. Half and Full Adders. Half & Full Subtractors, 4-bit binary Adder/Subtractor.

Electronics I Lab

List of Experiments (Any Five):

1. To Determine the V-I Characteristics of a Light Emitting Diode (LED) and calculate the Wavelength of the Emitted Light "OR" Determination of Planck's Constant using LED.
2. To study the V-I characteristics of a Zener diode and its use as voltage regulator.
3. Designing of a Half Wave and Full Wave rectifier with and without filter.
4. To study the characteristics of a Bipolar Junction Transistor in CE configuration.
5. To design AND, OR and a switch (NOT gate) using a diode and transistor.
6. To verify and design AND, OR, NOT and XOR gates using NAND gates. NAND and NOR gates as Universal Gates.

Optional (for Slow Learners):

1. To study V-I characteristics of PN junction diode (Both Forwards and Reverse bias mode).
2. Study of CRO & Measurement of Voltage Amplitude & Frequency.

Reference Books:

1. Digital Principles and Applications, A.P. Malvino, D.P.Leach and Saha, 7th Ed., 2011, Tata McGraw
2. Fundamentals of Digital Circuits, Anand Kumar, 2nd Edn, 2009, PHI Learning Pvt. Ltd.
3. Digital Circuits and systems, Venugopal, 2011, Tata McGraw Hill.
4. Digital Systems: Principles & Applications, R.J.Tocci, N.S.Widmer, 2001, PHI Learning
5. Logic circuit design, Shimon P. Vingron, 2012, Springer.
6. Digital Electronics, Subrata Ghoshal, 2012, Cengage Learning
7. Microprocessor Architecture Programming & applications with 8085, 2002, R.S. Goankar, Prentice Hall.
8. Integrated Electronics, J. Millman and C.C. Halkias, 1991, Tata Mc-Graw Hill.
9. Electronics: Fundamentals and Applications, J.D. Ryder, 2004, Prentice Hall.
10. Solid State Electronic Devices, B.G. Streetman & S.K. Banerjee, 6th Edn., 2009, PHI Learning4. ***Digital Systems: Principles & Applications***, R.J.Tocci, N.S.Widmer, 2001, PHI Learning

Paper Name: Quantum Mechanics

Paper Code: PHY202
L T P – 4-0-0

Course Objectives:

1. To understand the phenomenon of blackbody radiation and its significance in the development of quantum theory.
2. To explore quantum states and wave functions, focusing on their probabilistic interpretations and the role of quantum operators in describing physical observables.
3. To apply Schrödinger's equation to solve one-dimensional quantum problems, including potential wells and harmonic oscillators.
4. To investigate the operator formulation of quantum mechanics and analyze the addition of angular momentum.
5. To solve three-dimensional quantum problems using Schrödinger's equation and explore their physical implications.

Course Outcome:

On completion of this course, the students will be able to

CO1: **Define** fundamental concepts of quantum mechanics, including blackbody radiation, wave-particle duality, and the uncertainty principle.

CO2: **Explain** the mathematical foundation of quantum mechanics, including the Schrodinger equation, operators, and observables.

CO3: **Solve** one-dimensional quantum mechanical problems such as the potential step, infinite square well, and harmonic oscillator using the Schrodinger equation.

CO4: **Analyze** the behavior of wave packets, continuity equations, and angular momentum operators to understand the dynamics of quantum systems.

CO5: **Evaluate** the quantum mechanical solutions for the hydrogen atom and compare the results with classical models of the atom.

CO6: **Formulate** and model new quantum systems using principles of Schrodinger’s equation and angular momentum formalism.

Course Content:

Module I: Blackbody Radiation

Blackbody Radiation, Photoelectric Effect, Compton Effect, Pair Production, Matter wave, Wave-Particle duality, Uncertainty Principle, Localized Wave Packet, Motion of Wave packet.

Module II: **Mathematical Foundation of Quantum Mechanics**

Mathematical Foundation of Quantum Mechanics, Postulates of Quantum Mechanics, Schrodinger Equation, Operators and Observables, Equation of Continuity, Time evolution of system.

Module III: One Dimensional Problems

Application of Schrodinger equation in One dimension, Free Particle, Potential Step problem, Potential barrier, Infinite Square Well potential, Harmonic Potential, Delta Function potential.

Module IV: Angular Momentum

Angular Momentum, Orbital and Spin angular momentum, General Formalism of Angular momentum, Matrix representation

Module V: Three Dimensional Problems

Three dimensional problems, Hydrogen atom problem

Reference Books:

1. ***Concepts of Modern Physics***, Arthur Beiser, 2002, McGraw-Hill.
2. ***Introduction to Modern Physics***, Rich Meyer, Kennard, Coop, 2002, Tata McGraw Hill
3. ***Introduction to Quantum Mechanics***, David J. Griffith, 2005, Pearson Education.
4. ***Physics for scientists and Engineers with Modern Physics***, Jewett and Serway, 2010, Cengage Learning.
5. ***Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles***, 2ed. 2006, Robert Eisberg,Robert Resnick
6. ***Quantum Mechanics***, Leonard I. Schiff, 3rd Edn. 2010, Tata McGraw Hill.
7. ***Quantum Mechanics***, G. Aruldhas, 2nd Edn. 2002, PHI Learning of India.
8. ***Quantum Mechanics***, Bruce Cameron Reed, 2008, Jones and Bartlett Learning.
9. ***Quantum Mechanics***: Foundations & Applications, Arno Bohm, 3rd Edn., 1993, Springer
10. ***Quantum Mechanics for Scientists & Engineers***, D.A.B. Miller, 2008, Cambridge University

Paper Name: Electronics II

Paper Code: PHY203

L T P – 3-0-1

Course Objectives:

1. To understand the working principles and structures of Junction and Metal-Oxide Field Effect Transistors (MOSFETs) and explore their applications in electronic circuits.
2. To describe the characteristics and configurations of Operational Amplifiers (IC 741), including their use in inverting and non-inverting amplifiers, differentiators, and oscillators.
3. To classify different types of Integrated Circuits (ICs), considering the scale of integration and evaluating their advantages and limitations.
4. To analyze combinational and sequential logic circuits, employing components such as Flip-Flops, Shift Registers, and Counters in circuit design.
5. To apply knowledge of the 8085 Microprocessor, focusing on memory organization, instruction sets, and interfacing, for basic programming tasks and laboratory experiments.

Course Outcome:

On completion of this course, the students will be able to

CO1: **Recall and describe** the fundamental principles of four-terminal devices, feedback in amplifiers, and the characteristics of MOSFETs and operational amplifiers.

CO2: **Explain** the working principles of oscillators, digital circuits, and flip-flops, including their role in electronic system design.

CO3: **Use** operational amplifiers to design basic circuits such as amplifiers, adders, integrators, and oscillators, and implement digital logic designs using flip-flops and counters.

CO4: **Analyze** the performance of combinational and sequential logic circuits, and assess the impact of feedback on amplifier parameters such as gain and stability.

CO5: **Evaluate** the functionality and efficiency of microprocessor systems, including memory organization, timing states, and input-output interfacing.

CO6: **Design and develop** electronic systems such as regulated power supplies, analog-to-digital converters, and operational amplifier-based circuits to meet specific requirements.

Course Content:

Module I: Four terminal device:

Field effect Transistors: Junction and Metal oxide field effect transistors, Structure and physical operation. Types of MOSFETs, Capacitance in MOS devices, Applications. Feedback in Amplifiers: Effects of Positive and Negative Feedback on Input Impedance, Output Impedance, Gain, Stability, Distortion and Noise.

Module II: Op-AMPs (IC 741):

Characteristics of an Ideal and Practical Op-Amp. Open-loop and Closed- loop Gain. Null offset approach, Frequency Response, CMRR, Application of Op-Amp: (1) Inverting and non-inverting amplifiers, (2) Adder, (3) Subtractor, (4) Differentiator, (5) Integrator, (6) Schmitt trigger etc., Sinusoidal Oscillators, Barkhausen's Criterion for self-sustained oscillations. RC Phase shift oscillator, Determination of Frequency. Oscillators: Wein-bridge, Hartley & Colpitts, Crystal oscillators

Module III: Integrated Circuits and VLSI Integrated Circuits (Qualitative treatment only):

Active & Passive components. Discrete components. Wafer. Chip. Advantages and drawbacks of ICs. Scale ofintegration: SSI, MSI, LSI and VLSI (basic idea and definitions only). Classification of ICs. Examples of Linear and Digital ICs

Module IV: Combinational and Sequential Logic Gates Digital Electronics II:

Flip Flop: Sequential Circuits: SR, D, and JK Flip-Flops. Clocked (Level and Edge Triggered) Flip-Flops. Race-around conditions in JK Flip-Flop. M/S JK Flip Flop. Timers: IC 555: block diagram and applications: Multivibrator: Astable and Monostable, Shift registers: Serial-in-Serial-out, Serial-in-Parallel-out, Parallel- in-Serial-out and Parallel-in-Parallel-out Shift Registers (only up to 4 bits). Counters (4 bits): Ring Counter. Asynchronous counters, Decade Counter. Synchronous Counter.

Module V: Microprocessor Computer Organization, 8085 Microprocessor:

Input/output Devices. Data storage (idea of RAM and ROM).Computer memory. Memory organization & addressing. Memory Interfacing. Memory Map. Main features of 8085. Block diagram. Components. Pinout diagram. Buses. Registers. ALU. Memory. Stack memory. Timing & Control circuitry. Timing states.

Electronics II Lab

List of Experiments (Any Five):

- Experiment 1: Study a Regulated Power Supply based load and line regulation characteristics.

- Experiment 2: Half Subtractor, Full Subtractor, Adder-Subtractor using Full Adder ICs.
- Experiment 3: To design and test the following circuits using an OPAMP
- Inverting and Non-inverting amplifier
- Differential amplifier.
- Adder
- Integrator
- Differentiator.
- Experiment 4: To design a Wien bridge oscillator for given frequency using an OPAMP.
- Experiment 5: To design a digital to analog converter (DAC) of given specifications.
- Experiment 6: To study the analog to digital convertor (ADC) IC.
- Experiment 7: To build Flip-Flop (RS, Clocked RS, D-type and JK) circuits using NAND gates.
- Experiment 8: Write the following programs using 8085 Microprocessor:
- Addition and subtraction of numbers using direct addressing mode.
- Addition and subtraction of numbers using indirect addressing mode.
- Multiplication by repeated addition.
- Division by repeated subtraction.

Reference Books:

1. DigitalPrinciplesandApplications,A.P.Malvino,D.P.Leach,7thEd.,2011,TataMcGraw
2. Fundamentals of Digital Circuits, Anand Kumar, 2nd Edn., 2009, PHI Learning Pvt. Ltd.
3. Digital Circuits and systems, Venugopal, 2011, Tata McGraw Hill.
4. Digital Systems: Principles & Applications, R. J. Tocci, N. S. Widmer, 2001, PHI Learning
5. Logic circuit design, Shimon P. Vingron, 2012, Springer.
6. Digital Electronics, Subrata Ghoshal, 2012, Cengage Learning.
7. Microprocessor Architecture Programming & applications with 8085, 2002, R.S. Goankar, Prentice Hall.
8. Integrated Electronics, J. Millman and C.C. Halkias, 1991, Tata Mc-Graw Hill.
9. Electronics: Fundamentals and Applications, J.D. Ryder, 2004, Prentice Hall.
10. Solid State Electronic Devices, B.G.Streetman&S.K.Banerjee, 6th Edn.,2009, PHI Learning
11. Electronic Devices & circuits, S. Salivahanan& N. S. Kumar, 3rd Ed., 2012, Tata Mc-Graw Hill
12. OP-Amps and Linear Integrated Circuit, R. A. Gayakwad, 4th edition, 2000, Prentice Hall
13. Electronic circuits: Handbook of design & applications, U.Tietze, C.Schenk, 2008, Springer

Paper Name: Analytical Mechanics and Special Theory of Relativity

Paper Code: PHY204

L T P – 4-0-0

Course Objectives:

1. To understand the principles of Lagrangian mechanics and apply the Lagrange equations to analyze simple physical systems, including oscillators and pendulums.
2. To apply Hamilton's equations for solving mechanics problems related to conservative forces and electromagnetic fields.
3. To analyze small oscillations and continuous systems, identifying normal modes and frequencies in physical systems, such as coupled pendulums.
4. To interpret the fundamental concepts of the Special Theory of Relativity, focusing on time dilation, length contraction, and energy-momentum relations.
5. To solve problems in rigid body dynamics using advanced concepts, including Euler angles, rotational matrices, and the moment of inertia tensor.

Course Outcome:

On completion of this course, the students will be able to

CO1: **Recall and summarize** the fundamental principles of variational calculus, Lagrangian and Hamiltonian mechanics, and special theory of relativity.

CO2: **Explain** the physical significance of variational principles, canonical transformations, and relativistic effects such as time dilation, Lorentz contraction, and mass-energy equivalence.

CO3: **Apply** Lagrange's and Hamilton's equations to solve problems involving harmonic oscillators, central force fields, and pendulum systems.

CO4: **Analyze** systems with small oscillations, normal coordinates, and rigid body motion using mathematical techniques such as Euler's equations and transformation matrices.

CO5: **Evaluate** the outcomes of experiments like the Michelson-Morley experiment and assess the implications of relativistic transformations on classical mechanics.

CO6: **Formulate** new mechanical models or modify existing ones to incorporate relativistic corrections and principles for advanced physical systems.

Course Content:

Module I: Variational Principles and Lagrangian Formulation

Introduction to calculus of variations, few applications, Hamilton's VariationalPrinciple, D' Alembert's principle, Lagrange's Equation of motion, Linear harmonic Oscillator, Few applications like simple pendulum, linear harmonic oscillator, isotropic oscillator, particle moving under a central force field, Atwood's machine, particle on a sphere, Compound pendulum. Invariance of Lagrange's equation under Galilean Transformation.

Module II: Hamiltonian Formulation

Hamilton's equation of motion, Advantage of Hamiltonian approach, Applications of Hamilton's equation like simple pendulum, compound pendulum, Isotropic harmonic oscillator, Particle moving near the surface of earth, particle in a central force field. Hamiltonian for a charged particle in an electromagnetic field, Principle of least action, canonical transformation, Poisson's bracket.

Unit III: Mechanics of small oscillations and continuous systems

Stable and unstable Equilibrium, Formulation of the problem: Lagrange's equation of motion for small oscillations, Properties of T, V and ω , Normal co-ordinates and normal frequencies of vibration, Few applications- Parallel pendulum, Double pendulum, Triple pendulum, Transition from discrete to a continuous systems.

Unit IV: Special Theory of Relativity

Michelson-Morley Experiment, Postulates of Special Theory of Relativity. Lorentz Transformations. Simultaneity and order of events. Lorentz contraction. Time dilation. Relativistic transformation of velocity, frequency and wave number. Relativistic addition of velocities. Variation of mass with velocity. Massless Particles. Mass-energy Equivalence. Relativistic Doppler effect. Relativistic Kinematics. Transformation of Energy and Momentum. Energy-Momentum Four Vector.

Unit V: Rigid Body Motion

Degrees of freedom, Orthogonal Transformations and properties of transformation matrices, Euler angles, Euler's Theorems on the motion of a rigid body, Finite and infinitesimal rotations, Moment of Inertia tensor, Principal axis of transformation, solution of rigid body problem using Euler equation of motion

Reference Books:

1. ***Classical Mechanics***, H. Goldstein, C.P. Poole, J.L. Safko, 3rd Edn. 2002, Pearson Education.
2. ***Mechanics***, L. D. Landau and E. M. Lifshitz, 1976, Pergamon.

3. ***Classical Electrodynamics***, J.D. Jackson, 3rd Edn., 1998, Wiley.
4. ***The Classical Theory of Fields***, L.D Landau, E.M Lifshitz, 4th Edn., 2003, Elsevier.
5. ***Introduction to Electrodynamics***, D.J. Griffiths, 2012, Pearson Education.
6. ***Classical Mechanics***: An introduction, Dieter Strauch, 2009, Springer.
7. ***Solved Problems in Classical Mechanics***, O.L. Delange and J. Pierrus, 2010, Oxford Press

Paper Name: Electromagnetic Theory II

Paper Code: PHY300

L T P – 3-0-1

Course Objectives:

1. To analyze the motion of charged particles in electric and magnetic fields, applying electromagnetism principles to solve related problems.
2. To apply Maxwell's equations to explain the propagation of electromagnetic waves in various media and interpret energy transfer using the Poynting theorem.
3. To understand and explain the phenomena of interference, diffraction, and polarization in optics, employing wave theory principles to address related problems.
4. To evaluate the properties of waveguides, including phase and group velocities, and discuss their implications for electromagnetic wave propagation.
5. To develop practical skills through experiments related to electromagnetic theory, optics, and quantum effects, such as measuring self-inductance, studying LCR circuits, and verifying fundamental atomic theories.

Course Outcome:

On completion of this course, the students will be able to

CO1: **Recall** fundamental concepts of electromagnetic theory, such as Faraday's law, Maxwell's equations, and the basics of polarization.

CO2: **Explain** the behavior of electromagnetic waves in different media and the underlying principles of optical phenomena, such as interference, diffraction, and polarization.

CO3: **Solve** problems related to the motion of charged particles in electric and magnetic fields, self and mutual inductance, and electromagnetic wave propagation.

CO4: **Analyze** the principles of waveguides, including the conditions for guided waves, phase and group velocities, and eigenvalue equations for planar waveguides.

CO5: **Evaluate** experimental data to validate theoretical predictions, such as determining self-inductance, quality factors of LCR circuits, and refractive indices using laboratory setups.

CO6: **Design** and **interpret** experiments to investigate optical phenomena, such as interference using Michelson's interferometer, and analyze polarization states using wave plates and compensators and many more.

Course Content:

Module I: Motion of Charged Particles in Electro-magnetic field and Electromagnetic induction

Motion of a charged particle in external Electric and Magnetic field (when velocity is perpendicular to the Magnetic field/not perpendicular to the magnetic field), Crossed Electric and Magnetic field. Basic principles of J. J. Thompson's Experiment. Faraday's and Lenz's law; motional e.m.f-simple problems; calculation of self and mutual inductance in simple cases; inductances in series and parallel; reciprocity theorem.

Module II: Maxwell Equations and EM Wave Propagation in Unbounded and Bounded Media

Maxwell's equations. Gauge Transformations- Lorentz and Coulomb Gauge. Boundary Conditions at Interface between Different Media. Wave Equations. Poynting Theorem and Poynting Vector. Electromagnetic (EM) Energy Density, Plane EM waves through vacuum, isotropic dielectric medium, conducting medium. Fresnel's Formulae for perpendicular & parallel polarization cases, Brewster's law. Reflection & Transmission coefficients. Total internal reflection, evanescent waves. Metallic reflection (normal Incidence).

Module III: Optics

Interference: Division of amplitude and wave front. Young's double slit experiment. Fresnel's Bi-prism, Interference in Thin Films: parallel and wedge-shaped films. Newton's Rings, Interferometer: Michelson Interferometer, Fabry-Perot interferometer.

Diffraction: Fraunhofer diffraction: Single slit. Circular aperture, Resolving Power of a telescope. Double slit. Multiple slits. Diffraction grating. Resolving power of grating. Fresnel Diffraction, Fresnel's Half-Period Zones for Plane Wave. Theory of a Zone Plate, Fresnel diffraction pattern of a straight edge, a slit and a wire.

Polarization: Description of Linear, Circular and Elliptical Polarization. Fresnel's Formula. Uniaxial and Biaxial Crystals. Nicol Prism. Circularly and Elliptically Polarized Light. Quarter-Wave and Half-Wave Plates. Babinet Compensator and its Uses. Analysis of Polarized Light, Fresnel's Theory of optical rotation. Calculation of angle of rotation. Experimental verification of Fresnel's theory. Specific rotation.

(8 L)

Module IV: Wave Guides

Planar optical wave guides. Planar dielectric wave guide. Condition of continuity at interface. Phase shift on total reflection. Eigenvalue equations. Phase and group velocity of guided waves. Field energy and Power transmission.

(6 L)

Hands On Experiments: (at least 8)

Experiment 1: To determine *self-inductance* of a coil by Rayleigh's method.

Experiment 2: To study response curve of a Series LCR circuit and determine its (a) Resonant frequency, (b) Impedance at resonance, (c) Quality factor Q, and (d) Band width.

Experiment 3: To study the response curve of a parallel LCR circuit and determine its (a) Anti-resonant frequency and (b) Quality factor Q.

Experiment 4: Photo-electric effect: photo current versus intensity and wavelength of light; maximum energy of photo-electrons versus frequency of light

Experiment 5: To determine the wavelength of H-alpha emission line of Hydrogen atom.

Experiment 6: To determine the value of e/m by J. J. Thompson method.

Experiment 7: To setup the Millikan oil drop apparatus and determine the charge of an electron.

Experiment 8: To determine the wavelength and velocity of ultrasonic waves in a liquid (Kerosene Oil, Xylene, etc.) by studying the diffraction through ultrasonic grating.

Experiment 9: To determine the refractive Index of (1) glass and (2) a liquid by total internal reflection using a Gaussian eyepiece.

Experiment 10: Verification of Bohr's atomic theory by Franck Hertz Experiment.

Reference Books

1. ***Electricity and Magnetism***, Rakshit and Chattopadhyay, New Age Publisher
2. ***Foundations of Electricity and Magnetism***, B. Ghosh
3. ***Electricity and Magnetism***, D. C. Tayal, S. Chand Publisher
4. ***Electricity and Magnetism***, Edward M. Purcell, 1986 McGraw-Hill Education
5. ***Introduction to Electrodynamics***, D.J. Griffiths, 3rd Edn., 1998, Benjamin Cummings
6. ***Elements of Electromagnetics***, M.N.O. Sadiku, 2001, Oxford University Press.
7. ***Introduction to Electromagnetic Theory***, T.L. Chow, 2006, Jones & Bartlett Learning
8. ***Fundamentals of Electromagnetics***, M.A.W. Miah, 1982, Tata McGraw Hill
9. ***Electromagnetic Fields & Waves***, P.Lorrain&D.Corson, 1970, W.H.Freeman& Co.
10. ***Electromagnetics***, J.A. Edminster, Schaum Series, 2006, Tata McGraw Hill.

Paper Name: Statistical Mechanics

Paper Code: PHY301
L T P – 4-0-0

Course Objectives:

1. To describe the fundamental postulates of classical statistical physics, including the concepts of macro and micro states, entropy, and thermodynamic probability.
2. To apply the Maxwell-Boltzmann distribution law for calculating velocities and energy distribution in ideal gases.
3. To analyze the limitations of classical radiation theories, such as the Rayleigh-Jeans law and the ultraviolet catastrophe, and interpret solutions provided by quantum theory, including Planck's law.
4. To explain the principles of quantum statistics, focusing on Bose-Einstein and Fermi-Dirac distributions, and their applications to systems such as photon gas and electron gas in metals.
5. To evaluate the thermodynamic functions of systems using different statistical ensembles and examine applications, including the law of equipartition of energy and Bose-Einstein condensation.

Course Outcome:

On completion of this course, the students will be able to

CO1: **Recall and define** fundamental concepts of statistical physics, including phase space, entropy, and thermodynamic probability, and describe classical thermodynamic functions for an ideal gas.

CO2: **Explain** the principles of classical statistical physics, including the derivation of the law of equipartition of energy and its limitations, and describe the differences between microstates and macrostates in the context of statistical ensembles.

CO3: **Apply** Maxwell-Boltzmann statistics to analyze velocity distribution in gases and determine properties such as most probable velocity, average velocity, and RMS velocity; demonstrate understanding through problem-solving and examples.

CO4: **Analyze** the classical and quantum theories of radiation, including derivations and experimental verification of Stefan-Boltzmann law and Planck's quantum theory; assess the limitations of classical theories and the emergence of quantum statistics.

CO5: **Evaluate** the thermodynamic functions and behaviors of Bose-Einstein and Fermi-Dirac distributions; compare their applications to photon gases, electron gases in metals, and specific heat of metals, and assess the implications for low-temperature physics.

CO6: **Synthesize** knowledge of quantum statistics to solve complex problems involving Bose-Einstein condensation and Fermi energy in a metal, and use statistical models to predict and interpret real-world physical phenomena in the context of statistical mechanics

Course Content:

Module I: Basic Concepts in Classical Statistical Physics

Basic postulates of Statistical Physics, Macro and Micro States, Phase Space, Stirling's Approximation, Entropy and Thermodynamic probability, Boltzmann entropy relation. Classical Liouville's theorem (Statement only). Ensembles (elementary idea), Introduction to Partition Function, Thermodynamic Functions of an Ideal Gas, Gibbs Paradox, Sackur Tetrode equation, Law of Equipartition of Energy (with proof) – Applications to Specific Heat and its Limitations, Thermodynamic Functions of a Two-Energy Levels System, Negative Temperature.

Module II: Maxwell-Boltzmann statistics and Distribution law

Maxwell-Boltzmann Energy distribution function, Maxwell Boltzmann law of velocity distribution (most probable velocity, average velocity, RMS velocity), Limitations of M-B statistics, Law of Equipartition of Energy (with proof). Applications to Specific Heat and its Limitations, Elementary idea of quantum statistics.

Module III: Properties of Thermal Radiation

Classical Theory of Radiation**:** Blackbody Radiation. Kirchhoff's law. Stefan-Boltzmann law: Thermodynamic proof. Radiation Pressure. Wien's Displacement law. Wien's Distribution Law. Rayleigh-Jean's Law. Ultraviolet Catastrophe.

Quantum Theory of Radiation**:** Spectral Distribution of Black Body Radiation. Planck's Quantum Postulates. Planck's Quantum theory of Blackbody Radiation: Experimental Verification. Deduction of (1) Wien's Distribution Law, (2) Rayleigh-Jeans Law, (3) Stefan-Boltzmann Law, (4) Wien's Displacement law from Planck's law, Saha's Ionization equation.

Module IV: Introduction to Quantum Statistics

Bose-Einstein Statistics: B-E distribution law, Thermodynamic functions of a strongly Degenerate Bose Gas, Bose Einstein condensation, properties of liquid He (qualitative description), photon gas and Thermodynamic functions of photon gas. Bose derivation of Planck's law.

Fermi-Dirac Statistics: Fermi-Dirac Distribution Law, Thermodynamic functions of a Completely and strongly Degenerate Fermi Gas, Fermi Energy, Electron gas in a Metal, Specific Heat of Metals,

Reference Books:

1.***Introductions to Statistical Mechanics***, B.B.Laud
2. ***Statistical Physics (Allied Publishers)***, J. K. Bhattarjee:
3. ***Statistical Physics (Mc.Graw Hill)***, F.Reif:
4. ***Statistical Physics (Chapman and Hall/CRC)***, K.Hung:
5.***Statistical Mechanics***, R.K. Pathria

Paper Name: Advanced Quantum Mechanics

Paper Code: PHY302

L T P – 4-0-0

Course Objectives:

1. To describe the behavior of particles in three-dimensional potential problems, including the analysis of systems such as the hydrogen atom, harmonic oscillator, and the addition of angular momentum.
2. To apply time-independent perturbation theory for solving energy corrections in quantum systems, including relativistic mass corrections and the Zeeman effect.
3. To analyze the WKB approximation method and tunneling phenomena, applying these concepts to bound states and potential wells.
4. To explain time-dependent perturbation theory and utilize it for evaluating transition probabilities, including the adiabatic and sudden approximations.
5. To evaluate scattering cross-sections using the Born approximation and partial wave analysis to understand elastic scattering and particle interactions.

Course Outcome:

On completion of this course, the students will be able to

CO1: **Identify and describe** essential quantum mechanics concepts such as three-dimensional potential problems, angular momentum, and core approximation methods.

CO2: **Explain** the theoretical foundations and mathematical expressions of time-independent perturbation theory, WKB approximation, and variational methods.

CO3: **Use** time-dependent perturbation theory and Fermi's Golden Rule to analyze and solve problems involving quantum transitions and dynamic interactions.

CO4: **Examine** scattering phenomena using Born approximation and partial wave analysis, and interpret results in different reference frames such as the laboratory and center-of-mass frames.

CO5: **Critically evaluate** the strengths and limitations of various approximation techniques, including the Born approximation, by comparing them with exact solutions and experimental data.

CO6: **Create and develop** models for solving complex quantum mechanical problems using appropriate methods, including perturbation theory and variational approaches.

Course Content:

Module I: Three Dimensional Potential Problems and Angular Momentum

Recapitulation of Hydrogen atom, 3-D problems in Cartesian co-ordinate; free particle, Box potential, Delta function potential, Harmonic Oscillator, 3-D problems in Spherical polar co-ordinate; free particle, square well potential, isotropic harmonic oscillator. Addition of angular momenta, Clebsch-Gordan co-efficient.

Module II: Approximation methods in quantum mechanics

Time independent perturbation theory: (both non-degenerate and degenerate), First and Second order correction in energy Eigenvalues, and first order corrections in energy Eigen functions. Degenerate perturbation theory, application to one-electron system, Relativistic mass correction, Spin-orbit coupling (L-S and J-J coupling), Zeeman effect, Stark effect.

WKB Approximation: Quantization rule, General formalism, Bound states for potential wells with No rigid walls/ with One rigid wall/ with Two rigid walls, tunneling through a barrier, qualitative discussion of α decay.

Variational method: He atom as example; First order perturbation; Exchange degeneracy; Ritz principle for excited states for Helium atom.

Module III: Time dependent perturbation theory

The pictures of Quantum Mechanics, Schrodinger picture, Heisenberg's picture and Interaction picture. Theoretical framework of time-dependent perturbation theory, Transition probability for a Constant perturbation and Harmonic perturbation, Fermi Golden rule, Adiabatic and Sudden approximations.

Module IV: Scattering Theory

Scattering cross-section, lab frame and CM frame, Scattering amplitude and differential cross section, Green's function technique in scattering phenomena, Born approximation, Validity of Born Approximation, Partial Wave analysis for elastic scattering, scattering of identical particles.

Reference Books

1. ***Quantum Mechanics***; L.I. Schiff:
2. ***Quantum Mechanics***; NouredineZettili, John Wiley and Sons Ltd.
3. ***Quantum Mechanics***; David J. Griffiths
4. ***Advanced Quantum Mechanics***, J.J. Sakurai
5. ***Quantum Mechanics vol. 1 and 2***; C. Cohen-Tannoudji, B. Dier, and F. Laloe:
6.***Quantum Mechanics;***E. Merzbacher
7. ***Quantum Mechanics, Vol. II***; E. Merzbacher
8. ***Quantum Mechanics***, Bransden and Joachain, Pearson Education.

Paper Name: Numerical Methods and Simulation in Physics

Paper Code: PHY303

L T P – 1-0-3

Course Objectives:

1. To apply numerical methods such as the Bisection, Newton-Raphson, and Secant methods for solving transcendental equations in physical systems, including optics and potential wells.
2. To solve systems of linear equations using techniques like Gauss Elimination and Gauss-Seidel, applying these methods to practical problems such as electric circuits and coupled spring-mass systems.
3. To implement numerical solutions for first-order differential equations using the Euler and Runge-Kutta methods, modeling physical phenomena like radioactive decay and Newton's law of cooling.
4. To analyze second-order differential equations, particularly for harmonic oscillators, employing the Runge-Kutta method to address both damped and forced oscillatory systems.
5. To evaluate solutions to the Schrödinger equation using the Finite Difference Method and the Numerov algorithm, applying these techniques to quantum mechanical problems such as the hydrogen atom and screened Coulomb potentials.

Course Outcome:

On completion of this course, the students will be able to

1. CO1: **Recall** fundamental numerical methods such as Bisection, Newton-Raphson, and Secant methods, and identify their role in solving physical problems like diffraction equations and finite potential wells.

2. CO2: **Describe** and **interpret** the application of numerical techniques like Gauss Elimination and Gauss-Seidel methods in solving linear systems, including practical examples like electric circuits and coupled spring-mass systems.

3. CO3: **Use** numerical methods like Euler and Runge-Kutta to solve first-order differential equations, applying these techniques to model physical processes such as radioactive decay and Newton's law of cooling.

4. CO4: **Analyze** the behavior of second-order differential systems, including harmonic oscillators, by employing the Runge-Kutta method to study cases such as damped and forced oscillatory systems.

5. CO5: **Evaluate** quantum mechanical problems, such as the Schrödinger equation, using advanced methods like the Finite Difference Method and Numerov algorithm, interpreting energy eigenvalues and wave functions.

6. CO6: **Design** and **simulate** numerical models for advanced physical systems, such as random walk behavior or molecular dynamics using the Lennard-Jones potential, and validate the results against theoretical predictions.

Course Content:

1. Numerical solution of Transcendental equations by Bisection, Newton Raphson and Secant methods, Solution of linear and quadratic equation.

Problem:

- $I = I_0\left(\frac{\sin\alpha}{\alpha}\right)^2$ in optics.
- Particle in finite width potential well
- solving diffraction equation $\alpha = \tan\alpha$,

2. Solution of Linear system of equations by Gauss elimination method and Gauss-Seidal method.

Problem:

- Solution of mesh equations of electric circuits (3 meshes)
- Solution of coupled spring mass systems (3 masses).

3. First order differential equation, Euler, Modified Euler and Runge-Kutta second order method.

Problem:

- Solve equations for radioactive decay
- Newton's law of cooling ,
- Classical equations of motion.

4. Second order differential equation solving by RK 4 method

Problem:

- Harmonic oscillator (no friction)
- Damped Harmonic oscillator, for 3 different cases such as- Over damped, Critical damped, Oscillatory
- Forced Harmonic oscillator
- Transient and Steady state solution.

5. Finite Difference method/ Numerov algorithm to solve 2^{nd} order Differential Equation, Solution of Schrodinger Equation in 1D for different given potentials.

Problems:

- **Solve the s-wave Schrodinger equation** for the ground state and the first excited state of the hydrogen atom,

$$\frac{d^2y}{dr^2} = A(r)u(r), A(r) = \frac{2m}{\hbar^2}\left[V(r) - E\right] \text{, where } V(r) = -\frac{e}{r^2}$$

Here, m is the reduced mass of the electron. Obtain the energy Eigenvalues and plot the corresponding wave functions. Remember that the ground state energy of the hydrogen atom is ≈ -13.6 eV. Take e = 3.795 $(eVÅ)^{1/2}$, ħc = 1973 (eVÅ) and m = 0.511×106 eV/c^2.

- **Solve the s-wave radial Schrodinger equation** for an atom,

$$\frac{d^2y}{dr^2} = A(r)u(r), A(r) = \frac{2m}{\hbar^2}\left[V(r) - E\right]$$

where m is the reduced mass of the system (which can be chosen to be the mass of an electron), for the screened coulomb potential,

$$V(r) = -\frac{e^2}{r}e^{-r/a}$$

Find the energy (in eV) of the ground state of the atom to an accuracy of three significant digits. Also, plot the corresponding wave function. Take e = 3.795 (eVÅ)1/2, m = 0.511x106 eV/c2, and a = 3 Å, 5 Å, 7 Å. In these units ħc = 1973(eVÅ). The ground state energy is expected to be above -12 eV in all three cases.

- **Solve the s-wave radial Schrodinger equation** for a particle of mass m,

$$\frac{d^2y}{dr^2} = A(r)u(r), A(r) = \frac{2m}{\hbar^2}\left[V(r) - E\right],$$

for the anharmonic oscillator potential $V(r) = \frac{1}{2}kr^2 + \frac{1}{3}br^3$.

for the ground state energy (in MeV) of particle to an accuracy of three significant digits. Also, plot the corresponding wave function. Choose m = 940 MeV/c^2, k = 100MeV fm^{-2}, b = 0, 10, 30 MeV fm^{-3}. In these units, cħ = 197.3 MeV fm. The ground state energy is expected to lie between 90 and 110 MeV for all three cases.

6. Random Number generation and testing, Random number generation with given distribution

Problem:

- Coin tossing. Fit with binomial distribution.
- Random Walk: – In 1D and in 2D (Square grid) – Plot of r.m.s. value of end to end distance as a function of time step – fitting and finding of exponent

Projects and Assignments: (Any one)

- Simulation of Inverse Square Law of Gravitation and to check the stability of planetary orbits.
- Molecular Dynamics simulation using Lennard-Jones potential
- Electronic transmission through a nanostructure using Transfer Matrix method.
- Trace Map technique to analyze the eigen spectrum of a fractal lattice.

*Other problems might be given during class.

Paper Name: Solid State Physics

Paper Code: PHY304

L T P – 3-0-1

Course Objectives:

1. To explain the nature of interatomic forces and the various types of bonding in solids, including ionic, covalent, metallic, and intermolecular bonds.
2. To describe different crystal structures, the concept of Miller indices, Bragg's law, and lattice dynamics, including the role of phonons and their influence on the specific heat of solids.
3. To apply free electron theory and band theory to analyze the electrical and thermal properties of conductors, semiconductors, and insulators, including concepts like the Hall Effect and carrier mobility.
4. To analyze the magnetic properties of materials, explore superconductivity, and understand related phenomena such as the Meissner effect, hysteresis, and BCS theory.
5. To conduct hands-on experiments to measure properties such as the Hall coefficient, dielectric constant, and I-V characteristics of solar cells, while investigating tunneling effects in tunnel diodes.

Course Outcome:

On completion of this course, the students will be able to

1. **CO1**: **Identify** the types of interatomic bonding in solids, including ionic, covalent, metallic, and hydrogen bonds, and describe their influence on the cohesive forces in materials.

2. **CO2**: **Demonstrate** an understanding of crystal structures, lattice dynamics, and phonon spectra, along with the application of Bragg's Law and theories of specific heat in solids.

3. **CO3**: **Apply** the free electron and band theories to explain the electrical and thermal properties of materials, and solve problems involving conductors, semiconductors, and insulators.

4. **CO4**: **Analyze** the magnetic behavior of materials through classical and quantum mechanical theories, and analyze phenomena such as the B-H curve, hysteresis, and energy loss.

5. **CO5**: **Assess** the dielectric properties of materials, including polarization, susceptibility, and ferroelectricity, and evaluate their impact on material behavior and optical phenomena.

6. **CO6**: **Perform** hands-on experiments to measure properties like Hall coefficient, dielectric constant, and I-V characteristics of solar cells, and investigate tunneling in a tunnel diode.

Course Content:

Module I: Interatomic Forces and Bonding in Solids

Cohesive forces, Bonding in Solids, Ionic bonding, Covalent bonding, Metallic bonds, Intermolecular Bonds, Dipole, Hydrogen bonds.

Module II: Crystal Structure and Lattice Dynamics

Solids: Amorphous and Crystalline Materials. Lattice Translation Vectors. Lattice with a Basis Central and Non-Central Elements. Unit Cell. Miller Indices. Reciprocal Lattice. Types of Lattices. Brillouin Zones. Diffraction of X-rays by Crystals. Bragg's Law. Atomic and Geometrical Factor.

Lattice Vibrations and Phonons: Linear Monoatomic and Diatomic Chains. Acoustical and Optical Phonons. Qualitative Description of the Phonon Spectrum in Solids. Dulong and Petit's Law, Einstein and Debye theories of specific heat of solids.T^3 law.

Module III: Free Electron Theory and elementary band theory

Free Electron Gas, Electrical and Thermal conductivity, Electronic Specific Heat, Sommerfeld's correction, Kronig Penny model. Formation of energy bands, Band Gap. Conductor, Semiconductor (P and N type) and insulator. Boltzman Transport Equation, Conductivity of Semiconductor, mobility, Hall Effect. Measurement of conductivity (4 probe method) & Hall coefficient.

Module IV: Magnetism and Superconductivity

Dia-, Para-, Ferri- and Ferromagnetic Materials. Classical Langevin Theory of dia and Paramagnetic Domains. Quantum Mechanical Treatment of Paramagnetism. Curie's law, Weiss's Theory of Ferromagnetism and Ferromagnetic Domains. Discussion of B-H Curve. Hysteresis and Energy Loss.

Experimental Results. Critical Temperature. Critical magnetic field. Meissner effect. Type I and type II Superconductors, London's Equation and Penetration Depth. Isotope effect. Idea of BCS theory (No derivation)

Module V: Dielectric Properties of Materials:

Polarization. Local Electric Field at an Atom. Depolarization Field. Electric Susceptibility. Polarizability. Clausius Mosotti Equation. Normal and Anomalous Dispersion. Ferroelectricity, Piezoelectricity, Complex Dielectric Constant. Optical Phenomena.

Hands On Training:

1: Determine the Hall coefficient of a semiconductor sample (*p type and n type*).

2: Measure the Dielectric Constant of a dielectric Materials with frequency/temperature.

3: Determine the I-V characteristics of a Solar Cell.

4: Determine the temperature dependence of energy band-gap of a Ge semi-conductor.

5: Determine the refractive index of a dielectric layer using Surface Plasmon resonance (SPR).

6: Study the tunneling effect in tunnel diode using I-V characteristics

Reference Books:

1. ***Introduction to Solid State Physics***, Charles Kittel, 8th Edition, 2004, Wiley India Pvt. Ltd.
2. ***Elements of Solid State Physics***, J.P. Srivastava, 2nd Edition, 2006, Prentice-Hall of India
3. ***Introduction to Solids***, Leonid V. Azaroff, 2004, Tata Mc-Graw Hill
4. ***Solid State Physics***, N.W. Ashcroft and N.D. Mermin, 1976, Cengage Learning
5. ***Solid-state Physics***, H. Ibach and H. Luth, 2009, Springer
6. ***Elementary Solid State Physics***, 1/e M. Ali Omar, 1999, Pearson India
7. ***Solid State Physics***, M.A. Wahab, 2011, Narosa Publications.

Paper Name: Nuclear and Particle Physics

Paper Code: PHY305

L T P – 3-0-1

Course Objectives:

1. To explain the general properties of nuclei, including aspects such as mass, radii, binding energy, and the characteristics of nuclear forces.
2. To describe various nuclear models, including the liquid drop model, Bethe-Weizsäcker mass formula, Fermi gas model, and shell model, and their applications in nuclear physics.
3. To solve the Schrödinger equation for the ground and excited states of the deuteron, and to compare their potential energies in different configurations.
4. To analyze the different types of radioactive decay, including alpha, beta, and gamma decay, and to explore their specific features and implications in nuclear processes.
5. To conduct laboratory experiments related to beta particles, including studies on bremsstrahlung, G.M. counter characteristics, and to determine the range of beta particles and the plateau region of the counter.

Course Outcomes:

On completion of this course, the students will be able to

1. **CO1**: **Identify** the fundamental properties of nuclei, such as mass, radii, binding energy, and intrinsic properties of nuclear constituents, along with their roles in nuclear forces and isospin.

2. **CO2**: **Explain** the nuclear structure using models like the Liquid Drop Model, Bethe-Weizsäcker formula, Fermi Gas Model, and Shell Model, and their applications in describing nuclear behavior.

3. **CO3**: **Solve** problems related to the deuteron using the Schrödinger equation to compare the potential energies of its ground and excited states.

4. **CO4**: **Analyze** radioactive decay processes (alpha, beta, and gamma) by understanding their laws, features, and underlying mechanisms.

5. **CO5**: **Evaluate** nuclear reactions using conservation laws, Q-values, and cross sections, and assess energy generation through fission and fusion processes.

6. CO6: **Design** and **perform** experiments to investigate nuclear and particle properties, such as estimating beta particle ranges and analyzing G.M. counter characteristics, to validate theoretical principles.

Course Content

Module I: General Properties of Nuclei

Constituents of Nucleus and their Intrinsic Properties, Quantitative Facts about Mass, Radii, Charge Density, Matter Density, Binding Energy, Angular Momentum, Parity, Magnetic Moment, Electric Moments, Nature of Nuclear Forces, Isospin, Nuclear Form Factor, Rutherford Scattering

Module II: Nuclear Structure

Liquid Drop Model of Nucleus, Bethe-Weizsäcker Mass Formula, Fermi Gas Model, Shell Model

Module III: Deuteron Problems

Properties of deuteron, Schrödinger equation and its solution for ground state and excited state of deuteron. Comparison between potential energies of ground and excited states of deuteron

Module IV: Radioactive Decays

Law of radioactive decay, Detailed features of Alpha, Beta and Gamma Decay

Module V: Nuclear Reactions

Types of Reactions, Conservation Laws, Kinematics of Reactions, Q-value, Reaction Rate, Reaction Cross Section, Concept of Compound and Direct Reaction, Resonance Reaction, Fission and fusion- mass deficit, relativity and generation of energy Nuclear Fission

Module VI: Particle Physics

Classification of Elementary Particles, Basic Forces of Nature and their Characteristics, Characteristics of Coupling Constants, Feynman Diagram of Basic Interactions, Properties of neutrinos, Characteristics of Strange particles, Quantum numbers, Quark model for Baryon and Mesons in Eightfold Scheme, Gellman-NishijimaFormula, Decay of Elementary Particles and Relevant Conservation laws

Nuclear and Particle Physics Lab:

List of Experiments:

1. Estimation of range of beta particles

2. Production and attenuation of bremsstrahlung and estimation of back scattering of beta particles
3. Measurement of current-voltage characteristics of a G.M. counter using beta and gamma source and determination of plateau and resolving time of the counter

Reference Books:

1. ***Nuclear Physics***; E. Fermi
2. ***Nuclear Physics***; R. R. Roy, B. P. Nigam
3. ***Atomic and Nuclear Physics***; S. N. Ghoshal
4. ***Introduction to High Energy Physics***; D. H. Perkins
5. ***Introduction to Elementary Particles***; D. J. Griffiths
6. ***Nuclear and Particle Physics***; W. E. Burcham

Paper Name: Advanced Statistical Mechanics

Paper Code: PHY400
L T P – 4-0-0

Course Objectives:

1. To explain the fundamental principles of statistical mechanics, including concepts such as macrostates, microstates, phase space, and the Ergodic hypothesis.
2. To describe the properties of the microcanonical ensemble and its applications to classical ideal gases, spin systems, and calculations of entropy.
3. To apply the canonical ensemble and the concept of the partition function to solve problems related to thermal systems, magnetization, and fluctuations.
4. To analyze the grand canonical ensemble, focusing on the concepts of chemical potential, particle fluctuations, and the entropy of ideal gases.
5. To evaluate quantum statistical mechanics using density matrices, with applications to quantum ensembles and the behavior of ideal gases.

Course Outcome:

On completion of this course, the students will be able to

1. **CO1**: **Recall** the fundamental principles and key postulates of statistical mechanics, such as the ergodic hypothesis, the postulate of equal a priori probability (PEAP), and Boltzmann's postulate of entropy.

2. **CO2**: **Explain** the concepts of macrostates and microstates, phase space, and statistical ensembles, including how they relate to the determination of entropy and the significance of Liouville's Theorem.

3. **CO3**: **Demonstrate** the application of microcanonical, canonical, and grand canonical ensembles to determine thermodynamic properties such as the entropy of a classical ideal gas, the average energy of a system, and chemical potential in ideal gas systems.

4. **CO4**: **Analyze** complex problems involving statistical ensembles by using partition functions to derive expressions for entropy, energy, and other thermodynamic quantities, and evaluate fluctuations in energy and particle number.

5. **CO5: Assess** the differences between classical and quantum statistical mechanics, comparing classical microcanonical ensembles to quantum mechanical representations, such as density matrices and the statistics of identical particles.

6. CO6: **Develop and solve** problems involving density matrices and quantum ensembles, including applying the quantum Liouville's theorem and exploring the implications for

systems of identical particles.

Course Content:

Module 1: Introduction

Objective of statistical mechanics. Macrostates and microstates, phase space and statistical ensembles. Ergodic hypothesis, postulate of equal a priori probability (PEAP) and equality of ensemble average and time average. Boltzmann's postulate of entropy.Counting the number of microstates in phase space. Liouville’s Theorem (Derivation and description) Boltz H-theorem.

Module II: Ensembles

***Microcanonical Ensemble**:*Description, Probability distribution function, Different properties, Thermal and Mechanical interaction, Equation of state, Entropy of a classical ideal gas, Gibb’s paradox, spin 1/2 particles in an external magnetic field.

***Canonical Ensemble**:*System in contact with a heat reservoir, expression of entropy, canonical partition function, Equation of State, Average energy, Magnetization of spin 1/2 particles in an external magnetic field.Helmholtz free energy, fluctuation of internal energy.

***Grand Canonical Ensemble*:** System in contact with a particle reservoir, Chemical potential, Grand canonical partition function, fluctuation of particle number. Chemical potential of ideal gas. Entropy in terms of Grand partition function.

Module III: Quantum Statistical Mechanics

Introduction to density matrix, Quantum Liouville’s theorem, Density matrices for micro canonical, canonical and grand canonical systems, Simple examples of density matrices, Difference between energy and position space representation, particle in a box problem.

Identical particles, An ideal gas in quantum micro canonical ensemble, An ideal gas in other quantum mechanical ensemble. Statistics of occupation number.

Reference Books:

1. ***Introductions to Statistical Mechanics***;B.B.Laud
2. ***Statistical Physics (Allied Publishers)***; J. K. Bhattarjee:
3. ***Statistical Physics (Mc.Graw Hill)***; F.Reif:
4. ***Statistical Physics (Chapman and Hall/CRC)***; K.Hung
5. ***Statistical Mechanics***; R.K. Pathria:

CO-PO Correlation Matrix

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10
CO1	3	0	1	0	2	1	1	0	1	1
CO2	3	1	1	0	3	1	2	0	2	1
CO3	3	2	2	0	3	2	2	1	2	2
CO4	3	2	3	0	3	3	2	1	2	2
CO5	3	2	3	1	3	3	3	1	2	3
CO6	3	3	3	1	3	3	3	2	3	3

Paper Type: CC (Advanced Specialization)

Track: Astronomy and Astrophysics

Paper Name: Introduction to Astronomy and Astrophysics

Paper Code: PHY401
L T P – 3-0-1

Course Objectives:

1. To define the fundamental concepts of differential geometry and tensor calculus that are essential for understanding General Relativity.
2. To explain the principles of General Relativity, focusing on Einstein's field equations and the equivalence principle as foundational concepts.
3. To analyze the Schwarzschild solution and describe the properties of black holes, including their event horizons and singularities.
4. To apply the Friedmann-Robertson-Walker metric to various cosmological models and discuss the implications of cosmic microwave background radiation in the context of these models.
5. To conduct experiments and evaluate observations related to General Relativity, such as the detection of gravitational waves and the study of black hole phenomena.

Course Outcome:

1. **CO1: Recall** and define key astronomical concepts such as distance, mass, time scales, and celestial coordinate systems.
2. **CO2: Explain** the functioning of different types of telescopes and the principles of radiative transfer in astrophysics.
3. **CO3: Apply** astronomical techniques to measure stellar properties and interpret observational data.
4. **CO4**: **Analyze** the structure, energy dynamics, and processes of stellar formation and evolution.
5. CO5: **Evaluate** models of stellar evolution, including the formation of compact stars and the significance of supernovae.
6. **CO6: Design** a conceptual model explaining stellar formation, evolution, and the dynamics of the Milky Way.

Course Content:

Module I: Basic Concepts of Astronomical Scale and Positional Astronomy

Astronomical Distance, Mass and Time, Scales, Brightness, Radiant Flux and Luminosity, Measurement of Astronomical Quantities, Stellar Radii, Masses of Stars, Stellar Temperature, Celestial Sphere, Astronomical Coordinate Systems, Horizon System, Equatorial System, Diurnal Motion of the Stars, Measurement of Time, Sidereal Time, Apparent Solar Time, Mean Solar Time

Module II: Astronomical Techniques

Basic Optical Definitions for Astronomy, Types of Reflecting Telescopes, Telescope Mountings, Space Telescopes, Detectors and Their Use with Telescopes

Module III: Physical Principles

Gravitation in Astrophysics, Systems in Thermodynamic Equilibrium, Theory of Radiative Transfer, Optical Depth, Solution of Radiative Transfer Equation, Local Thermodynamic Equilibrium, Solar Parameters, Solar Photosphere, Solar Atmosphere, Chromosphere. Corona, Solar Activity, Basics of Solar Magneto-hydrodynamics, Origin of the Solar System, The Nebular Model, Tidal Forces and Planetary Rings, Stellar spectra and classification Structure

Module 4: Stellar Structure

Hydrostatic Equilibrium of a Star, Virial Theorem, Sources of Stellar Energy, Modes of Energy Transport, Simple Stellar Model, Polytropic Stellar Model, Basic composition of Interstellar medium, Interstellar Gas, Interstellar Dust, Formation of Protostar, Jeans criterion, Fragmentation of collapsing clouds, From protostar to Pre-Main Sequence, Hayashi Line

Module 5: Nucleosynthesis and Stellar Evolution

Cosmic Abundances, Stellar Nucleo-synthesis, Evolution of Stars, Supernovae, Basic Familiarity with Compact Stars, Equation of State and Degenerate Gas of Fermions, Theory of White Dwarf, Chandrasekhar Limit, Neutron Star Black Hole, Basic Structure and Properties of the Milky Way, Nature of Rotation of the Milky Way, Stars and Star Clusters of the Milky Way, Properties of and around the Galactic Nucleus

Reference Books:

1. ***Modern Astrophysics***; B.W. Carroll & D.A. Ostlie
2. ***Introductory Astronomy and Astrophysics***; M. Zeilik and S.A. Gregory
3. ***The physical universe: An introduction to astronomy***; F.Shu
4. ***Fundamental of Astronomy***; H. Karttunen
5. ***An introduction to Astro physics***; by BaidyanathBasu

Paper Name: Introduction to Cosmology

Paper Code: PHY406

L T P – 3-0-1

Course Objectives:

1. To describe the different types of galaxies and their morphological classifications, including spiral, elliptical, and irregular galaxies.
2. To explain the principles of relativity, encompassing both special and general relativity, and to discuss their implications on the nature of spacetime.
3. To analyze cosmological models, including the Robertson-Walker metric, and to explore various geometries of the universe.
4. To apply the concepts of physical cosmology to understand the thermal history of the universe and the significance of cosmic microwave background radiation in cosmological studies.
5. To evaluate observational data related to galaxies, cosmology, and relativity, and to discuss current research findings and theoretical models in these fields.

Course Outcome:

On completion of this course, the students will be able to

1. **CO1:** Recall fundamental concepts of galaxy morphology, Hubble's classification, and active galactic nuclei.
2. **CO2:** Explain the principles of special and general relativity, including spacetime curvature and gravitational effects.
3. **CO3:** Use the distance ladder and Hubble's law to analyze the large-scale structure and expansion of the Universe.
4. **CO4:** Differentiate between various cosmological models (open, closed, flat) using the Robertson-Walker metric.
5. **CO5:** Evaluate the physical implications of cosmic microwave background radiation and early Universe thermal history.
6. **CO6:** Develop conceptual models to explain phenomena like cosmic inflation, density perturbations, and the accelerating Universe.

Course Content:

Module I: Galaxies

Galaxy Morphology, Hubble's Classification of Galaxies, Elliptical Galaxies, Spiral and Lenticular Galaxies, The Milky Way Galaxy, Gas and Dust in the Galaxy, Spiral Arms, Classification and Behaviour of Active Galaxies, Emission Mechanisms Related to the Study of Active Galaxies, Unified Model of the Various Active Galaxies

Module II: Overview of Relativity

Principles of Relativity: Overview of Special Relativity, Spacetime interval and Lorentz metric four vectors, Introduction to general relativity (GR), Notions of curvature, Gravitation as a manifestation of the curvature of spacetime, Gravitational redshift and clock corrections, Orbits in strong gravity, light bending and gravitational lensing, Hydrostatic equilibrium in GR, Gravitational radiation

Module III: Cosmological Models

Universe at large scales, Homogeneity and isotropy, Distance ladder, Newtonian cosmology, Expansion and redshift, Cosmological Principle, Hubble's law, Robertson-Walker metric, Observable quantities – luminosity and angular diameter distances, Horizon distance, Dynamics of Friedman- Robertson-Walker models, Discussion of closed, open and flat Universes

Module IV: Physical Cosmology and Early Universe

Cosmic Distance Ladder, Hubble's Law (Distance- Velocity Relation), Clusters of Galaxies, Friedmann Equation and its Solutions, Thermal History of the Universe, Distribution functions in the early Universe – relativistic and nonrelativistic limits, Cosmic microwave background radiation (CMB), Anisotropies in CMB, Inflation, Origin and growth of Density Perturbations, Accelerating universe and type-Ia supernovae, The Intergalactic medium and reionization, Evolving vs. Steady State Universe

Reference Books:

1. ***An Introduction to Modern Cosmology***; Andrew Liddle
2. ***Introduction to Cosmology***; Matts Roos
3. ***Introduction to Cosmology***; Barbara Ryden

Paper Name: Introduction to General Theory of Relativity

Paper Code: PHY411

L T P – 3-0-1

Course Objectives:

1. To define key mathematical concepts essential for General Relativity, including tensors, Christoffel symbols, and the mathematical framework that supports them.
2. To explain the principles of General Relativity, focusing on Einstein's field equations and the concept of spacetime curvature and its physical implications.
3. To analyze the Schwarzschild solution, discussing its significance for understanding black holes, including characteristics such as event horizons and the effects of gravitational time dilation.
4. To apply cosmological models, particularly the Friedmann-Robertson-Walker metric, to examine the evolution of the universe and the role of cosmic microwave background radiation in cosmological studies.
5. To evaluate experimental tests of General Relativity, such as the detection of gravitational waves and observations of black holes, and to discuss their implications for ongoing research and understanding of the universe.

Course Outcome:

On completion of this course, the students will be able to

1. **CO1:** Recall fundamental concepts of tensors, manifolds, and the mathematical framework essential for General Relativity.
2. **CO2:** Explain the Equivalence Principle and the geometric interpretation of gravity in Einstein's theory.
3. **CO3:** Solve geodesic equations for different metrics, including Schwarzschild and Friedmann-Robertson-Walker metrics.
4. **CO4:** Analyze the implications of spacetime curvature on celestial mechanics, black hole properties, and cosmological phenomena.
5. **CO5:** Evaluate the experimental evidence supporting General Relativity, such as gravitational waves and solar system tests.
6. **CO6:** Formulate mathematical models to address contemporary problems in relativistic astrophysics and cosmology.

Course Content:

Module I: Mathematical Foundations
Introduction to differential geometry, Manifolds and coordinate systems, Tensors and tensor calculus, Covariant and contravariant tensors, Christoffel symbols and the metric tensor, Parallel transport and geodesics

Module II: Principles of General Relativity
Equivalence Principle, Geodesic equation and the principle of least action, Curvature of spacetime, Einstein's field equations, Newtonian limit and weak gravitational fields, Energy-momentum tensor and conservation laws

Module III: Schwarzschild Solution and Black Holes
Introduction to the Schwarzschild metric, Geodesics and orbits around a spherically symmetric mass, Event horizons and black hole singularities, Gravitational time dilation and redshift, Black hole thermodynamics and Hawking radiation

Module IV: Cosmology and the Big Bang
Introduction to cosmology, Friedmann-Robertson-Walker metric, Cosmological redshift and Hubble's law, Cosmic microwave background radiation, Early universe and inflation, Dark matter and dark energy

Module V: Experimental Tests and Applications
Solar system tests of General Relativity, Gravitational waves and LIGO/VIRGO detectors, Black hole observations and astrophysical phenomena, GPS and relativistic corrections, Modern developments and ongoing research

Reference Books:

1. ***A First Course in General Relativity***; Bernard F. Schutz
2. ***General Relativity: An Introduction for Physicists***; M.P. Hobson, G.P. Efstathiou, and A.N. Lasen
3. ***Gravitation***; Charles W. Misner, Kip S. Thorne, and John Archibald Wheeler
4. ***General Relativity***; Robert M. Wald
5. ***Spacetime and Geometry: An Introduction to General Relativity***; by Sean Carroll

Paper Type: CC (Advanced Specialization)

Track: Nanoscience

Paper Name: Nanomaterials and Fabrication Technology

Paper Code: PHY402
L T P – 3-0-1

Course Objectives:

1. To define the classifications of nanostructures, including one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) nanostructures, while explaining the principles of quantum confinement and its significance in nanotechnology.
2. To describe various synthesis methods for nanomaterials, differentiating between top-down and bottom-up approaches, and elaborating on specific techniques such as ball milling and chemical vapor deposition.
3. To analyze the size-dependent properties of nanomaterials, including changes in their chemical, optical, thermal, electrical, magnetic, and mechanical characteristics as a function of size.
4. To apply diverse characterization techniques to evaluate the properties of nanomaterials, including but not limited to electron microscopy, X-ray characterization, and UV-VIS spectroscopy.
5. To conduct hands-on experiments for synthesizing and characterizing nanomaterials, such as metal thin films and nanoparticles, while evaluating the impact of size reduction on their physical and chemical properties.

Course Outcome:

On completion of this course, the students will be able to

1. **CO1:** Recall the historical development, classifications, and basic concepts of nano-materials and nanoscale phenomena.
2. **CO2:** Explain various synthesis techniques and the fundamental principles governing na-nomaterial fabrication processes.
3. **CO3:** Utilize appropriate techniques for synthesizing and fabricating nanomaterials, such as thin films or nanoparticles.
4. **CO4:** Distinguish and evaluate the unique size-dependent physical and chemical proper-ties of nanomaterials.
5. **CO5:** Assess and interpret data from advanced nanomaterial characterization techniques

to determine material properties.

6. **CO6:** Design and execute experiments for the synthesis, characterization, and application of nanomaterials to address real-world challenges.

Course Content:

Module I: Introduction to Nanomaterials

Historical development, Classification of Nanostructures: 1D, 2D and 3D nanostructures (nanodots, thin films, nanowires and nanorods), Classification as per composition, Nanoscale forces, Bulk to Surface transition, Size effect: quantum confinement.

Module II: Nanomaterial Synthesis

Top down and Bottom up approach, Mechanical route synthesis: Ball milling. Vacuum deposition techniques: Physical vapor deposition (Thermal Evaporator, E-beam evaporator, sputtering (magnetron)-DC, RF), Pulsed LASER deposition, Atomic Layer Deposition, Hydrothermal/solvo-thermal synthesis of nanomaterials, Chemical vapor deposition synthesis: Plasma Enhanced Chemical Vapor Deposition. Precipitative synthesis: Hydrothermal/solvothermal methods, Sol-gel methods, Electro-chemical method: Electro-deposition technique, solution-growth based chemical synthesis: Fundamentals of nucleation and growth.

Module III: Properties of Nanomaterials

Size dependence of properties-Chemical Optical, Thermal, Electrical, Magnetic and Mechanical properties of nanomaterials.

Module IV: Nanomaterial characterization techniques

Limitation of optical microscopy and introduction to electron microscopy. Scanning and Transmission Electron Microscopy. Prospect of Scanning Probe Microscopies: Atomic Force, scanning tunneling microscopy, Fundamentals of X-ray characterization.

UV-VIS and IR spectroscopic techniques Mechanical characterization of nanophase Materials: Nano-indentation Technique.

List of Experiments:

Experiment-1: Deposition of metal thin films on glass substrate by thermal evaporation techniques.

Experiment-2: Synthesis of oxide semiconductor nanoparticles and study its band gap.

Experiment-3: Chemical synthesis of ferrite nanoparticles (Hydrothermal/ Sol Gel route)

Experiment-4: Study of microstructure of nanomaterials with optical microscopy.

Experiment-5: Synthesis of thin films by spin coating method.

(Or)

Effect of size reduction on the properties of nanomaterials

Books for References:

1.***Materials Science***, M.S.Vijaya, G.Rangarajan, Tata McGraw-Hill publishing company Ltd., New Dehli, 2014.
2.***Encyclopedia of Nanoscience and Nanotechnology***; 25-Volume Set, H. S. Nalwa American Scientific Publishers, USA, 2005.
3. ***Encyclopedia of Materials Characterization***, C. Richard Brundle, C. A. Evans, Jr., S. Wilson, Butterworth-Heinemann, Braille edition, 1992.
4. ***Introduction to Nanoscience and Nanotechnology***, K. K. Chattopadhyay and A. N. Banerjee Prentice Hall India, 2009.

Paper Name: Nanoelectronics and Nanophotonics

Paper Code: PHY407

L T P – 3-0-1

Course Objectives:

1. To describe the fundamental concepts and materials in nanoelectronics, including the transport mechanisms of electrons in low-dimensional structures and the principles of nanolithography for device fabrication.
2. To explain the operation and limitations of nanoscale MOSFETs and other nanoelectronic devices, focusing on quantum effects and their applications in molecular electronics and MEMS/NEMS systems.
3. To analyze the theoretical foundations of nanophotonics, including macroscopic electrodynamics, wave equations, and the behavior of evanescent fields in nanoscale environments.
4. To apply principles of nanophotonics to practical applications such as confocal microscopy, near-field optical microscopy, and surface plasmon resonance, utilizing simulation tools and experimental techniques for demonstration.
5. To conduct simulations and experiments on nanophotonic devices, including single-electron transistors, photonic crystals, and surface plasmonic devices, in order to investigate their functionalities and real-world applications.

Course Outcome:

On completion of this course, the students will be able to

1. **CO1**: **Recall** fundamental concepts of nanoelectronics and nanophotonics, including Moore's law, materials for nanoelectronics, and theoretical principles of nanophotonics.
2. **CO2**: **Explain** the electron transport in low-dimensional structures, quantum effects in nanoscale MOSFETs, and optical phenomena in nanoscale environments.
3. **CO3**: **Demonstrate** the ability to model and simulate nanoelectronic devices, such as single-electron transistors, and analyze optical properties of nanoscale devices using computational tools.
4. **CO4**: Critically **analyze** the limitations of nanoscale MOSFETs, the principles behind nanophotonic imaging techniques, and the behavior of light in periodic structures like photonic crystals.
5. **CO5**: **Evaluate** the performance of nanophotonic probes, nanoscale imaging techniques, and metamaterials for their suitability in specific applications such as microscopy and optical sensors.

6. **CO6: Design** and **develop** nanoelectronic and nanophotonic devices, such as photonic crystal-based sensors or surface plasmonic devices, for advanced technological applications.

Course Content:

Module I: Basics of Nanoelectronics

Introduction to Nanoelectronics, Moore's law, Materials for Nanoelectronics: Semiconductors, Carbon nanomaterials and nanotubes, Transport of electrons in low-dimensional structures – Electrons in quantum wells, Electrons in quantum wires and Electrons in quantum dots. Crystal growth and Nanolithography, molecular electronics, Micro-electromechanical and Nano-electromechanical system

Module II: Nanoelectronic devices: Basics and applications

Nanoscale MOSFETs- Challenges in miniaturization, quantum effects, thin oxides, random dopant fluctuations, tunnelling and subthreshold currents, power density, hot electron effects, fundamental limits of MOS operations, GaN based High Electron Mobility Field Effect Transistors, MOSFET to Single-electron-transfer devices, Coulomb Blockade, Resonant-tunneling diodes, Nanoelectronics for molecular biology: next generation DNA sequencing

Module III: Theoretical Foundations of Nanophotonics

Macroscopic electrodynamics, wave equations, time harmonic fields, Dyadic Green's function, Evanescent fields. Propagation and focusing of optical fields – field operators, paraxial approximation of optical fields, polarized electric and magnetic fields, focusing of fields, point spread function.

Module IV: Applications of Nanophotonics

Principles of confocal microscopy, near field optical microscopy, scanning near –field optical microscopy, Nanoscale optical microscopy – far field illumination and detection, near field illumination and far-field detection, far field illumination and near field detection, energy transfer microscopy. Near –field optical probes- dielectric probes- conical, tapered, tetrahedral, Aperture probes. Probe –sample distance control. Light emission and optical interactions in nanoscale environments- multipole expansion, radiating electric dipole, spontaneous decay, delocalized excitations, Quantum emitters, dipole emission near planar interfaces, Light in periodic structures: Photonic crystals and resonators, Surface Plasmon. Metamaterials

List of Experiments:

1. Computational simulation of single electron transistor using MATLAB.
2. Determine Numerical Aperture (NA) of a single mode optical fiber using scanning and visual method.
3. Simulation on Finite Element Method (FEM) based surface plasmonic devices

4. Modelling of Photonics crystal-based devices for various applications (Sensor/ Optical fiber laser etc.)

Reference Books:

1. ***Lessons from Nanoelectronics: A New Perspective on Transport (Lessons from Nanoscience: a Lecture Notes Series);***S. Datta, World Scientific, 2012
2. ***Introduction to Nanoelectronics: Science, Nanotechnology, Engineering, and Applications***; V. Mitin, V. Kochelap, and M. Stroscio, Cambridge University Press, 200
3. ***Introduction to nanotechnology***; C. P. Poole and F. J. Owens, John Wiley & Sons, 2003.
4. ***Principles of Nano-optics***; L Novotny and B Hecht, Cambridge University Press, 2006.
5. ***Introduction to Nanophotonics***; S V Gaponenko, Cambridge University Press, 2010.
6. ***Principles of nanophotonics***; MotoichiOhtsu, , CRC Press, 2008

Paper Name: Quantum Transport

Paper Code: PHY412

L T P – 3-0-1

Course Objectives:

1. To understand the characteristic length scales and properties of 2D Electron Gas, Quantum Wires, and Quantum Dots, facilitating a foundation for further exploration of low-dimensional systems.
2. To apply the tight-binding model to various systems, including Graphene, Graphene nanoribbons, and Fractal Geometries, in order to calculate energy dispersion and eigenstates, enhancing computational skills in solid-state physics.
3. To analyze transport mechanisms using the Landauer-Büttiker formalism, and compute transmission probabilities via different methods such as the Transfer Matrix and Green's Function, fostering a deeper understanding of quantum transport phenomena.
4. To evaluate quantum transport in closed systems by studying quantum interference effects, the Aharonov-Bohm effect, and persistent current phenomena, linking theoretical concepts to experimental observations.
5. To investigate electronic localization in quasi-crystals and disordered lattices, and apply models like the Aubry-Andre-Harper to study energy eigenstates in quasi-periodic systems, thereby exploring the implications of disorder in quantum mechanics.

Course Outcomes:

On completion of this course, the students will be able to

1. CO1: **Recall** fundamental concepts of quantum transport, including quantum confinement, characteristic length scales, and properties of quantum wires and dots.
2. CO2: **Explain** the tight binding theory, energy dispersion relations, and eigenstates in systems such as 1D ordered chains, graphene, and quasi-crystals.
3. CO3: **Apply** the Landauer-Büttiker formalism, waveguide theory, and transfer-matrix methods to calculate transmission probabilities in quantum transport systems.
4. CO4: **Analyze** quantum transport phenomena such as Aharonov-Bohm effects, persistent current phenomena, and magnetic susceptibility in closed quantum systems.
5. CO5: **Evaluate** localization properties of electronic states using tools like Lyapunov exponent, Shannon entropy, and inverse participation ratio in disordered and quasi-periodic systems.
6. CO6: **Design** and model quantum transport systems, such as Fibonacci lattices or Thue-

Morse chains, to investigate electronic localization and transport mechanisms.

Course Content:

Module I: Introduction to Length Scales

Introduction to the Characteristic Length scales, Mesoscopic observables in nanostructures, Nano-structures and Nano-devices, Quantum confinement, 2D Electron Gas and its properties, Lateral confinement in Quantum Wires and Quantum Dots.

Module II: Tight Binding Theory

Tight Binding Model in discrete Wannier basis. Energy dispersion relation and Eigenstates calculations in various linear systems like 1D ordered chain, alternating chain, Ladder network, 2D square lattice, Graphene, Graphene nano-ribbons (Zigzag and Armchair edge), Kagome Lattice, Lieb Lattice, Fractal Geometries etc.

Module III: Transport Mechanism

Conductance from Transmission, Landauer-Büttiker formalism for open system transport for Two-terminal and Multi-terminal quantum systems, Landauer formula. Calculation of Transmission probability by (i) Wave-guide Theory, (ii) Transfer-Matrix Method, (iii) Green's Function Technique. S matrix and T matrix, Fisher-Lee relation.

Module IV: Quantum Transport

Quantum Transport in Closed systems, Quantum Interference, Aharonov-Bohm Effect, Persistent Current Phenomena, Drude Weight, Magnetic susceptibility, Calculation of persistent current by (i) Derivative Method, (ii) Green's function Technique.

Module V: Idea of Localization and Quasi crystals

Electronic Localization, Inverse Participation Ratio, Lyapunov Exponent, Shanon entropy, Electronic localization in Random disordered lattice, Quasi-crystals, Aubry-Andre-Harper Model. Study of energy Eigenstates in various Quasi-periodic systems like Fibonacci lattice (Golden Mean sequence, Silver mean, copper mean etc.), Thue-Morse lattice, Period Doubling chain etc.

Reference Books:

1. ***Lessons from Nanoscience: A Lecture Note Series***; Supriyo Dutta, World Scientific (2012).
2. ***Quantum Transport- Atom to Transistor***; Supriyo Dutta, Cambridge University Press (2005).
3. ***Introduction to Nanoelectronics***; V. Mitin, V. Kochelap, M. Stroscio,Cambridge University Press (2008).
4. ***Nanoelectronics and Information Technology***: Advanced Electronic Materials and Novel Device; Rainer Waser, Wiley-VCH (2003).

5. ***Nanoelectronics and Nanosystems***; Karl Goser, Peter Glosekotter, Jan Dienstuhl,Springer (2004).

6. ***Introduction to Nanoelectronics: Science, Nanotechnology, Engineering &Applications;*** Vladimir. V. Mitin.

Track: Optoelectronics and Photonics: Principles and Practices

Paper Name: Guided Wave Optics

Paper Code: PHY403
L T P – 3-0-1

Course Objectives:

1. To describe the fundamental concepts and materials in nanoelectronics, including the transport mechanisms of electrons in low-dimensional structures and the principles of nanolithography for device fabrication.
2. To explain the operation and limitations of nanoscale MOSFETs and other nanoelectronic devices, focusing on quantum effects and their applications in molecular electronics and MEMS/NEMS systems.
3. To analyze the theoretical foundations of nanophotonics, including macroscopic electrodynamics, wave equations, and the behavior of evanescent fields in nanoscale environments.
4. To apply principles of nanophotonics to practical applications such as confocal microscopy, near-field optical microscopy, and surface plasmon resonance, utilizing simulation tools and experimental techniques for demonstration.
5. To conduct simulations and experiments on nanophotonic devices, including single-electron transistors, photonic crystals, and surface plasmonic devices, in order to investigate their functionalities and real-world applications.

Course Outcome:

On completion of this course, the students will be able to

1. **CO1**: Recognize fundamental concepts of guided wave optics, including optical fiber waveguide modes, numerical aperture, V-parameters, and types of fibers.
2. **CO2**: Explain the mechanisms of dispersion, attenuation, non-linear effects, and amplification in single-mode fibers and optical communication systems.
3. **CO3**: Apply principles of coupled mode theory and fiber optic communication to design systems such as multiplexers, demultiplexers, and erbium-doped fiber amplifiers.
4. **CO4**: Analyze the performance of optical networks, including linear optical networks, SONET, SDH, and the impact of nonlinear effects on fiber communication systems.
5. **CO5**: Evaluate the efficiency of fiber optic sensors for real-world applications, considering design constraints, fabrication techniques, and environmental factors.

6. **CO6:** Design and simulate advanced optical communication systems and sensors, integrating technologies such as photonic integrated circuits and energy-aware optical networks.

Course Content

Module I: Electromagnetic Modes and Waveguides

Electromagnetic Modes in Planar waveguides and Cylindrical Waveguides, Basic characteristic of Optical Fiber Waveguides – Ray theory- Acceptance angle, Numerical aperture, skew rays, V-Parameters, Power Distribution and Confinement Factor, Goos-Haenchen shift, cutoff wavelength, attenuation, bending loss, mode field diameter birefringence measurements, OTDR, Index profile, effect of material dispersion of optical fibers, Step index and Graded index Fibers-Single Mode and Multimode fibers, Photonic Crystal Fibers, other specialty optical fibers

Module II: Single Mode Fibres and Limitations

Dispersion in single mode fibers, limitations, Fiber losses attenuation coefficient, Nonlinear optical effects-SRS, SBS, SPM, modal birefringence and polarization maintaining fibers, Coupled mode theory and applications

Optical Fiber Amplifiers- Optical amplification, Erbium doped Fiber Amplifier, Fiber Raman Amplifier, Wide band amplifiers, Optical integrated circuits.

Time Division Multiplexing, Frequency Division Multiplexing (FDM), Dense Wavelength Division Multiplexing (DWDM), Coarse Wavelength Division Multiplexing (CWDM)Passive Components, Multiplexers and Demultiplexers, Active components, Topologies and Architectures

Module III: Optical Fibre Communication

Optical Fiber Communications- Essential components of Fiber Communication System, Types of Topologies, Types of Networks, Submarine cables, Open system interconnection (OSI), System Architectures, Line coding in Optical Links, Error control or Correction.

Performance of Passive Linear Optical Networks, Performance of Star Optical Network, SONET and SDH, Metro and Long-Haul optical Networks, Nonlinear effect, Dispersion, Solitons.

Optical Fiber Sensors- Essential components of Fiber Optic Sensor (OFS), Fiber optics cables and connectors, Splicer, Classification of OFS, res, Applications of FOSs.

Various OFS fabrication/ modeling techniques, Real application of Conventional and specialty optical fiber based sensor

List of Experiments:

Experiment 1:
Determine Numerical Aperture (NA) of a single mode optical fiber using scanning and visual method.

Experiment 2
Study of optical fiber-based pressure/turbidity/displacement sensor

Experiment 3
Simulation on thin film coated optical fiber-based surface plasmon resonance (SPR) refractive index sensor

Experiment 4

- Design of Optical fiber communication network
- Integration of Optical Network with Radio Access Network
- Multi-Tenant oriented Optical Network Virtualization and Slicing
- Inter or Intra Data Center Connection in Edge Computing
- Energy-Aware Communication in Optical Network
- Improved Design and Optimization of Optical Network
- Photonic Integrated Circuits Manipulation in Optical Networks

Experiment 5

Modelling of Photonic sensor using Finite Element Method.

Reference Books:

1. ***Guided Wave Optics and Photonic Devices***; Shyamal Bhadra and AjoyGhatak, , CRC Press, 1st edition, 2013.
2. ***Fundamentals of Guided-Wave Optoelectronic Devices***; William S. C. Chang, CambridgeUniversity Press, 2011.
3. ***Fiber Optic Communication***; Joseph C Palais, Pearson Prentice Hall, 2013
4. ***Optical Fiber Communications: Principles and Practice***; J M Senior, , Pearson 2011
5. Zujie Fang, Ken Chin, Ronghui Qu, Haiwen Cai, Kai Chang, Fundamentals of Optical Fiber Sensors, Wiley, ISBN: 978-0-470-57540-6, 2012
6. Eric Udd, William B. Spillman Jr., Fiber Optic Sensors: An Introduction for Engineers and Scientists, Wiley, ISBN: 9781118014080
7. Introduction to Fiber Optics, Ghatak and Thyagarajan, Cambridge University Press (2009)

Paper Name: Nonlinear Optics and Bio-Photonics

Paper Code: PHY408

L T P – 3-0-1

Course Objectives:

1. To explain the principles of nonlinear optical susceptibility and their significance in optical interactions, including processes such as second harmonic generation and phase matching.
2. To apply quantum mechanical theories, including Schrödinger equation and density matrix methods, for the calculation of nonlinear optical susceptibility in various materials.
3. To analyze parametric processes such as third-order nonlinear optics and Kerr-type nonlinearities, with a focus on four-wave mixing and optical breakdown phenomena.
4. To evaluate the effects of light-tissue interactions in biological systems, utilizing imaging techniques such as fluorescence microscopy and confocal microscopy for practical applications.
5. To demonstrate and refine experimental techniques for studying optical solitons and nonlinear effects in ultrafast and intense field optics.

Course Outcome:

On completion of this course, the students will be able to

CO1: Define fundamental concepts of nonlinear optics, such as second harmonic generation, phase matching conditions, and optical parametric oscillators.

CO2: Describe the quantum mechanical basis of nonlinear optical susceptibility and processes like stimulated Brillouin and Raman scattering.

CO3: Use nonlinear optical principles to solve problems related to Kerr nonlinearities, optical breakdown, and self-focusing in practical scenarios.

CO4: Analyze ultrafast nonlinear optical phenomena, including multiphoton absorption, optical solitons, and their implications in high-intensity fields.

CO5: Assess the impact of light-tissue interactions and the effectiveness of advanced microscopy techniques like confocal and two-photon microscopy for biological imaging.

CO6: Design advanced optical systems and imaging technologies tailored for biophotonics applications in medical diagnostics and research.

Course Content:

Module I: Nonlinear Optics

Nonlinear optical susceptibility, wave equation description of nonlinear optical interactions – Sum frequency generation, Difference frequency generation, Second Harmonic generation, Phase matching condition, Optical parametric Oscillators

Module II: Quantum Mechanical theory of Nonlinear Optics

Quantum mechanical theory of nonlinear optical susceptibility- Schrodinger equation calculation, density matrix calculation.

Spontaneous light scattering and acousto-optic, Stimulated Brillouin Scattering, Stimulated Rayleigh Scattering, Stimulated Raman Scattering

Module III: Harmonic generation and Kerr type

Second harmonic generation, parametric processes, 3rd order nonlinear optics, Kerr type nonlinearities, 4-wave mixing, self-focusing collapse, optical breakdown, two beam coupling, electro optics and photorefractive effects, optically induced damage and multiphoton absorption

Ultrafast and intense field nonlinear optics and optical solitons.

Module IV: Light-tissue and Cell interactions

Light-tissue and biological cell interactions and light induced effects in biological systems.
Basic principles of optical imaging and spectroscopy systems. Principles of standard optical microscopy/fluorescence microscopy/endoscopy and instrumentation. Confocal microscopy: Principles and Instrumentation and Applications. Two-Photon and Multi-photon Microscopy.

Reference Books:

1. ***Nonlinear optics***, second Edition, Robert W Boyd, Academic Press (2003).

2. ***Photonics-Optical Electronics in Modern communications***, A Yariv and P Yeh, Sixth edition, Oxford University Press (2007).

3. ***The Principles of nonlinear Optics***, Y R Shen, Wiley-Interscience, 1991.

4. ***Handbook of Nonlinear Optics***, R L Sutherland, Marcel Dekker, 1996.

5. ***Biomedical Photonics Handbook*** by Tuan Vo-Dinh, CRC Press, 2003.

6. ***Introduction to Biophotonics*** by P.N. Prosad, John-Wiley 2003.

Paper Name: LASER and Optoelectronic Devices

Paper Code: PHY413

L T P – 3-0-1

Course Objectives:

1. To explain the fundamental principles of laser action, including atomic energy levels, mechanisms behind laser radiation, and advanced concepts like Q-switching, mode locking, and population inversion.
2. To describe and differentiate between various types of laser systems, such as continuous wave (CW) lasers, pulsed lasers, and semiconductor lasers, and to discuss their industrial and scientific applications, as well as safety protocols for laser handling.
3. To analyze the application of lasers across diverse fields, including communications, material processing, and biomedical technologies, with a focus on understanding their practical uses.
4. To evaluate the working principles of photovoltaic cells and optical detectors, including performance metrics and noise characteristics, enhancing students' knowledge of photodetector systems.
5. To conduct experiments that assess the characteristics of laser beams, optoelectronic devices, and the behavior of photodetectors and solar cells, thereby reinforcing the theoretical knowledge through hands-on learning.

Course Outcome:

On completion of this course, the students will be able to

CO1: Recall fundamental concepts of laser radiation, including the quantum theory of atomic energy levels, laser action, and the properties of different types of lasers such as CW and pulsed lasers.

CO2: Describe the working principles of various laser systems (e.g., Ruby, Nd:YAG, fiber lasers) and their components, including population inversion and the function of optical resonators.

CO3: Apply the principles of laser radiation and optoelectronic devices in real-world applications such as communication systems, material processing, and biomedical applications like laser tweezers and LIDAR.

CO4: Analyze the performance of semiconductor photodetectors and optical receivers, including evaluating their parameters, noise, and Bit Error Rate (BER) in communication systems.

CO5: Evaluate the efficiency and application of photovoltaic cells and optical amplifiers, such as semiconductor optical amplifiers and fiber Raman amplifiers, in renewable energy and communication technologies.

CO6: Design and model optoelectronic systems integrating lasers, photodetectors, and optical amplifiers for advanced applications in communication, manufacturing, and biomedical fields.

Course Content:

Module I: Quantum Theory of Laser Radiation

Quantum Theory of Atomic Energy Levels, Radiative and Nonradiative decay of excited state atoms, Emission Broadening and linewidth, Radiation and Thermal equilibrium, properties of laser radiation, and laser safety; Principle of Laser action and basic Laser components, Population Inversion, Einstein's A and B coefficients, Optical Resonator: Quality Factor, Q-switching, Mode locking

CW lasers systems: Ruby-, Nd:YAG- and Nd:Glass lasers, DPSS lasers, fiber lasers, gas lasers,
Pulsed lasers: ns, ps, and fs lasers, excimer, dye, X-ray and free-electron lasers;
Semiconductor lasers: DH, QW, QCL, VCSEL, DFB and DBR lasers; Quantum-well Lasers

Module II: Application of Lasers in Storage and Communication

Application of lasers in data storage, communication and information technology; Principle of holography; Laser applications in optical metrology; Surface profile and dimensional measurements; Laser Applications in material processing and manufacturing; 3D-printing, marking, drilling, cutting, welding, hardening and manufacturing; Laser Doppler velocimetry, LIDAR, laser spectroscopy, LIF, LIBS, Bio-medical applications of lasers, Laser tweezers and applications, laser applications in defence.

Module III: Photovoltaics and applications

Principle of Photovoltaic Cell, Basic Model of Solar cell, Dye-Sensitized Cells, Application of Photovoltaic Cell. Principle of Photonic detection. Optical Receiver, Principles of Semiconductor photodetectors, Performance parameters of Photodetectors, noise of photodetectors, Types of optical detectors, Receiver analysis, BER of an Ideal Optical Receiver
Optical Amplifiers: Semiconductor optical Amplifiers, Fiber Raman Amplifier (FRA), Application, Optical Switches (MEMS, MOMS etc.)

List of Experiments:

Experiment 1
Determine the peak power and beam divergence of Laser beam.

Experiment 2

Study characteristic of Optoelectronic devices.
i) Study of response characteristic of a solar-cell using Laser light.
ii) Study of V-I characteristic of LDR. Also study the response characteristic of LDR.
iii) Study of V-I characteristic and response characteristic of a phototransistor.
iv) To study the response characteristic of a photodiode.
v) To study response characteristic of an opto-coupler.

Reference Book:

1. ***Laser Fundamentals***; W.T. Silfvast, Second Edition, Cambridge University Press, 2004
2. ***Principles of Lasers***; O. Svelto, Fourth edition, Springer, 1998
3. ***Photonics: Optical Electronics in Modern Communications***; A. Yariv and P. Yeh, Sixth Edition, Oxford University Press, 2007
4. ***Semiconductor Optoelectronic devices***; Pallab Bhattacharya, Prentice Hall of India, 1995
5. ***Semiconductor Optoelectronics***; Jasprit Singh, Tata Mc Graw Hill, 1995
6. ***Optoelectronics - an Introduction***; Wilson and Hawkes, Prentice Hall, 1998

Paper Type: CC (Advanced Specialization)

Track: Condensed Matter Physics

Paper Name: Properties of Solids I

Paper Code: PHY404
L T P – 3-0-1

Course Objectives:

1. To explain the dielectric function in solids and its importance, focusing on concepts such as dielectric losses, Kramer's-Kronig relations, and exciton-polaritons, providing a foundation for understanding electronic interactions in materials.
2. To analyze the electronic properties of materials using theoretical models like the Nearly Free Electron Model and Tight Binding Model, with emphasis on effective mass, excitons, and quantum confinement in low-dimensional systems.
3. To examine transport properties in bulk and mesoscopic systems, focusing on electrical and thermal conductivity, quantized conduction, and the Landauer-Buttiker formulation, to understand how materials behave at different scales.
4. To compare the effects of temperature on various properties, including Fermi gases, band bending, heterojunctions, and two-dimensional electron gases, helping students grasp how low-dimensional systems respond to temperature variations.
5. To apply theoretical models to explore advanced phenomena such as the Quantum Hall Effect, Spin Hall Effect, persistent current, and conduction fluctuations, deepening understanding of mesoscopic and quantum systems.

Course Outcome:

On completion of this course, the students will be able to

CO1: Remember (Knowledge)
Recall key concepts related to the dielectric and optical properties of solids, including the dielectric function, interband transitions, and ferroelectricity, and identify the various types of polaritons (Phonon-Polaritons, Exciton-Polaritons).

CO2: Understand (Comprehension)
Explain the fundamental principles behind the electronic properties of solids, such as nearly free electrons, effective mass, excitons, and quantum confinement, and describe the role of heterojunctions and band bending in semiconductor devices.

CO3: Apply (Application)

Apply the concepts of dielectric and electronic properties to explain real-world phenomena such as absorption in insulators, the formation of superlattices, and the behavior of the 2D electron gas in mesoscopic systems.

CO4: Analyze (Analysis)
Analyze the transport properties of solids, including electrical and thermal conductivity, resistivity, and electron transport in low-dimensional systems using models like the Landauer-Büttiker formulation, and understand the key features of mesoscopic systems.

CO5: Evaluate (Evaluation)
Evaluate the effects of quantum confinement, disorder, and temperature on the density of states in confined systems, and critically assess phenomena such as conduction quantization, persistent currents, and the spin Hall effect in solid-state systems.

CO6: Create (Synthesis)
Design experiments or computational models to study transport properties in mesoscopic and low-dimensional systems, and predict the behavior of charge carriers in quantum confined materials under varying conditions (e.g., temperature, applied fields).

Course Content:

Module I: Dielectric and Optical properties of solids:

The dielectric function: the dielectric function for a harmonic oscillator, dielectric losses of electrons, Kramer's-Kronig relations; Real and imaginary parts of dielectric functions, Interband transition, direct and indirect transition; Absorption in insulators, Ferroelectricity, Soft Modes, Polaritons, Phonon-Polaritons, Lyddane-Sachs-Teller relation, Exciton-Polaritons.

Module II: Electronic properties:

Recapitulations of Nearly Free Model and Tight Binding Model, effective mass, excitons, Metals and Fermi gas, Fermi Gas at $T = 0$, Fermi Gas at finite temperature, Band Bending and Hetero-junctions, Quantum confinement, Density of States in Quantum-Confined systems, Super lattices, Disorder in quantum confined systems, The Two-Dimensional electron gas.

Module III: Transport properties

Recapitulation of transport properties in bulk and B-E equation, Electrical and Thermal conductivity, Origin of resistivity, Introduction to mesoscopic systems, idea of length scales, Characteristic features of low-dimensional systems: Conduction quantization, Conduction fluctuation, persistent current etc. Formulation to study electron transport phenomena: Landauer-Buttiker formulation (Qualitative discussions only). Landau band and Quantum Hall effect, Spin Hall Effect (Qualitative discussions only).

Reference Books

1. ***Optical Properties of Solids***; Mark Fox, Oxford Master series
2.***Solid State Physics: An Introduction to Theory and Experiments***; H. Ibach and H. Luth:
3. ***Solid State Physics: Essential Concepts***; avid W. Snoke.
4. ***Principles of the Theory of Solids***; J.M. Ziman:
5. ***Electronic Transport in Mesoscopic systems***; Supriyo Datta, Cambridge Universuty Press
6. ***Quantum Transport: Atom to Transistor;*** Supriyo Datta, Cambridge Universuty Press
7. ***Lessons from Nanoelectronics***; Supriyo Datta

Paper Name: Material Science

Paper Code: PHY409

L T P – 3-0-1

Course Objectives:

1. To describe the structure and bonding in various materials, including crystalline, amorphous, and advanced materials such as metals, semiconductors, ceramics, and polymers, establishing a foundational understanding of their material properties.
2. To explain the significance of phase diagrams, phase transformations, and the properties of alloys, focusing on binary and ternary systems, to provide insights into material behavior during phase changes.
3. To analyze the electronic properties and structures of different carbon-based materials, such as graphene, diamond, fullerenes, and carbon nanotubes, emphasizing their unique characteristics and potential applications.
4. To examine the role of defects in solids, including dislocations and color centers, and assess their impact on the mechanical, electrical, and optical properties of materials.
5. To conduct hands-on experiments on semiconductor materials, such as band-gap determination, Hall effect, and magneto-resistance measurements, and analyze experimental results to reinforce theoretical concepts.

Course Outcome:

On completion of this course, the students will be able to

1. **CO1**: Recall the fundamental concepts of crystalline and amorphous structures, types of bonding, and the properties of various material categories including metals, semiconductors, ceramics, and polymers.

2. **CO2:** Explain the concepts of phase diagrams, phase transformations, and solid solutions in alloys, and describe the formation and characteristics of advanced materials like composites and optoelectronic materials.

3. **CO3:** Apply the phase rule and lever rule to analyze and interpret phase diagrams for single and multicomponent systems, including eutectic systems.

4. **CO4:** Analyze the structure, properties, and electronic characteristics of carbon-based materials like graphene, diamond, and carbon nanotubes, and compare their applications.

5. **CO5:** Evaluate the impact of defects in solids on material properties by examining lattice imperfections, dislocation densities, and their influence on hardness and color centers.

6. **CO6:** Design and conduct experiments to measure material properties such as bandgap energy, Hall coefficient, and magnetoresistance, and interpret the results to propose im-

provements in material applications.

Course Content:

Module I: Recapitulations of Structure & bonding in solids

Crystalline and amorphous materials. Crystal structure of solids, Bravais lattice, Symmetry operation. Introduction to space group and point group. Single crystals, polycrystalline and nano-crystalline solids. Interatomic forces and types of bonding (Ionic Bonds, Covalent Bonds, Metallic Bonds, Hydrogen Bonds and Vander Waal's Bonds). Introduction to metallic materials and semiconductor materials, Properties of Dielectric material, Properties of ceramics & polymers, fundamentals of magnetic materials. Advanced materials: Composite materials, Smart materials, solar energy materials, Optoelectronic materials).

Module II: Solid solutions and Alloys

Phase diagrams: Gibb's phase rule, Single component systems, Eutectic phase diagram, lever rule. Study of phase diagrams, phase transformation Nucleation kinetics and growth. Introduction to Haussler alloy: binary and Ternary

Module III: Different form of Carbon Materials

Graphene, Diamond and fullerenes, Carbon Nano Tube (Density of States, Elementary electronic properties and band structure), Single wall and multiwall carbon nanotube.

Module IV: Study of Defects in Solids

Idea of closed packed structure, lattice constant/cell volume, Imperfection in solids, Different dimension of defects: linear defects, Planar defects, Volume defects, Formation of colourcentres.

Dislocations: Burger vectors, Dislocation densities, Slip, A brief discussion on hardness of materials/alloys.

List of Laboratory Experiments:

1. Determine energy band-gap a semiconductor by measuring temperature dependence of reverse saturation current of a junction diode

2. Determine of Hall-coefficient of a semiconductor.

3. Determine magneto-resistance of a semiconductor.

4. Determination of Current voltage characteristics of a CdS photo resistor.

Reference Books:

1. ***Introduction to Solid State Physics***; C. Kittel, Wiley Eastern Ltd, 2005.
2. ***Materials Science and Engineering: A First Course***; V. Raghavan, Prentice Hall, 2006
3. ***Solid State Physics***; A.J. Dekker, Macmillan & Co, 2000.
4. ***Essentials of Solid-State Physics***; S. P. Kuila, New Central Book Agency, 2013.

Paper Name: Properties of Solids II

Paper Code: PHY414

L T P – 3-0-1

Course Objectives:

1. To describe the fundamental concepts of magnetic systems, including spin-spin interactions, magnons, and spontaneous magnetization, establishing a foundational understanding of magnetism in materials.
2. To explain the thermodynamics of magnons and spin-waves, particularly in ferri- and antiferromagnetic materials, and explore the Ising model for magnetic systems.
3. To analyze the phenomena of superconductivity, focusing on key concepts such as Cooper pairing, the BCS wave function, and the Meissner effect, to develop an in-depth understanding of superconducting materials.
4. To evaluate the Josephson effect and investigate novel high-temperature superconductors using the Ginzburg-Landau theory and Bogoliubov transformation, applying advanced theoretical models to real-world materials.
5. To explore the significance of topological phases of matter, including topological insulators, superconductors, and Chern insulators, by applying the SSH Hamiltonian, and studying the unique properties of these materials.

Course Outcome:

On completion of this course, the students will be able to

CO1: Recall fundamental concepts related to spin systems, magnetic interactions, and superconductivity, including terminologies like spin waves, magnons, and Cooper pairing.

CO2: Explain the principles of magnetism, ferromagnetism, antiferromagnetism, and superconductivity, focusing on phenomena like spontaneous magnetization, domain walls, and the Meissner effect.

CO3: Apply theoretical models such as the Ising Model and Ginzburg-Landau theory to solve problems related to spin-spin interactions, magnetic domains, and superconducting materials.

CO4: Analyze the physical properties of superconductors, including their excitation spectra, magnetic effects, and quasiparticle behavior, and evaluate their dependence on temperature and magnetic fields.

CO5: Evaluate experimental techniques for studying magnon spectra, spin dephasing, and the Josephson effect, and assess the practical implications of these phenomena in real-world applications.

CO6: Design and simulate models to explore topological phases of matter, including topological insulators, superconductors, and SSH Hamiltonians, using concepts like Chern numbers and Zak phases.

Course Outcome:

Module I: Spin and Magnetic Systems:

Origin of the exchange interaction, Spin-waves in ferromagnets, magnons, Spontaneous magnetization, thermodynamics of magnons, Spin-waves in lattices with a basis, ferri- and Antiferromagnetism, Measurement of magnon spectrum, Stoner's criterion for metallic ferromagnets, The Ising Model, Domain and Domain walls, Spin-spin Interactions, Spin flip and Spin dephasing.

Module II: Superconductivity:

Superconductors, Constructing Bosons from Fermions, Cooper pairing, BCS wave-functions, Excitation spectrum of a superconductor, Magnetic effects of a superconductor, Bogoliubov transformation notion of quasiparticles, Ginzburg-Landau theory and London equation, Meissner effect, Type-II superconductors characteristic length, Josephson effect, Novel High Temperature" superconductors, Josephson Junctions, Metal-Superconductor junction, Andreev Reflection.

For Project:

Topological Phases of Matter

Significance of Topological phases, Topological insulator and topological superconductor. SSH Hamiltonian, Winding number and edge states, Symmetries: time-reversal, Particle-hole and Chiral symmetries, Chern no and Zak phase. TI in higher dimension and Chern insulators.

Reference Books

1. ***Magnetism in Condensed Matter (Oxford Master Series in Condensed Matter Physics)*** – Stephen Blundell
2. ***Introduction to Superconductivity***: v. 1 (Dover Books on Physics)- Michael Tinkham
3. ***Introduction to topological Phases in Condensed Matter***; Adolfo G. Grushin

Paper Type: CC (Advanced Specialization)

Track: Biomedical Instrumentation

Paper Name: Physics for Medicine

Paper Code: PHY405

L T P – 3-0-1

Course Objectives:

1. To describe the organization and structural differences between prokaryotic and eukaryotic cells, and to understand the composition of tissues in the human body.
2. To explain how light interacts with biological tissues, including key phenomena such as absorption, scattering, and the optical properties of skin layers and blood.
3. To analyze the dynamics of biomolecules, including diffusion, osmosis, and surface tension, and their relevance to biological processes.
4. To evaluate thermodynamic principles in living systems, with a focus on energy conservation, entropy, and Gibbs free energy in biological contexts.
5. To apply the principles of biomechanics and the electrical properties of tissues to investigate human body movement and neuron excitability.

Course Outcome:

On completion of this course, the students will be able to

CO1: Recall fundamental concepts of cell organization, tissue structure, and their physical properties relevant to medical applications.

CO2: Explain the interaction of light with biological tissues, including absorption, scattering, and the spectral properties of key biomolecules.

CO3: Demonstrate the application of diffusion laws, osmosis, and transport phenomena to understand the dynamics of biomolecules in living systems.

CO4: Analyze the thermodynamic principles of living systems, such as energy conservation, entropy, and coupled reactions, to explain biological processes.

CO5: Evaluate the mechanics of human motion using principles of statics, dynamics, and biomechanics to understand kinematic and kinetic measurements.

CO6: Design equivalent circuit models to represent excitable membranes and simulate ionic conductance in neuron and membrane systems.

Course Content:

Module I: Cell and Tissue

Cell Organization Cell as the basic structural unit, Origin & organization of Prokaryotic and Eukaryotic cell, Cell size & shape, Fine structure of Prokaryotic & Eukaryotic cell organization (Bacteria, Cyanobacteria, plant & Animal cell), Internal architecture of cells, Connection between cell & its environment, Extracellular Matrix, Kinetics of cell growth, Structure and type of tissues in human body.

Module II: Tissue Optics

Light-matter interaction: absorption, scattering, reflection, refraction, luminescence, interference, polarization; their physical models and mechanisms. Specific features of living tissues from the point of optics. Relations of scattering and absorption in tissues -different interaction of lasers with tissues – Thickness and optical properties of appropriate skin layers - Skin pigments (melanin, bilirubin, carotene, hemoglobin) and their spectra - Composition of blood. Spectral properties of erythrocytes, thrombocytes and blood plasma - Differences between oxygenated and deoxygenated hemoglobin absorption spectra.

Module III: Dynamics of biomolecules

Biological importance of Diffusion, Laws of diffusion, Active transport, Facilitated diffusion, Osmosis, Osmotic pressure, Osmoregulation, Viscosity and biological importance, Surface tension, Factors influencing surface tension.

Module IV: Thermodynamics of living systems

Conservation of energy in living systems, Entropy and Life, Gibbs and Standard free energy, Equilibrium constant, Coupled reactions.

Module V: Statics and kinematics of the body

Forces, moments, angular momentum, Rigid Body Mechanics, Musculoskeletal Anatomy, Basic Statics and Joint Mechanics (elbow, shoulder, spine, hip, knee, ankle), Basic Dynamics to Human Motion: Review of linear and angular kinematics; Kinetic equations of motion; Work & energy methods; Momentum methods; Examples in biomechanics; Modern kinematic measurement techniques; Applications of human motion analysis

Module VI: Electrical properties of excitable membranes

Basic electricity and electric circuits; Neurons as conductors of electricity; Equivalent circuit representation; Electrical properties of excitable membranes: Membrane conductance, linear and nonlinear membrane, ionic conductance, current-voltage relations; Ion movement in excitable cells: Physical laws, Nernst-Planck Equation.

Reference Books:

1. ***Physics of the Human Body***, Herman, I.P. (2007), Springer. ISBN: 978-3540296034
2. ***Physics of the Body***, Cameron, J. R., Skofronick, J. G. and Grant, R. M. (1999), , Medical Physics Publishing, 2nd Ed., ISBN: 978-0944838914
3. ***Physics in Biology and Medicine***; Davidovits, P., (2008), , 3rd Edition, Elsevier/Academic Press, ISBN: 978-0123694119.

Paper Name: Biomedical Instrumentation

Paper Code: PHY410
L T P – 3-0-1

Course Objectives:

1. To describe the sources of biomedical signals and the essential design constraints associated with medical instrumentation systems.
2. To explain the working principles and applications of diagnostic instruments such as oximeters, spirometers, and blood pressure measurement systems in healthcare.
3. To illustrate the need for therapeutic instruments, including pacemakers, defibrillators, and ventilators, and explain their operational mechanisms.
4. To analyze the principles behind cutting-edge biomedical technologies, such as wearable sensors, AI-driven healthcare solutions, and telemedicine applications.
5. To conduct experiments using biomedical instruments like ECG machines, pulse oximeters, and spirometers, and develop skills in measuring and calibrating health parameters.

Course Outcome:

On completion of this course, the students will be able to

CO1: Describe the fundamental principles of biomedical signals and instrumentation, including the sources of bioelectric signals and their applications in medical devices.

CO2: Explain the operational principles and functionalities of diagnostic instruments such as oximeters, spirometers, and blood pressure monitoring systems.

CO3: Demonstrate the use of therapeutic instruments like pacemakers, defibrillators, and anesthesia machines, and interpret their clinical applications.

CO4: Evaluate the performance and constraints of biomedical devices through calibration and experimental data analysis, considering patient safety and ethical standard.

CO5: Assess the advantages and limitations of emerging trends in biomedical instrumentation, including wearable sensors, AI-driven healthcare, and telemedicine.

CO6: Design a basic biomedical instrumentation system or experimental protocol that integrates medical device safety standards and clinical requirements.

Course Content:

Module I: Introduction to Biomedical Signals and Instrumentation

Sources of biomedical signals, basic medical instrumentation system, PC based medical instruments, General constraints in design of medical instrumentation systems, origin of bioelectric signals, Electrocardiogram (ECG) -block diagram, ECG leads, effects of artifacts, multi-channel, ECG machine, Phonocardiograph-origin of heart sounds, microphones and amplifiers for PCG, Electroencephalogram (EEG) - block diagram, computerized analysis of EEG, Electromyogram (EMG), Myoelectric control, Voluntary control of myoelectric signals, use of myoelectric signal for control - signal processing and recording, biofeedback instrumentation. Medical device regulations and standards, Risk management and patient safety, Ethical considerations in biomedical instrumentation research and development.

Module II: Diagnostic Instruments

Oximetry- In-vitro and in-vivo, ear oximetry, pulse oximetry, skin reflectance oximeters, intravascular oximeter. Blood flowmeter types and their principle, Pulmonary function measurement measurements-respiratory volumes and capacities, compliance and related pressures, dynamic respiratory parameters, basic spirometer, ultrasonic spirometer, pneumotacometer, Blood Pressure Measurement - Non-invasive and invasive techniques, Arterial blood pressure waveform analysis, Blood pressure monitoring systems

Module III: Therapeutic Instruments

Need for cardiac pacemaker, external pacemaker, implantable pacemakers-types, ventricular synchronous demand pacemaker, programmable pacemaker, power sources for implantable pacemakers. Need for defibrillator, DC defibrillator, automatic external defibrillator, implantable defibrillators, Principle of surgical diathermy and surgical diathermy machine, Anesthesia-Need for anesthesia, delivery of anesthesia, anesthesia machine, Ventilator – types, controlling parameters, working principle.

Module IV: Emerging Trends in Biomedical Instrumentation

Clinical laboratory instrumentation, Blood cell counter and associated hematology system, Endoscopic diagnosis and foreign body removal, blood gas analyzers, Wearable sensors and mobile health technologies, Telemedicine and remote patient monitoring, Artificial intelligence in healthcare, Safety and Ethical Considerations.

List of Experiments:

Experiment 1: Experiments and calibration with ECG machine.
Experiment 2: Experiments with Pulse-oximeter machine.
Experiment 3: Experiments with Audiometer
Experiment 4: Experiment and calibration of Sphygmomanometer.

Experiment 5: Experiments with glucometer.
Experiment 6: Experiments for measuring pulmonary functions with spirometer.

Reference Books:

1. ***Hand book of Biomedical Instrumentation***; Khandpur R.S., TMH, 2003.
2. ***Biomedical Digital Signal Processing***; Tompkins,.
3. ***Biomedical Instrumentation and Measurements***; Leslie Cromwell, Fred J. Weibell, Pub: Erich A. Pfeiffer.
4. ***Introduction to biomedical engineering***; Enderle, John, and Joseph Bronzino, eds.. Academic press, 2012.

Paper Name: Medical Imaging and Image Processing

Paper Code: PHY415

L T P – 3-0-1

Course Objectives:

1. To describe the fundamental principles behind various medical imaging modalities, including X-rays, CT scans, MRI, and ultrasound, and their diagnostic applications.

2. To explain the technical aspects of image formation, sampling, and quantization in medical imaging, with a focus on the 2D-DFT and other image transforms.

3. To analyze techniques for enhancing, filtering, and restoring medical images to improve quality and assist in accurate diagnosis.

4. To evaluate modern image processing techniques, including edge detection, segmentation, and classification, using neural networks and statistical methods.

5. To design and conduct experiments involving AI-driven medical imaging systems, with consideration for ethical and regulatory standards.

Course Outcome:

On completion of this course, the students will be able to

CO1: Recall and describe the fundamental physics principles behind various medical imaging modalities, including X-ray, CT, PET, MRI, ultrasound, and optical imaging.

CO2: Explain the concepts of image sampling, quantization, and fidelity, and demonstrate an understanding of the mathematical transforms used in medical image processing.

CO3: Apply image enhancement techniques such as histogram modeling and spatial operations to improve medical image quality.

CO4: Analyze medical images by employing feature extraction, edge detection, and segmentation techniques to classify images for diagnostic purposes.

CO5: Evaluate the performance of different image restoration methods, such as inverse filtering and Wiener filtering, to assess the quality of degraded medical images.

CO6: Develop a small-scale AI-driven image processing application or experiment to demonstrate advanced techniques in computational pathology or image-guided interventions, considering ethical and regulatory aspects. *(Knowledge Level: Create)*

Course Content:

Module I: Medical Imaging Modalities

Physics of diagnostic radiology – Production of X-rays - diagnostic X-ray tube and its electrical circuits- X-ray tube rating - X-ray film, properties and Processing -Intensifying screens - Factors affecting radiographic imaging. Principle and Theory of computer tomography (CT) scanning, spiral CT scanning and (positron emission tomography) PET scan, Gamma camera. Physics of MRI and its application in the field of diagnostics. Physics of ultrasound imaging, probes and modes of scanning, uses in diagnosis, Image quality description and patient risk, Theory and applications of optical, thermography imaging.

Module II: Image Fundamentals

Image Perception, MTF of the visual system, image fidelity criteria, image model, image sampling and quantization – 2 dimensional sampling theory, image quantization, optimum mean square quantizer, image transforms- 2 D – DFT and other transforms.

Module III: Image processing, analysis and classification

Image enhancement –point operation, histogram modelling, spatial operation, transforms operations. Image restoration- image degradation model, inverse and wiener filtering. Image analysis- spatial feature extraction, edge detection, image segmentation classification technique-statistical methods, neural network approaches.

Module IV: Emerging Trends and Challenges

AI-driven medical imaging, Computational pathology, Image-guided interventions, Ethical considerations and regulatory aspects in medical imaging

List of Experiments:

1. Programs for image gray-level transform.
2. Program to show histogram equalization effect for an image.
3. Programs for image filtering in spatial domain
4. Programs for image filtering in frequency domain.
5. Program for image segmentation.
6. Programs for image edge detection.

Reference Books:

1. Richard P. Feynman, Robert B. Leighton, Matthew Sands: Feynman lectures on physics, Vol 2 & 3 Narosa Pub., 1986.
2. ***Medical imaging systems***; Albert Macovski:, Prentice-Hall, Englewood Cliffs, 1983.
3.***Medical Imaging Physics***; W.R.Hendee&E.R. Ritenour, ,3rdedition, Mosbey year Book,Inc.,1992.
4. ***Digital Image Processing***; R.C.Gonzalez and R.E. Woods, , Second Edition, Pearson Education, 2018.
5. ***Fundamentals of Digital Image Processing***; Anil Kumar Jain, , Prentice Hall of India, 1989.

Compulsory Courses (CC With Research)

Paper Name: Research Methodology

Paper Code: PHY440
L T P – 3-0-1

Course Objectives:

1. To identify the nature and significance of research in Physics, emphasizing the distinction between qualitative and quantitative research approaches to foster a comprehensive understanding of scientific inquiry.

2. To formulate precise research questions and hypotheses, selecting appropriate data collection methods to ensure validity and reliability in physics research, thereby laying a solid foundation for independent investigation.

3. To apply relevant statistical techniques and software tools for analyzing and interpreting research data, including error analysis and uncertainty estimation, enhancing the robustness of research findings.

4. To develop skills in scientific writing by structuring research reports and preparing effective presentations, ensuring clarity and impact in communication within scientific communities.

5. To demonstrate ethical principles in research by understanding responsible conduct, authorship guidelines, and the ethical treatment of human subjects, thus preparing students for conducting independent research projects with integrity.

Course Outcome:

On completion of this course, the students will be able to

CO1: Define fundamental research concepts, including qualitative and quantitative approaches, ethical principles, and research methodologies in Physics.

CO2: Explain the purpose of various research designs, the importance of data validity and reliability, and the role of ethical considerations in scientific research.

CO3: Utilize appropriate data collection methods and statistical software to conduct research, ensuring the accuracy and reliability of experimental data in Physics.

CO4: Evaluate research data using statistical techniques, error analysis, and uncertainty estimation to identify trends and draw meaningful conclusions.

CO5: Assess the quality and integrity of research papers and proposals by critiquing their structure, ethical adherence, and data interpretation.

CO6: Design and execute a small-scale research project, including formulating research questions, collecting and analyzing data, and presenting findings through written and oral communication.

Course Content:

Module I: Introduction to Research Methodology

Understanding the nature and significance of research, difference between quantitative and qualitative research, identifying research objectives and formulating research questions, exploring ethical considerations and responsible conduct of research

Module II: Research Design and Data Collection

Understanding different research designs (experimental, observational, survey, etc.) in physics, formulating hypotheses and defining research variables, selecting appropriate data collection methods and instrumentation, ensuring validity, reliability, and accuracy of data collection

Module III: Data Analysis and Interpretation

Introduction to statistical analysis techniques for physics research, using statistical software for data analysis and visualization, interpreting and drawing conclusions from research data, understanding error analysis and uncertainty estimation

Module IV: Research Communication and Scientific Writing

Structuring and organizing research papers and reports, enhancing scientific writing skills for research articles and proposals, preparing effective research presentations (oral and poster), developing communication skills for scientific conferences and collaborations

Module V: Ethics, Responsible Conduct, and Research Project

Understanding ethical considerations and regulations in physics research, discussing responsible conduct of research and authorship guidelines, applying ethical principles in data management and protection of human subjects, implementing research project and presenting research findings

Reference Books:

1. ***Research Methodology: A Step-by-Step Guide for Beginners***, Ranjit Kumar
2. ***Research Design: Qualitative, Quantitative, and Mixed Methods Approaches***; John W. Creswell and J. David Creswell

3. ***Writing for Science***, Robert Goldbort
4. ***Ethics in Research: Continuum Research Methods***, Margaret Adolphus
5. ***Research Methods in Physics and Astrophysics***, Hale Bradt

Compulsory Courses (CC Without Research)

Paper Name: Machine Learning and Data Analytics

Paper Code: PHY441

L-T-P: 1-0-3

Course Objectives:

1. To understand the fundamental concepts of machine learning, including supervised, unsupervised, and reinforcement learning, providing a foundational framework for exploring advanced topics in the field.
2. To analyze key elements of machine learning, such as data formats, the issues of underfitting and overfitting, and the principles of statistical learning approaches, enabling informed decision-making in model development.
3. To apply Python libraries like Pandas and Scikit-Learn for visualizing and processing datasets, equipping students with practical skills for executing machine learning tasks effectively.
4. To evaluate feature selection methods and dimensionality reduction techniques, including Principal Component Analysis (PCA), in order to enhance model performance and interpretability.
5. To implement various machine learning algorithms, such as linear regression, decision trees, clustering techniques, and neural networks, using Python libraries, fostering hands-on experience in developing predictive models.

Course Outcomes

On completion of this course, the students will be able to

CO1: Recall and describe fundamental concepts and techniques in machine learning, including supervised, unsupervised, and reinforcement learning.

CO2: Explain the significance of different data formats, error measures, and concepts like underfitting, overfitting, and PAC learning in the context of machine learning.

CO3: Utilize Pandas and Scikit-Learn to prepare data, create dataframes, visualize data, and implement basic machine learning models within Jupyter Notebook.

CO4: Examine datasets to identify patterns and insights, and perform feature selection and dimensionality reduction techniques such as principal component analysis (PCA).

CO5: Assess the performance of different machine learning models, including linear regression, decision trees, and neural networks, by applying validation techniques and error metrics.

CO6: Develop and build machine learning models from scratch, integrating various techniques and algorithms to solve complex data problems and implement them using Python and PyTorch.

Course Content

Module I: Introduction to Machine Learning

Introduction – Classic and Adaptive Machines, Supervised Learning, Unsupervised Learning, Reinforcement Learning

Module II: Important Elements in Machine Learning

Data formats, Underfitting, Overfitting, Error Measures, PAC Learning, Statistical Learning Approaches

Module III: Introduction to Pandas and Scikit-Learn

Basic Concept of Pandas, Pandas Dataframes, Visualization the Data in Dataframes, Idea of Jupyter Notebook, Overview of Scikit-Learner

Module IV: Feature Selection and Feature Engineering

Creating training and test sets, Data Scaling and Normalization, Feature Selection and Filtering, Principal Component Analysis

Module V: Fundamentals of Regression

Linear Models, Linear Regression with Scikit-Learn, Linear Classification, Logistic Regression

Module VI: Fundamentals of Decision Trees

Building Decision Tree, Binary Decision Trees, Decision Tree in Python, Decision Tress Classification with Scikit-Learn

Module VII: Fundamentals of Clustering

K-Means, Agglomerative Clustering, Hierarchical Strategies, Dendrograms

Module VIII: Fundamentals of Neural Networks

Basics of PyTorch, Perceptron, Introduction to Artificial Neural Networks

Reference Books:

1. ***Machine Learning Algorithms***; by G. Bonaccorso
2. ***Hands-on Machine Learning with Python***; by A. Pajankar, A. Joshi
3. ***Machine Learning using Python***; M. Pradhan, U. D. Kumar
4. ***Hands-On Data Preprocessing in Python***; by R. Jafari
5. ***Machine Learning with PyTorch and Scikit-Learn***; S. Raschka, Y. Liu, V. Mirjalili

Compulsory Courses (CC Without Research)

Paper Name: X Ray Crystallography and related Techniques

Paper Code: PHY442

L T P – 3-0-1

Course Objectives:

1. To understand the fundamental concepts of machine learning, including supervised, unsupervised, and reinforcement learning, providing a foundational framework for exploring advanced topics in the field.
2. To analyze key elements of machine learning, such as data formats, the issues of underfitting and overfitting, and the principles of statistical learning approaches, enabling informed decision-making in model development.
3. To apply Python libraries like Pandas and Scikit-Learn for visualizing and processing datasets, equipping students with practical skills for executing machine learning tasks effectively.
4. To evaluate feature selection methods and dimensionality reduction techniques, including Principal Component Analysis (PCA), in order to enhance model performance and interpretability.
5. To implement various machine learning algorithms, such as linear regression, decision trees, clustering techniques, and neural networks, using Python libraries, fostering hands-on experience in developing predictive models.

Course Outcome:

On completion of this course, the students will be able to

1. **CO1**: Recall the fundamental concepts of crystal structures, crystal systems, and crystal defects.

2. **CO2:** Explain the principles of X-ray diffraction methods, including Bragg's law and diffraction intensity calculations, and describe the functioning of spectrometers and diffractometers.

3. **CO3:** Utilize X-ray diffraction techniques like powder diffraction and Debye-Scherrer methods for determining crystal structures and lattice parameters.

4. CO4: Analyze the quality and orientation of single crystals and polycrystalline aggregates using back-reflection Laue and transmission methods.

5. **CO5:** Assess the accuracy and reliability of data from electron and neutron diffraction methods for structural analysis, including interpreting crystal strain and magnetic structures.

6. **CO6:** Design and perform a project-based X-ray diffraction experiment to determine material properties, integrating data collection and structure refinement techniques.

Course Content:

Module I: Introduction Structure of materials and Defects

Crystal structure: lattices, unit cell., Definition of the crystal lattice and unit cell, Lattices, lattice parameters, and symmetry: The seven crystal systems, Conventional and primitive lattices: The 14 Bravais lattices, Crystal structure of the elements, Closed-packed metals-cubic and hexagonal packed structure, Crystal structure of some simple inorganic (NaCL, KCL,etc.) compounds. Crystal defects: point defects, dislocations and stacking faults

Module II: X-ray Diffraction Methods and Analysis

Diffraction geometry: Bragg's law, Diffraction methods; Laue's Method, Rotating Crystal method, and powder Method, Diffraction Intensity: scattering by an electron, scattering from atoms, scattering by a unit cell; structure factor function. Structure-factor calculations; Application to powder method, Multiplicity factor, Lorentz factor, Absorption factor, Temperature factor, Intensities of powder pattern lines, Intensity calculations, Measurement of x-ray intensity.

Application to polycrystal diffraction: powder diffraction and crystal structure determination. Diffractometer measurements. Diffraction methods; Laue's Method; Laue photograph, Camera and specimen and holders, collimators, Rotating Crystal method, and powder Method; Debye-Scherrer method, Specimen preparation and film loading.

Diffractometer and Spectrometer Measurements: Introduction and description of the spectrometer, X-ray optics Counters, Proportional counters, Geiger counters, Scintillation counters, Semiconductor counters, Pulse-height analysis, Special kinds of diffractometry. Monochromatic operation.

Module III: Application of X-rays

Orientation and Quality of Single Crystals,The back-reflection Laue method. Transmission Laue method and Diffractometer method. Structure of Polycrystalline Aggregates, Crystal Size:Grain size, Particle size and calculation of lattice strain, Crystal Quality: Crystal quality, Depth of X-ray penetration.

Module IV: Electron and Neutron Diffraction

Low energy electron diffraction technique of structure analysis. Methods of neutron diffraction: data collection, structure analysis and refinement. Use of polarised neutron beams for structure analysis. Refinement of crystal structures. Diffraction at small angles/interpretation of larger structures. Working examples of Structure Determination of self-assembled structures, polymers etc. by diffraction. Determination of magnetic structure by neutron diffraction.

Laboratory Experiment:

One small project work associated with X-ray diffraction experiment may be included if possible.

Reference Books:

1. ***Contemporary Crystallography***; M. J. Buerger, , McGraw Hill, l970.
2. ***X-ray Structure***; G. H. Stout and L. H. Jenson, ,Mcmillan, l968.
3. ***Structure Analysis by Small Angle X-ray and Neutron Scattering***; L. A. Feigin and D. I. Svergun, Springer, 2013.
4. ***Elements of X-ray Diffraction***; B.D.Cullity,.

Compulsory Courses (CC Without Research)

Paper Name: Introduction to Vacuum Technology and Its Application

Paper Code: PHY443
L T P – 3-0-1

Course Objectives:

1. To define key concepts and basic terms in vacuum technology, including the physical state of matter, gas laws, and rarefied gas theory, to establish a foundational understanding of the subject.
2. To describe the various types of vacuum pumps and their operational principles, focusing on mechanical, diffusion, turbo-molecular, cryogenic, and getter pumps to understand their applications and functionality.
3. To evaluate different vacuum measurement techniques and pressure gauges used for low to ultra-high vacuum applications, ensuring proficiency in selecting appropriate measurement tools.
4. To analyze methods for producing and maintaining low temperatures, including techniques like the Joule-Thomson effect, adiabatic demagnetization, and dilution refrigeration, to comprehend their importance in vacuum technology.
5. To implement clean room standards and practices, including design, high-efficiency air filtration, and quality control, and apply vacuum technology effectively to scientific and industrial applications.

Course Outcome:

On completion of this course, the students will be able to

CO1: Recall fundamental concepts of the kinetic theory of gases, vacuum terminology, and the basic principles of gas flow at low pressure.

CO2: Explain the working principles of various vacuum pumps and pressure measurement techniques, distinguishing between their applications and limitations.

CO3: Use appropriate vacuum technologies to achieve specific pressure levels and maintain controlled environments for experimental or industrial processes.

CO4: Analyze the characteristics of low-temperature production and measurement techniques, and assess the suitability of different thermometers for specific applications.

CO5: Evaluate the design and operational standards of clean room technology, emphasizing quality control and the efficiency of filtration systems.

CO6: Design a vacuum system or clean room setup tailored to a specific industrial or research application, integrating vacuum pumps, measurement tools, and temperature control techniques.

Course Content:

Module I: Recapitulation of Kinetic Theory of Gases and Introduction to Vacuum Technology

Physical state of matter, General gas laws, Motion of molecules in rarefied gases, Pressure and mean free path, Transport phenomenon in viscous and molecular state, Thermal diffusion and energy transport, Gas flow at low pressure, Introduction to vacuum, Basic terms, Definitions and Units, Rarefied Gas Theory for vacuum technology, Physico-Chemical phenomena in vacuum techniques

Module II: Production of Vacuum and Vacuum Pumps

Vacuum measuring units, vacuum ranges, pumping speed and pump down time, Mechanical pumps, Diffusion pump, Turbo-Molecular pump, Cryogenic pumps, Getter pumps (Electrical cleanup and ion pumps, Sputter ion pumps)

Module III: Vacuum Measurements

Measurement of low pressure, Pressure gauges for low to high vacuum, Mc Leod manometer, Thermal conductivity gauges, Pressure gauges for high to ultrahigh vacuum, Hot cathode ionization gauges, Cold cathode ionization gauges, Operation of High-vacuum gauges

Module IV: Production and Measurement of Low Temperature

Joule Thomson effect, Regenerative cooling, Use of Vacuum pumps, Liquefaction of air, Maintenance of low temperature and Production of temperature below 1 K, Adiabatic demagnetization, Evaporative cooling of He^3, Dilution Refrigeration. Gas Thermometer and its Corrections, Secondary thermometers- Resistance Thermometers, Thermocouples, Vapour Pressure Thermometers, Magnetic thermometers

Module V: Liquid And Solid Cryogens and Clean Room Technology

Liquification of Gases and Liquid Cryogens, He^4 and He^3, Lamda point, Superfluidity, Compressibility factor, Viscosity and Thermal Properties, Velocity of Sound in Liquid Helium, Needs and Types of Clean Rooms, Basics of Clean Room Standards, Design of Clean Room, High Efficiency Air Filtration, Clean Room Disciplines, Quality control, Industrial and Scientific application of clean room,

1. Note: Students will be given projects in the following topics: "Applications of Vacuum Technology in science, research, technology, research, space science, material science, particle accelerators".

Reference Books:

1. ***Experimental Techniques in Low Temperature Physics***; White G. K., Philip M.
2. ***Vacuum Science and Engineering***; V. Atta
3. ***Vacuum Technology***; Harris N. S.
4. ***Vacuum Technology***; Roth A
5. ***Fundamentals of Vacuum Technology***; W. Umrath

Compulsory Courses (CC Without Research)

Paper Name: Solar Energy and Its Application

Paper Code: PHY444
L T P – 3-0-1

Course Objectives:

1. To explain the concepts of solar radiation, including the solar constant, solar irradiance calculations, and the use of solar radiation measurement instruments, providing a foundation for understanding solar energy applications.
2. To describe various solar thermal systems, such as flat plate collectors, concentrating collectors, solar cookers, and solar hot water systems, including their design, operation, and practical applications in energy generation.
3. To demonstrate the working principle of photovoltaic cells, covering their fabrication processes, types, and applications, highlighting the role of solar photovoltaic systems in renewable energy solutions.
4. To analyze the electrical and optical properties of photo-detectors and solar cells through simulation software and practical measurements, enabling students to assess performance characteristics.
5. To construct solar energy systems, incorporating solar panels in series and parallel configurations, and to assess their efficiency through experimental setups, fostering hands-on experience in solar technology.

Course Outcome:

On completion of this course, the students will be able to

CO1: **Recall and describe** the fundamental concepts of solar radiation, solar constants, and instruments used for measuring solar irradiance.

CO2: **Explain** the principles of solar thermal systems and the processes of converting solar radiation into thermal energy using collectors.

CO3: **Demonstrate** the working principles and practical uses of solar photovoltaic systems for energy conversion and specific applications such as lighting and water pumping.

CO4: **Analyze** the performance and efficiency of solar energy systems, including thermal and photovoltaic applications, under varying conditions.

CO5: **Assess** the advantages, limitations, and suitability of different solar energy systems, such as flat plate collectors and solar cells, for diverse applications.

CO6: **Design and develop** basic models or systems for harnessing solar energy, such as a solar water heater, solar dryer, or photovoltaic-powered device, considering efficiency and sustainability.

Course Content:

Module I: Solar Radiation

Solar radiation at the earth's surface – Solar Constant, solar radiation measurements – estimation of average solar radiation, Sun as a source of energy, Calculation of solar irradiance at surfaces - Pyroheliometer, Pyranometer- Optical pyrometer and polarizing pyrometer , Sunshine recorder, Prediction of available solar radiation, Solar energy-Importance, Storage of solar energy.

Module II: Solar Thermal Systems

Principle of conversion of solar radiation into heat, Collectors used for solar thermal conversion: Flat plate collectors and Concentrating collectors, Solar Thermal Power Plant, Solar cookers, Solar hot water systems, Solar dryers, Solar Distillation, Solar greenhouses.

Module III: Solar Photovoltaic Systems

Conversion of Solar energy into Electricity - Photovoltaic Effect -function of solar cells from semiconductor physics, Solar photovoltaic cell and its working principle, Generations of photovoltaics, Different types of Solar cells, Fabrication of Solar cell, Connection of PV Module in Series and Parallel, Estimation and measurement of PV Module Power, Selection of PV Module,, Cell module and panel concept, Photovoltaic applications: Battery chargers, domestic lighting, street lighting and water pumping model.

List of Experiments

1. The electrical and optical properties of various photo-detectors.
2. Solar cell characteristics study using simulation software (PC1D or AMPS 1D).
3. Connect solar panels in series & parallel and measure voltage and current.
4. Construct an illuminated house using Solar PV panel.
5. I-V characteristic of solar cell and calculate efficiency of the solar cell.

Reference Books:

1. ***Solar Energy: Fundamentals and Applications***; H Garg and J Prakash, , McGraw Hill Education, 2017.

2. ***Energy- Fundamentals, design, modeling & applications***; G.N. Tiwari,Solar, Narosa Pub., 2005.

3. ***Solar Energy-Principles of thermal energy collection & storage***; S.P. Sukhatme,, Tata McGraw Hill Publishers, 1999.

4. ***Solar Photovoltaics- Fundamentals, technologies and applications***; Chetan Singh Solanki, PHI Learning Pvt. Ltd., 2015.

5. ***Solar Photovoltaic Basics***; S. White, , Taylor & Francis, 2018

Compulsory Courses (With Research)

Paper Name: Dissertation

L T P – 0-0-12

Paper Code : PHY499

Course Objectives:

1. To identify a relevant research topic and formulate research questions and objectives based on a comprehensive literature review, establishing a strong foundation for the research project.
2. To collect and analyze data using appropriate experimental, theoretical, or computational methods and tools, ensuring rigorous and systematic investigation of the research problem.
3. To compose a structured dissertation that includes the introduction, methods, results, discussion, and conclusion, adhering to academic writing standards for clarity and coherence.
4. To present research findings through an oral presentation, utilizing visual aids effectively and demonstrating the ability to defend the research methodology and results against critical questioning.
5. To review and revise the dissertation based on feedback and peer review, ensuring clarity, accuracy, and adherence to academic standards for successful completion of the research project.

Course Outcomes

On completion of this course, the students will be able to

CO1: **Recall and articulate** key concepts, theories, and methodologies relevant to the chosen dissertation topic by conducting a comprehensive literature review.

CO2: **Explain and justify** the research question, objectives, and proposed methodology in the context of existing knowledge in Physics.

CO3: **Implement** appropriate experimental, computational, or theoretical methods to collect and analyze data aligned with the research objectives.

CO4: **Critically evaluate** the data, identifying patterns, relationships, and deviations to draw meaningful insights and conclusions.

CO5: **Assess** the significance of the research findings, **comparing** them with existing studies to **determine** their contribution to the field of Physics.

CO6: **Compose** a comprehensive dissertation and **deliver** an effective oral presentation to clearly communicate the research findings and their implications.

Catalog Description

The Dissertation paper is a culminating academic experience for students in the B.Sc. Physics program, designed to provide an opportunity for independent, in-depth research on a topic of choice within the field of physics. Under the guidance of a faculty advisor, students will identify a research question, conduct a comprehensive literature review, design and perform experiments or simulations, analyze data, and present their findings in a written dissertation and oral presentation.

Course Content:

1. **Research Proposal:**
    - Identification of a research topic
    - Literature review
    - Formulation of research questions and objectives
    - Research design and methodology

2. **Research Execution:**
    - Data collection (experimental, theoretical, or computational)
    - Data analysis and interpretation
    - Use of relevant tools and techniques

3. **Dissertation Writing:**
    - Structure and organization of a dissertation
    - Writing of individual sections (introduction, methods, results, discussion, conclusion)
    - Citation and referencing

4. **Presentation:**
    - Preparation of oral presentation
    - Use of visual aids (e.g., slides, graphs)
    - Delivery and defense of research findings

Paper Name: Internship

Paper Code: PHY340

L T P – 0-0-4

This internship provides a unique opportunity for students to apply theoretical knowledge in real-world settings, bridging the gap between classroom learning and practical experience. By working in research laboratories, industries, or academic institutions, students gain valuable hands-on experience, develop professional skills, and build a network of contacts in their field of interest. The internship is designed to enhance their understanding of Physics in practical applications, foster problem-solving skills, and significantly boost their employability. Through this immersive experience, students not only solidify their grasp of Physics concepts but also gain insights into potential career paths and the demands of the professional world, thereby improving their readiness for future career opportunities or higher studies. This practical exposure ensures that graduates are well-prepared and competitive in the job market.

Course Objectives:

1. To apply theoretical knowledge of Physics in real-world settings through practical work in research laboratories, industries, or academic institutions, fostering hands-on experience in the field.
2. To develop problem-solving skills by tackling real-world challenges and projects within the internship environment, enhancing critical thinking and adaptability.
3. To evaluate the practical aspects of Physics concepts and their relevance to industrial and research contexts, bridging the gap between theory and application.
4. To communicate effectively with professionals and peers by presenting internship findings and insights in a structured manner, promoting clarity and engagement in discussions.
5. To reflect on the internship experience to identify areas of strength and improvement, and integrate this feedback into future career planning or academic pursuits, fostering continuous personal and professional development.

Course Outcome

CO1: **Recall** foundational Physics concepts and theories relevant to the tasks and projects under-taken during the internship.

CO2: **Explain** the application of theoretical Physics principles in practical scenarios observed during the internship.

CO3: **Demonstrate** the ability to apply Physics knowledge and techniques to solve real-world problems encountered during the internship.

CO4: **Examine** and **evaluate** the practical implementation of Physics principles in professional environments, identifying gaps between theoretical models and real-world outcomes.

CO5: **Assess** the effectiveness of methods, tools, or processes used in the internship setting, providing constructive feedback and recommendations for improvement.

CO6: **Develop** a detailed report or presentation summarizing internship experiences, including innovative approaches, project outcomes, and lessons learned, while proposing future applications or solutions.

Paper Name: Project

Paper Code: PHY341

L T P – 0-0-4

As part of the B.Sc. Physics program, students are required to undertake a project, which serves as a vital component of their undergraduate education. This project allows students to engage deeply with a specific area of interest, applying their theoretical knowledge to investigate and solve real-world problems. Through this process, students enhance critical skills such as research methodology, data analysis, scientific writing, and presentation. The hands-on experience gained from working on the project not only reinforces their understanding of Physics but also significantly boosts their employability. By demonstrating their ability to independently conduct research and produce substantial findings, students make themselves more attractive to potential employers and academic institutions. This project experience equips them with the practical skills and confidence needed to excel in their future careers or higher studies, ensuring they are well-prepared to meet the challenges of the professional world.

Course Objectives:

1. To identify a specific area of interest within Physics for the project, demonstrating the ability to select and define a research topic that aligns with personal and academic goals.
2. To apply theoretical knowledge and research methodology to investigate the chosen project topic, showcasing the practical application of Physics concepts in a real-world context.
3. To analyze and interpret data collected during the project, employing appropriate techniques to draw meaningful conclusions and enhance understanding of the subject matter.
4. To develop a comprehensive scientific report and presentation that effectively communicates project findings and their significance, fostering skills in scientific communication.
5. To evaluate the outcomes of the project by reflecting on the research process, identifying strengths and weaknesses, and recognizing areas for future work or improvement to contribute to ongoing learning and development.

Course Outcomes (COs)

CO1: **Recall** and **summarize** foundational Physics concepts and principles to identify and define a focused research topic for the project.

CO2: **Explain** the theoretical framework and methodologies relevant to the selected project topic, demonstrating a clear understanding of their applications.

CO3: **Apply** appropriate research methodologies and experimental techniques to collect and analyze data related to the chosen project area.

CO4: **Examine** and **interpret** data using appropriate analysis tools, identifying patterns, correlations, and implications within the context of the research objectives.

CO5: **Critically evaluate** the research process and outcomes, reflecting on challenges, strengths, and areas for improvement to draw valid conclusions.

CO6: **Design** and **present** a comprehensive scientific report and oral presentation, effectively communicating findings and their significance to an academic audience.

CO-PO Mapping for the program B.Sc. (Physics) (4 year NEP batch)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10
PHY100	**Mathematical Methods I**									
CO1	3	0	0	2	2	0	0	0	0	1
CO2	3	0	0	2	3	0	0	0	0	1
CO3	3	0	1	2	2	0	1	0	0	1
CO4	3	0	1	2	3	0	1	0	0	1
CO5	3	0	2	2	2	0	1	0	0	1
CO6	3	0	2	2	3	0	1	0	1	2
PHY101	**Mechanics and Waves**									
CO1	3	1	0	2	2	0	0	0	0	1
CO2	3	1	0	2	2	0	0	0	0	1
CO3	3	2	0	2	2	0	1	0	0	1
CO4	3	2	0	2	2	0	1	0	0	1
CO5	3	2	0	2	3	0	1	0	0	1
CO6	3	3	0	2	3	0	1	0	0	2
PHY102	**Electromagnetic Theory I**									
CO1	3	1	0	1	2	0	0	0	0	1
CO2	3	1	0	1	2	0	0	0	0	1
CO3	3	1	0	2	2	0	1	0	0	1
CO4	3	2	0	2	2	0	1	0	0	1
CO5	3	2	0	2	2	1	1	0	0	1
CO6	3	3	0	3	1	1	1	0	0	2
PHY103	**Thermal Physics**									
CO1	3	1	0	1	2	0	0	0	0	1
CO2	3	1	0	1	2	0	0	0	0	1
CO3	3	1	0	2	2	0	1	0	0	1
CO4	3	1	0	2	2	0	1	0	0	1
CO5	3	3	0	2	1	1	1	0	0	1
CO6	3	3	0	3	1	1	1	0	0	2

PHY200	Mathematical Methods II								
CO1	3	0	0	1	3	0	0	0	0	1
CO2	3	0	0	1	3	0	0	0	0	1
CO3	3	0	1	1	3	0	1	0	0	1
CO4	3	0	1	1	3	0	1	0	0	1
CO5	3	0	2	2	3	0	1	0	0	1
CO6	3	1	3	2	2	0	1	0	1	2
PHY201	Electronics I									
CO1	2	1	0	1	0	0	0	0	0	1
CO2	3	1	0	1	0	0	0	0	0	1
CO3	3	1	0	2	0	0	1	0	0	1
CO4	3	1	0	2	0	0	1	0	0	1
CO5	3	2	0	2	1	1	1	0	0	1
CO6	3	3	0	3	1	1	1	0	0	2
PHY202	Quantum Mechanics									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	3	0	0	1	2	0	1	0	0	1
CO3	3	0	0	1	3	0	1	0	0	1
CO4	3	0	0	1	3	0	1	0	0	1
CO5	3	0	0	1	3	0	1	0	0	1
CO6	3	0	0	1	3	0	1	0	0	1
PHY203	Electronics II									
CO1	2	1	0	1	0	0	0	0	0	1
CO2	3	1	0	1	0	0	0	0	0	1
CO3	3	1	0	2	0	0	1	0	0	1
CO4	3	1	0	2	0	0	1	0	0	1
CO5	3	2	0	2	1	1	1	0	0	1
CO6	3	3	0	3	1	1	1	0	0	2
PHY204	Analytical Mechanics and Special Theory of Relativity									
CO1	2	0	0	0	2	0	1	0	0	1
CO2	3	0	0	0	2	0	1	0	0	1

CO3	3	0	0	0	2	0	1	0	0	1
CO4	3	0	0	0	2	0	1	0	0	1
CO5	3	0	0	0	2	0	1	0	0	1
CO6	3	0	0	2	3	0	2	0	1	2
PHY300	**Electromagnetic Theory II**									
CO1	3	1	0	2	2	0	2	0	0	0
CO2	3	1	0	2	2	0	2	0	0	0
CO3	3	2	0	2	2	0	2	0	0	0
CO4	3	2	0	2	2	0	3	0	0	1
CO5	2	3	1	2	2	1	2	0	0	1
CO6	2	3	1	2	3	1	3	0	0	1
PHY301	**Statistical Mechanics**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	3	0	0	1	2	0	1	0	0	1
CO3	3	0	0	1	3	0	1	0	0	1
CO4	3	0	0	1	3	0	1	0	0	1
CO5	3	0	0	1	3	0	1	0	0	1
CO6	3	0	0	1	3	0	1	0	0	1
PHY302	**Advanced Quantum Mechanics**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	3	0	0	1	2	0	1	0	0	1
CO3	3	0	0	1	3	0	1	0	0	1
CO4	3	0	0	1	3	0	1	0	0	1
CO5	3	0	0	1	3	0	1	0	0	1
CO6	3	0	0	1	3	0	1	0	0	1
PHY303	**Numerical Methods and Simulation in Physics**									
CO1	1	0	3	1	0	0	0	0	1	1

CO2	1	0	3	1	0	0	0	0	1	1
CO3	1	0	3	1	0	0	0	0	1	1
CO4	1	0	3	1	0	0	0	0	1	1
CO5	1	0	3	1	0	0	0	0	1	1
CO6	1	0	3	1	0	0	0	0	1	1
PHY304	**Solid State Physics**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	1	0	2	2	2	1	0	0	0
CO6	2	3	0	2	2	3	3	0	1	1
PHY305	**Nuclear and Particle Physics**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	1	0	2	2	2	1	0	0	0
CO6	2	3	1	2	2	3	3	0	1	1
PHY400	**Advanced Statistical Mechanics**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	3	0	0	1	2	0	1	0	0	1
CO3	3	0	0	1	3	0	1	0	0	1
CO4	3	0	0	1	3	0	1	0	0	1
CO5	3	0	0	1	3	0	1	0	0	1
CO6	3	0	0	1	3	0	1	0	0	1
PHY401	**Introduction to Astronomy and Astrophysics**									

CO1	2	0	0	0	2	0	0	0	0	0
CO2	3	0	0	1	2	0	1	0	0	1
CO3	3	0	0	1	3	0	1	0	0	1
CO4	3	0	0	1	3	0	1	0	0	1
CO5:	3	0	0	1	3	0	1	0	0	1
CO6:	3	1	2	1	3	0	1	0	0	2
PHY406	**Introduction to Cosmology**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	0	0	1	2	0	1	0	0	1
CO3	3	0	0	1	3	0	1	0	0	1
CO4	3	0	0	1	3	0	1	0	0	1
CO5	3	0	0	1	3	0	1	0	0	1
CO6	3	0	2	1	3	0	1	0	0	2
PHY411	**Introduction to General Theory of Relativity**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	0	0	1	2	0	1	0	0	1
CO3	3	0	0	1	3	0	1	0	0	1
CO4	3	0	0	1	3	0	1	0	0	1
CO5	3	0	0	1	3	0	1	0	0	1
CO6	3	0	2	1	3	0	1	0	0	2
PHY402	**Nanomaterials and Fabrication Technology**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	2	0	2	2	2	1	0	0	2

CO6	2	3	0	2	2	3	3	0	1	2
PHY407	**Nanoelectronics and Nanophotonics**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	2	0	2	2	2	1	0	0	2
CO6	2	3	0	2	2	3	3	0	1	2
PHY412	**Quantum Transport**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	2	0	2	2	2	1	0	0	2
CO6	2	0	3	2	2	2	3	0	1	2
PHY403	**Guided Wave Optics**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	2	0	2	2	2	1	0	0	2
CO6	2	3	0	2	2	3	3	0	1	2
PHY408	**Non-Linear Optics and Biophotonics**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0

CO5	3	2	0	2	2	2	1	0	0	2
CO6	2	3	0	2	2	3	3	0	1	2
PHY413	**LASER and Optoelectronic Devices**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	2	0	2	2	2	1	0	0	2
CO6	2	3	0	2	2	3	3	0	1	2
PHY404	**Properties of Solids I**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	1	0	2	2	2	1	0	0	0
CO6	2	3	0	2	2	3	3	0	1	1
PHY409	**Material Science**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0
CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	1	0	2	2	2	1	0	0	0
CO6	2	3	0	2	2	3	3	0	1	1
PHY414	**Physics of Solids II**									
CO1	2	0	0	0	2	0	0	0	0	0
CO2	2	1	0	0	2	0	0	0	0	0
CO3	3	1	0	2	2	1	1	0	0	0

CO4	3	1	0	2	2	1	1	0	0	0
CO5	3	1	0	2	2	2	1	0	0	0
CO6	2	3	0	2	2	3	3	0	1	1
PHY405	**Physics for Medicine**									
CO1	2	0	0	0	2	0	1	0	0	0
CO2	2	1	0	0	2	0	1	0	0	0
CO3	3	1	0	2	2	1	2	0	0	0
CO4	3	1	0	2	2	1	2	0	0	0
CO5	3	2	0	2	2	2	2	0	0	2
CO6	2	0	3	2	2	2	3	0	1	2
PHY410	**Biomedical Instrumentation**									
CO1	2	0	0	0	2	0	1	0	0	0
CO2	2	1	0	0	2	0	1	0	0	0
CO3	3	2	0	2	2	1	2	0	0	0
CO4	3	2	0	2	2	1	2	0	0	0
CO5	3	2	0	2	2	2	2	0	0	2
CO6	2	2	1	2	2	2	3	0	1	2
PHY415	**Medical Imaging and Image Processing**									
CO1	2	0	1	0	1	0	1	0	0	0
CO2	2	0	1	0	1	0	1	0	0	0
CO3	3	0	2	1	1	0	2	0	0	0
CO4	3	1	2	1	1	0	2	0	0	0
CO5	3	2	3	2	2	0	2	0	0	2
CO6	3	2	3	2	2	0	3	0	1	2
PHY440	**Research Methodology**									
CO1	2	0	0	1	1	1	1	0	0	0
CO2	2	0	0	1	1	1	1	2	0	1

CO3	2	2	2	1	1	1	1	0	0	1
CO4	2	2	2	1	1	1	1	0	0	1
CO5	2	2	2	1	1	1	1	0	0	1
CO6	2	3	3	1	1	1	1	0	0	1
PHY441	**Machine Learning and Data Analytics**									
CO1	1	0	3	1	0	0	2	1	0	0
CO2	1	0	3	2	0	0	2	1	0	0
CO3	1	0	3	2	0	0	2	1	0	0
CO4	1	2	3	2	0	0	2	1	0	0
CO5	1	1	3	2	0	0	2	1	0	1
CO6	1	1	3	2	0	0	2	1	0	2
PHY442	**X Ray Crystallography and related Techniques**									
CO1	3	1	0	0	0	1	1	0	0	0
CO2	3	1	0	1	0	2	1	0	0	0
CO3	3	1	0	1	0	2	1	0	0	0
CO4	3	2	0	1	0	2	1	0	0	0
CO5	3	2	0	2	0	2	1	0	0	0
CO6	3	2	0	2	0	2	3	0	1	1
PHY443	**Introduction to Vacuum Technology and Its Application**									
CO1	2	1	0	2	0	1	1	0	0	0
CO2	2	1	0	2	0	1	1	0	0	0
CO3	2	1	0	2	0	1	1	0	0	0
CO4	2	2	0	2	0	1	1	0	0	0
CO5	3	2	0	2	0	2	1	0	0	0
CO6	3	3	0	2	0	2	1	0	0	0
PHY444	**Solar Energy and Its Application**									
CO1	2	2	0	3	0	1	2	0	0	0

CO2	2	2	0	3	0	1	2	0	0	0
CO3	2	2	0	3	0	1	2	0	0	0
CO4	2	2	0	3	0	1	2	0	0	0
CO5	2	3	0	3	0	2	2	0	0	0
CO6	2	3	0	3	0	2	2	0	0	0
PHY340	**Internship**									
CO1	1	0	0	2	0	0	1	2	2	1
CO2	1	0	0	2	0	0	1	2	2	1
CO3	1	1	1	2	0	0	1	2	2	1
CO4	1	1	1	3	0	2	1	2	2	1
CO5	1	1	2	3	0	2	2	2	3	1
CO6	1	1	2	3	0	2	2	2	3	1
PHY341	**Project**									
CO1	3	2	2	2	0	0	0	0	1	0
CO2	3	2	2	2	1	0	0	0	1	0
CO3	3	2	2	2	1	0	0	0	1	1
CO4	3	2	2	2	0	0	0	0	1	1
CO5	3	2	2	2	1	0	1	0	1	3
CO6	3	2	2	2	1	0	1	0	1	3
PHY499	**Dissertation**									
CO1	3	2	2	2	2	0	1	0	1	3
CO2	3	2	2	2	2	0	1	0	1	3
CO3	3	2	2	2	2	0	1	0	1	3
CO4	3	2	2	2	2	0	1	0	1	3
CO5	3	2	2	2	2	0	1	0	1	3
CO6	3	2	2	2	2	0	1	0	1	3

PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10
2.54	**1.0**	**0.5**	**1.43**	**1.69**	**0.59**	**1.04**	**0.09**	**0.21**	**0.79**