**SYLLABUS**

**FOR**

**TWO-YEAR M.Sc. PROGRAMME**

**IN**

**APPLIED PHYSICS**



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| **NAAC – A Grade** |

**DEPARTMENT OF PHYSICS**

**COLLEGE OF ENGINEERING & TECHNOLOGY**

**(An Autonomous and Constituent College of BPUT, Odisha)**

**Techno Campus, Mahalaxmi Vihar, Ghatikia,**

**Bhubaneswar-751029, Odisha, INDIA**

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**Semester-1**

**Core-1: Classical Mechanics (PPCPH101)**

**Course Objectives:**

Students will be able to:

1. Develop familiarity with the physical concepts and facility with the mathematical methods of classical mechanics.
2. Develop skills in formulating and solving physics problems.
3. To demonstrate knowledge and understanding of the following fundamental concepts in:
4. the dynamics of system of particles,
5. motion of rigid body,
6. Lagrangian and Hamiltonian formulation of mechanics
7. Small oscillation problems
8. To represent the equations of motion for complicated mechanical systems using the Lagrangian and Hamiltonian formulation of classical mechanics.

**Module-I**

***Mechanics of a system of particles:***

Inertial and non-inertial frames of reference. Lagrangian Formulation, Velocity dependent potentials and Dissipation Function, conservation theorems and symmetry properties, Homogeneity and Isotropy of space and Conservation of linear and Angular momentum, Homogeneity of time and conservation of energy.

***Hamiltonian Formulation:***

Calculus of variations and Euler-Lagranges equation, Brachistochrone problem, Hamiltons principle, extension of Hamiltons principle to nonholonomic systems, Legendre transformation and the Hamilton equations of motion, physical significance of Hamiltonian, Derivation of Hamiltons equations of motion from a variational principle, Rouths procedure, Principle of least action.

**Module-II**

***Canonical transformations:***

Canonical Transformation, types of generating function, conditions for Canonical Transformation, integral invariance of Poincare, Poissons theorem, Poisson and Lagrange bracket, Poisson and Lagrange Brackets as canonical invariant, Infinitesimal canonical Transformation and conservation theorems, Liouvilles theorem.

***Hamilton -Jacobi Theory:***

Hamilton - Jacobi equation for Hamiltons’ principal function, Harmonic oscillator and Kepler problem by Hamilton - Jacobi method, Action angle variables for completely separable system, Kepler problem in Action angle variables, Geometrical optics and wave mechanics.

**Module-III**

***Small oscillation:***

Problem of small oscillations, Example of two coupled oscillator, General theory of small oscillations, Normal coordinates and Normal modes of vibration, Free vibrations of a linear Triatomic molecule.

***Rigid body motion:***

The independent of coordinates of a rigid body, orthogonal transformations, The Eulers angles, The Cayley-Klein parameters, Eulers theorems on the motion of a rigid body, infinitesimal rotations, rate of change of a vector, The Coriolis Force.

***Rigid body dynamics:***

Angular Momentum and kinetic energy of motion about a point. The Inertia Tensor and momentum of Inertia, Eigenvalues of Inertia Tensor and the principal Axis transformation. The Heavy symmetrical Top with one point Fixed.

***Non-Linear Systems:***

Elementary idea about non- linearity and chaos.

**BOOKS:**

1. Classical Mechanics -H. Goldstein
2. Classical Mechanics - Landau and Liftshitz
3. Classical Mechanics Corben&Stehle
4. Classical Dynamics Marion & Thornton
5. Analytical Mechanics L. Hand and J. Finch
6. Classical Mechanics J. C. Upadhyaya

**Course Outcomes:**

Students will be able to:

1. Define and understand basic mechanical concepts related to discrete and continuous mechanical systems,
2. Describe and understand the vibrations of discrete and continuous mechanical systems,
3. Describe and understand planar and spatial motion of a rigid body and understand the motion of a mechanical system using Lagrange-Hamilton formalism.
4. Demonstrate a working knowledge of classical mechanics and its application to standard problems such as central forces.

**Core-2: Mathematical Methods in Physics-I (PPCPH102)**

**Course Objective:**

The objectives of this course are to:

1. Provide students with basic skills necessary for the application of mathematical methods in physics.
2. Introduction of various existing mathematical methods in order to analyse theories, methods and interpretations.
3. Develop understanding among the students how to use methods within his/her field of study of research and in the field of scientific knowledge to work independently.

**Module-I**

***Complex Analysis:***

Brief revision of Complex Numbers and their Graphical Representation. Euler's formula, De Moivre's theorem, Roots of Complex Numbers. Functions of Complex Variables. Analyticity and Cauchy-Riemann Conditions. Examples of analytic functions. Singular functions: poles and branch points, order of singularity, branch cuts. Integration of a function of a complex variable. Cauchy's Inequality. Cauchy’s Integral formula. Simply and multiply connected region. Laurent and Taylor’s expansion. Residues and Residue Theorem. Application in solving definite Integrals.

**Module-II**

***Integral Transforms:***

Fourier Transforms: Fourier Integral theorem. Fourier Transform. Examples. Fourier transform of trigonometric, Gaussian, finite wave train & other functions. Representation of Dirac delta function as a Fourier Integral. Fourier transform of derivatives, Inverse Fourier transform, Convolution theorem. Properties of Fourier transforms (translation, change of scale, complex conjugation, etc.). Three-dimensional Fourier transforms with examples. Application of Fourier Transforms to differential equations: One-dimensional Wave and Diffusion/Heat Flow Equations.

**Module-III**

***Laplace Transforms:***

Laplace Transform (LT) of Elementary functions. Properties of LTs: Change of Scale Theorem, Shifting Theorem. LTs of Derivatives and Integrals of Functions, Derivatives and Integrals of LTs. LT of Unit Step function, Dirac Delta function, Periodic Functions. Convolution Theorem. Inverse LT. Application of Laplace Transforms to Differential Equations: Damped Harmonic Oscillator, Simple Electrical Circuits.

***Groups and Group representation:***

Definition of groups, Finite groups, example from solid state physics, sub groups and classes, Group Representation, Combining Representation (Chlebsch Gorden) Characters, Infinite groups and Lie groups, Lie algebra and application, Irreducible representation of SU(2), SU(3)and O(3). Beta and Gamma functions.

**BOOKS:**

1. Mathematical methods of physics J. Mathews & R. L. Walker.
2. Mathematical methods of physics Arfken and Weber.
3. Mathematical methods for physicists Dennery & Krzywicki.
4. Mathematical methods of physics H. K. Das
5. Mathematical methods of physics Dr. Rama verma (S. Chand)
6. Mathematical methods of physics Satyaprakash (S. Chand)
7. Mathematical methods of physics Binoy Bhattacharya. (NCBA Publication)
8. Introduction to Tensor calculus - Goreux S. J.
9. Mathematical methods of physics Dettman J. W.
10. Advanced Engineering Mathematics, E. Kreyszig (New Age Publication) 2011.
11. Complex Variables, A. S. Fokas& M. J. Ablowitz, 8th Ed., 2011, Cambridge Univ. Press
12. Complex Variables and Applications, J. W. Brown & R. V. Churchill, 7th Ed. 2003, Tata McGraw•
13. First course in complex analysis with applications, D. G. Zill and P. D. Shanahan, 1940, Jones & Bartlett.
14. Mathematical Physics –C. Harper, (Prentice Hall India) 2006.
15. Mathematical Physics-Goswami (Cengage Learning) 2014

**Course Outcomes:**

Upon completion of this course, students should be able to:

1. Demonstrate the utility and limitations of a variety of powerful calculation techniques and to provide a deeper understanding of the mathematics underpinning theoretical physics.
2. Understand elementary ideas in linear algebra, special functions and complex analysis.
3. Will be able to apply these to solve problems in classical, statistical and quantum mechanics, electromagnetism as well as solid state physics.
4. Use integral transform methods (Fourier Transform and Laplace Transform) to solve elementary differential equations in physics and engineering.

**Core-3: Quantum Mechanics-I (PPCPH103)**

**Course Objectives:**

Students will be able to:

1. Study postulates and formalism of quantum mechanics
2. Study operator formulation of quantum mechanics
3. Study time evolution of a state and operator and apply Schrodinger equation to 1D harmonic oscillator
4. Study operator algebra of orbital angular momentum and spin angular momentum operator
5. Study motion in spherical symmetric potential and apply Schrodinger equation to solve hydrogen atom

**Module-I**

***General principle of Quantum mechanics:***

Linear Vector Space Formulation: Linear vector Space (LVS) and its generality. Vectors: Scalar product, metric space, basis vectors, linear independence, linear superposition of general quantum states, completeness and orthogonal relation, Schmidtsorthonormalisation procedure, Dual space, Bra and Ket vectors, Hilbert space formalism for quantum mechanics.

***Operator:***

Linear, Adjoint, hermitian, Unitary, inverse, anti linear operators, Non commutativity and uncertainty relation, complete set of compatible operators, simultaneous Measurement, Projection operator, eigenvalue and Eigenvector of linear, hermitian, Unitary operators, Matrix representation of vectors and operators, matrix elements, eigenvalue equation and expectation value, algebraic result on Eigenvalues, transformation of basis vectors, similarity transformation of vectors and operators, diagonalization. Vectors of LVS and wave function in co-ordinate, momentum and energy representations.

**Module-II**

***Quantum Dynamics:***

Time evolution of quantum states, time evolution of operators and its properties, Schrodinger picture, Heisenberg picture, Dirac/Interaction picture, Equation of motion, Operator method of solution of 1D Harmonic oscillator, time evolution and matrix representation of creation and annihilation operators, Density matrix.

Rotation and orbital angular momentum:

Rotation matrix, Angular momentum operators as the generation of rotation, components of angular momentum Lx, Ly, Lz and L2 and their commutator relations, Raising and lowering operators L+ and L\_; Lx, , Ly , Lz and L2 in spherical polar co-ordinates, Eigenvalue and eigen function of Lz and L2 (operator method), Spherical harmonics, matrix representation of Lz, L+, L\_ and L2, .

***Spin angular momentum:***

Spin 1/2 particle, Pauli spin matrices and their properties, Eigenvalues and Eigen function, Spinor transformation under rotation.

**Module-III**

***Addition of angular momentum:***

Total angular momentum J. Eigenvalue problem of Jz and J2, Angular momentum matrices, Addition of angular momenta and C. G. Coefficients, Angular momentum states for composite system in the angular momenta (1/2, 1/2) and (1, 1/2).

***Motion in Spherical symmetric Field:***

Hydrogen atom, Reduction to one dimensional one body problem, radial equation, Energy eigenvalue and Eigen function, degeneracy, radial probability distribution, evaluation of <r>, <1/r>, <r2> for H-atom.

***Free particle problem:***

Incoming and outgoing spherical waves, expansion of plane waves in terms of partial waves. Bound states in a 3-D square well potential, particle in a sphere.

**Books:**

1. Quantum Mechanics S. Gasiorowicz
2. Quantum Mechanics J. Sukurai
3. Quantum Mechanics R. Shankar
4. Quantum Mechanics S. N. Biswas
5. Quantum Mechanics A. Das
6. Quantum Mechanics A. Ghatak and S. Lokanathan
7. Advanced Quantum Mechanics P. Roman
8. Quantum Mechanics (Non Relativistic theory) L. D. Landau and E. M. Lifshitz
9. Elementary Theory of Angular Momentum M. E. Rose
10. Principles of Quantum Mechanics P. A. M. Dirac
11. Quantum Mechanics, concepts and application, N Zettili

**Course Outcomes:**

Students will be able to:

1. State basic postulates of quantum mechanics
2. Understand properties of different operators such ashermitean operators, projection operators, unitary operators etc.
3. Solve Schrodinger equation of harmonic oscillator problem completely by operator method
4. State addition of angular momentum theorems and spin angular momentum statistics
5. Solve the Schrodinger equation for the hydrogen atom

**Core-4: Electrodynamics (PPCPH104)**

**Course Objectives:**

Students will be able to:

1. Study Maxwell’s wave equation in different dielectric media and free space
2. Understand vector and scalar potential and their importance in electromagnetics
3. Study electromagnetic energy transport and Poynting vector
4. Understand Lorentz and Coulomb gauge conditions, covariant form of Maxwell’s equation.
5. Study laws of geometrical optics using Maxwell’s equation
6. Study Kramer Kronig relation on reflection and absorption of electromagnetic wave
7. Study and understand propagation of electromagnetic waves in different types of waveguides.
8. Study of retarded potential and solving it by Green’s Function techniques for different types of charge distributions
9. Study electric, magnetic dipole and quadrupole radiation
10. Study electromagnetic radiation due to moving point charge and accelerated charge

**Module-I**

***Electrostatics:***

Method of Images, Point Charge in the Presence of a Grounded Conducting Sphere, Point Charge in the Presence of a Charged, Insulated, Conducting Sphere, Point Charge Near a Conducting Sphere at Fixed Potential, Conducting Sphere in a Uniform Electric Field by Method  of Images, Green Function for the Sphere; Orthogonal Functions and Expansions, Separation of Variables; Laplace Equation in Rectangular, Coordinates, A Two-Dimensional Potential Problem; Summation of Fourier Series, Fields and Charge Densities in Two-Dimensional Corners and Along Edges. Solving potential problem using conformal transformation.

***Dielectrics polarisation:***

Multipole Expansion, Multipole Expansion of the Energy of a Charge Distribution in an External Field, Elementary Treatment of Electrostatics with Ponderable Media, Boundary-Value Problems with Dielectrics, Molecular Polarizability and Electric Susceptibility, Models for Electric Polarizability, Electrostatic Energy in Dielectric Media.

**Module-II**

***Magnetostatics:***

Introduction and Definitions, Biot and Savart Law, Differential Equations of Magnetostatics and Ampere's Law, Vector Potential, Vector Potential and Magnetic Induction for a Circular Current, Loop, Magnetic Fields of a Localized Current Distribution, Magnetic Moment, Force and Torque on and Energy of a Localized Current Distribution in an External Magnetic Induction, Macroscopic Equations, Boundary Conditions on B and H, Methods of Solving Boundary-Value Problems in Magnetostatics, Uniformly Magnetized Sphere, Magnetized Sphere in an External Field.

***Time varying field, Faraday’s law and Displacement current:***

Faraday's Law of Induction, Energy in magnetic field, Energy of self and mutual induction; Maxwells equations in free space; Magnetic charge; Maxwells equations inside matter; Displacement current; Vector and scalars potentials; Wave equation for potentials; Lorentz and Coulomb gauge conditions; Wave equation for Electric and Magentic fields in absence of sources. Derivation of the Equations of Macroscopic Electromagnetism.

**Module - III**

***Covariant Formulation of Maxwell’s Equation:***

Lorentz transformation; Scalars, vectors and Tensors; Maxwell’s equations and equations of continuity in terms of A and J; Electromagnetic field tensor and its dual; Lagrangian for a charged particle in presence of external electromagnetic field and Maxwell’s equation as Euler-Lagrange equations.

***Plane Waves in Non-Conducting Media:***

Plane waves in non-conducting media; velocity of wave propagation and energy flow; linear, circular and elliptic polarization; Reflection and refraction of electromagnetic waves at a plane inter-face between dielectrics; normal and oblique incidence; total internal reflection and polarization by reflection; waves in dispersive media, Kramer-Kronig relation.

***Plane Waves in Conduction Media:***

Plane waves in conduction media; Reflection and transmission at a conducting surface; Cylindrical cavities and wave guides; Modes in rectangular wave guide and resonant cavities. Diffraction:  Kirchhoff 's formulation of diffraction by a circular aperture. Electromagnetic fields of moving point charge using Lorentz transformation.

**Books:**

1. Classical Electrodynamics - J. D. Jackson
2. Classical Theory of Fields - L. Landau and Lifshitz
3. Introduction to Electrodynamics - D. J. Griffiths.
4. Classical Electricity and Magnetism – Panofsky and Phillips

**Course Outcomes:**

Students will be able to:

1. Write down and analyze Maxwell’s wave equation in different media
2. Derive scalar and vector potential in presence of different sources
3. Derive the Poynting theorem
4. Apply Gauge invariance condition to Maxwell’s equation
5. Derive Maxwell’s equation in co-variant form
6. Derive covariant form of Maxwell’s equations
7. Derive relation between reflection coefficient and absorption coefficient
8. Calculate different modes of electromagnetic waves in waveguides
9. Calculate angular distribution of radiation and power emitted by dipole
10. Show that accelerating charge produce electromagnetic radiation

**SEC-1: Research Methodology (POEPH105)**

**Course Objectives:**

Students will be able to:

1. Understand how to do literature survey to start any scientific research
2. Learn digital platforms available for survey of scientific research articles
3. Learn how to write scientific articles and ethics involved in that.
4. Learn how to do scientific data analysis.

**Module-I**

***Literature Survey:***

Print: Sources of information: Primary, secondary, tertiary sources; Journals: Journal abbreviations, abstracts, current titles, reviews, monographs, dictionaries, Text-Books, current contents Subject Index, Substance Index, Author Index, Formula Index, and other Indices with examples.

***Digital:***

Web resources, E-journals, Journal access, TOC alerts, Hot articles, Citationindex, Impact factor, H-index, E-consortium, UGC infonet, E-Books, Internet discussion groups and communities, Blogs, Preprint servers, Search engines, Scirus, Google Scholar, Wiki- Databases, Science Direct, Sci Finder, Scopus. Information Technology and Library Resources: The Internet and World Wide Web. Internet resources for Physics. Finding and citing published information.

**Module-II**

***Methods of Scientific Research and Writing Scientific Papers:***

Reporting practical and project work. Writing literature surveys and reviews. Organizing a poster display. Giving an oral presentation. Writing scientific papers – justification for scientific contributions, bibliography, description of methods, conclusions, the need for illustration, style, publications of scientific work. Writing ethics. Avoiding plagiarism.

**Module-III**

***Data Analysis:***

The Investigative Approach: Making and Recording Measurements. SI Units and theiruse. Scientific method and design of experiments. Analysis and Presentation of Data: Descriptive statistics. Choosing and using statistical tests. Analysis of variance (ANOVA), Correlation and regression, Curve fitting, fitting of linear equations, simple linear cases, weighted linear case, analysis of residuals, General polynomial fitting, linearizing transformations, exponential function fit, r and its abuse. Basic aspects of multiple linear regression analysis.

**Books**

1. Dean, J. R., Jones, A. M., Holmes, D., Reed, R., Weyers, J. & Jones, A.(2011) Practical skills in chemistry. 2nd Ed. Prentice-Hall, Harlow.
2. Hibbert, D. B. & Gooding, J. J. (2006) Data analysis for chemistry. Oxford University Press.
3. Topping, J. (1984) Errors of observation and their treatment. Fourth Ed., Chapman Hall, London.
4. Levie, R. de, How to use Excel in analytical chemistry and in general scientific data analysis. Cambridge Univ. Press (2001) 487 pages.

**Course Outcomes:**

Students will be able to:

1. Do literature survey for scientific research
2. Tell citation notation and index values of scientific research article.
3. Write project report and scientific research article.
4. Do scientific data analysis such as plotting, error analysis, curve fitting etc.

**SEC-1: Fundamentals of Computer and Programming in C (POECS103)**

**Module-I**

***Introduction***

Algorithm, flowchart, Structured Programming Approach, structure of C program (header files, C preprocessor, standard library functions, etc.), identifiers, basic data types and sizes, Constants, variables, arithmetic, relational and logical operators, increment and decrement operators, conditional operator, bitwise operators, assignment operators, expressions, type conversions, conditional expressions, precedence and order of evaluation. Input-output statements, statements and blocks, if and switch statements, loops:-while, do-while and for statements, break, continue, goto, programming examples.

**Module-II**

***Designing structured programs:***

 Functions, parameter passing, storage classes- extern, auto, register, static, scope rules, user defined functions, recursive functions. Arrays- concepts, declaration, definition, accessing elements, and functions, two-dimensional and multi-dimensional arrays, applications of arrays. pointers- concepts, initialization of pointer variables, pointers and function arguments, address arithmetic, Character pointers and functions, pointers to pointers, pointers and multidimensional arrays, dynamic memory management functions, command line arguments

**Module – III**

***Derived types-structures:***

Declaration, definition and initialization of structures, accessing structures, nested structures, arrays of structures, structures and functions, pointers to structures, self-referential structures, unions, typedef, bit fields, C program examples. Input and output – concept of a file, text files and binary files, streams, standard I/O, Formatted I/O, file I/O operations, error handling, C program examples.

**BOOKS:**

1. Balagurusamy: “C Programming” Tata McGraw-Hill
2. P. Dey & M. Ghosh, “Computer Fundamental & Programming in C”-Oxford University Press
3. Deitel - “C How to programme” PHI publication/ Pearson Publication

**Lab 1 (Core Lab-1): General Physics Laboratory (PLCPH101)**

***List of Experiments:***

1. To calculate the velocity of ultrasonic sound through solid medium using ultrasonic interferometer.
2. To calculate the adiabatic compressibility of the given solid using ultrasonic interferometer
3. Verification of Stefan’s law and Stefan’s constant measurement.
4. Determination of magnetic susceptibility of a paramagnetic solution using Quinck’s tube method.
5. Measurement of dielectric constant by plate capacitor.
6. To determine the Planck’s constant using LEDs of at least 4 different colors.
7. To study different Flip-flop
8. Measurement of very small resistance using Precision Kelvin double bridge (Maxwell double bridge).
9. To determine wavelength of He-Ne laser using plane diffraction grating
10. Calibration of an oscilloscope using standard waveform.
11. Determination of particle size of lycopodium powder by light scattering
12. To study the dependency of the magnetic field on coil diameter and number of turns
13. To study of Resonance absorption of a passive RF oscillator circuit
14. Determining the refractive index and dispersion of liquids using hollow prism and a light source
15. To verify the relationship of speed of light with permeability and permittivity of air.
16. Determination of specific charge of electron (e/m)
17. Determination of electrical permittivity of free space and dielectric constant of various materials.

**Lab 2 (SEC Lab-1): Programming in C Laboratory (PLCCS103)**

**(Minimum 10 programs to be done covering 8 Experiments)**

**Experiment No. 1**

1. Write a C program to find the sum of individual digits of a positive integer.
2. A Fibonacci sequence is defined as follows: the first and second terms in the sequence are 0 and 1. Subsequent terms are found by adding the preceding two terms in the sequence. Write a C program to generate the first n terms of the sequence.
3. Write a C program to generate all the prime numbers between 1 and n, where n is a value supplied by the user.

**Experiment No. 2**

1. Write a C program to calculate the following Sum: Sum=1-x2 /2! +x4 /4!-x6 /6!+x8 /8!-x10/10!
2. Write a C program to find the roots of a quadratic equation.

**Experiment No. 3**

Write C programs that use both recursive and non-recursive functions i) To find the factorial of a given integer. ii) To find the GCD (greatest common divisor) of two given integers. iii) To solve Towers of Hanoi problem.

**Experiment No. 4**

1. Write a C program to find both the larges and smallest number in a list of integers.
2. Write a C program that uses functions to perform the following: i) Addition of Two Matrices ii) Multiplication of Two Matrices

**Experiment No. 5**

1. Write a C program that uses functions to perform the following operations: i) To insert a sub-string in to given main string from a given position. ii) To delete n Characters from a given position in a given string.
2. Write a C program to determine if the given string is a palindrome or not

**Experiment No. 6**

1. Write a C program to construct a pyramid of numbers.
2. Write a C program to count the lines, words and characters in a given text.

**Experiment No. 7**

1. Write a C program that uses functions to perform the following operations:
2. Reading a complex number
3. Writing a complex number
4. Addition of two complex numbers
5. Multiplication of two complex numbers (Note: represent complex number using a structure.

**Experiment No. 8**

1. Write a C program which copies one file to another.
2. Write a C program to reverse the first n characters in a file. (Note: The file name and n are specified on the command line.

**BOOKS:**

1. PVN. Varalakshmi,
2. Project Using C Scitech Publisher

**Lab 2 (SEC Lab-1): Advanced Computational Physics Laboratory (PLCCS104)**

Introduction to computer hardware and software, introduction to storage in computer memory, stored program concepts, storage media computer operating system, LINUX, Commands;

***JAVA programs on:***

1. Introduction, Compiling & executing a java program.
2. Data types & variables, decision control structures: if, nested if etc.
3. Loop control structures: do, while, for etc.
4. Classes and objects.
5. Data abstraction & data hiding, inheritance, polymorphism.
6. Threads, exception handlings and applet programs
7. Interfaces and inner classes, wrapper classes, generics

***Programming with FORTRAN:***

Programme solving on computers-algorithm and flow charts in FORTRAN 77 data types, Exercises for acquaintance:

1. Find the largest or smallest of a given set of numbers
2. To generate and print 1st hundred prime numbers
3. Sum of an AP series, GP series, Sine series, Cosine series
4. Factorial of a number
5. Transpose of a square matrix
6. Matrix multiplication and addition
7. Evaluation of log and exponentials
8. Solution of quadratic equation
9. Division of two complex numbers
10. To find the sum of the digits of a number
11. Basic introduction to parallel programming, open MP & MPI

***Numerical Methods:***

1. Interpolation by Lagrange methods
2. Numerical solution of simple algebraic equation by Newton-Ralphson Methods
3. Least square fit using rational functions
4. Numerical integration: Trapezoidal methods, Simsons method, Romberg method, Gauss quadrature method.
5. Eigenvalues and Eigenvectors of a matrix
6. Solution of linear homogenous equations
7. Trace of a matrix
8. Matrix inversion
9. Solution of ordinary differential equation by Runge-Kutta Method
10. Introduction to Monte Carlo techniques

**Semester-2**

**Core-5: Statistical Mechanics (PPCPH201)**

**Course Objectives:**

Students will be able to:

1. Understand postulates of classical and quantum statistical mechanics
2. Study different formalism of statistical physics such as microstate, macrostate and ensembles
3. Understand the Boltzmann and Gibb’s interpretation of entropy.
4. Study Fermi-Dirac statistics and Bose-Einstein statistics
5. Understand phase transitions and Ising model to study ferromagnetism

**Module-I**

***Classical Statistical Mechanics:***

Review of Thermodynamics

***Classical probabilities:***

Binomial distribution of probability, variance, mean value; Poisson’s distribution, fluctuation, variance, mean value; Gaussian distribution, variance, mean value and applications.

***Classical statistical Mechanics:***

Basic principles and application of classical statistical mechanics, Liouville’s theorem, micro canonical ensemble, density functions, review of thermodynamics, equipartition theorem, classical ideal gas, Gibb’s paradox, Canonical ensemble, density functions and energy fluctuation, grand canonical ensemble, density function and density fluctuation, Equivalence of Canonical and grand canonical ensemble.

**Module-II**

***Quantum Statistical Mechanics:***

The density matrix, ensembles in quantum statistical mechanics, third law of thermodynamics, Ideal gas in micro, canonical and grand canonical ensembles, Distribution functions for Maxwell- Boltzman, Fermi-Dirac and Bose- Einstein systems

***Ideal Fermi Gas:***

Equation of states for ideal Fermi gas, thermodynamics, behaviour of ideal Fermi gas in low density and high temperature, and in high density and low temperature, Specific heat, Zero-point Pressure. Theory of white dwarf stars.

***Ideal Bose gas:***

Equation of state of an ideal Bose gas in grand canonical ensemble, internal energy, Photons and Planck’s radiation law, Stefan’s law, Bose-Einstein condensation and thermodynamics in condensed state. Phonons and behavior of specific heat of solids at different temperatures.

**Module-III**

***Ising model:***

Definition of Ising model, One-dimensional Ising model and its application to Ferromagnetism.

***Phase Transition:***

Thermodynamics description of Phase Transitions, Phase Transitions of first and second kind, order parameter, Landau theory of phase transition and its application to magnetic systems, critical indices, scale transformation and dimensional analysis,

***Fluctuations:***

Correlation of space-time dependant fluctuation, fluctuations and transport phenomena, Brownian motion.

**Books:**

1. Statistical physics - K. Huang
2. Statistical Physics- B B Laud
3. Statistical physics - R. K. Pathria
4. Statistical physics - F. Mohling
5. Elementary Statistical physics - C. Kittel
6. Statistical physics - Landau and Lifsitz
7. Physics Transitions & Critical Phonomena – H. E. Stanly
8. Fundamental of statistical & Thermal physics- F. Reif

**Course Outcomes:**

Students will be able to:

1. State postulates of classical and quantum statistical mechanics
2. Differentiate between microstate and macrostate
3. Tell the significance Gibb’s paradox and indistinguishability in statistical mechanics
4. Describe Planck’s blackbody radiation relation, electronic specific heat in metals and Bose-Einstein condensation
5. Describe thermodynamics of phase transition and formulate the Ising model of phase transitions for ferromagnetism.

**Core-6: Mathematical Methods in Physics-II (PPCPH202)**

**Course Objectives:** Students will be able to:

1. Familiar with advanced mathematical methods of physics
2. Develop required mathematical skills to solve various problems in classical mechanics, quantum mechanics and electrodynamics.

**Module-I**

***Tensor analysis:***

Cartesian tensor in three space, Curves in three space and Frenet Formula, General Tensor analysis, geodesics.

**Module-II**

***Special functions:***

Elementary functions in terms of Hypergeometric function, its intgral representation, confluent Hypergeometric function and its derivatives, integral representation.

Bessel’s differential equation, its solution, Bessel function in terms of Hypergeometric function, recurrence relation, its generating function, orthogonality relation, Bessel function of second kind, Neumann’s function, Hankel function, Spherical Bessel function.

Laguerre’s differential equation and its solution, generating function, recurrence relation, Laguerre’s function, Associated Laguerre’s differential equation and Lagurre Function.

**Module-III**

Ordinary differential equations, differential operations and Sturm- Liouville theory, Partial differential equations, Greens function in one, two and in three dimension, Solution of inhomogeneous partial differential equation by Green function method.

**BOOKS:**

1. Mathematical methods of physics, J. Mathews & R. L. Walker.
2. Mathematical methods of physics, Arfken and Weber.
3. Mathematical methods for physicists Denner and Krzywicki.
4. Mathematical methods of physics, H. K. Das
5. Mathematical methods of physics, Dr. Rama verma (S. Chand)
6. Mathematical methods of physics Satyaprakash (S. Chand)
7. Mathematical methods of physics Binoy Bhattacharya. (NCBA Publication)
8. Introduction to Tensor calculus - Goreux S. J.
9. Mathematical methods of physics Dettman J. W.
10. Gravitation and Cosmology, S Weinberg

**Course Outcomes:**

Students will be able to:

1. Understand basic theory of
2. Tensors
3. Special functions
4. Partial differential equations
5. Green’s function
6. Work with
7. Tensors in various fields of physics
8. Bessel functions
9. Green’s function to solve differential equations

**Core-7: Quantum Mechanics-II (PPCPH203)**

**Course Objectives:**

Students will be able to:

1. Understand the importance of perturbation theory in quantum mechanics
2. Study time independent and time dependent perturbation theory and apply those to various physical problem
3. Understand fine structure of hydrogen atom, Stark effect, Zeeman effect,
4. Understand interaction of radiation with matter, selection rules
5. Understand quantum mechanical description of scattering
6. Understand variational principle and its application

**Module-I**

***Approximation Method for stationary states:***

Rayleigh - Schrodinger Method for Time-independent Non degenerate Perturbation theory, First and second order correction, perturbed harmonic oscillator, An-harmonic oscillator, The Stark Effect, Quadratic Stark Effect and polarizability of Hydrogen atom, Degenerate perturbation theory, Removal of Degeneracy, parity selection rule, linear stark effect of hydrogen atom, Spin orbit Coupling, Relativistic correction, ne structure of Hydrogen like atom, normal and anomalous Zeeman effect, The strong- field Zeeman effect, The weak-field Zeeman effect and Lande’s g-factor. Elementary ideas about field quantization and particle processes.

**Module-II**

***Variational Methods:***

Rayleigh-Ritz variational technique and its application to He-atom.

***WKB Approximation***

General formalism, Validity of WKB method, Connection Formulae, derivation of Bohr quantization rule, Application to Harmonic oscillator, Bound states for potential well with one rigid wall and two rigid walls, Tunnelling through potential Barrier, Cold emission, Alpha decay and Geiger - Nutal relation.

***Time dependent perturbation Theory:***

Transition probability, constant and harmonic perturbation, Fermi Golden rule, electric dipole Radiation and Selection Rule, Spontaneous emission: Einstein’s A and B- coefficients, Basic principle of laser and Maser.

**Module-III**

***Scattering Theory:***

Scattering amplitude and Cross section. Born approximation, Application to Coulomb and Screened Coulomb potential, Partial wave analysis for elastic and inelastic Scattering. Effective range and Scattering length. Optical theorem, Black Disc Scattering, Hard-sphere Scattering, Resonance Scattering from square well potential. Complex potential and absorption.

***Identical Particles:***

Symmetric and antisymmetric wave function, collisions of identical particles, spin angular momentum, spin functions of many electron atoms.

**BOOKS:**

1. Quantum Mechanics -S. Gasiorowicz
2. Quantum Mechanics -J. Sukurai
3. Quantum Mechanics -R. Shankar
4. Quantum Mechanics -S. N. Biswas
5. Quantum Mechanics -A. Das
6. Quantum Mechanics -A. Ghatak and S. Lokanathan
7. Advanced Quantum Mechanics- P. Roman
8. Quantum Mechanics (Non-Relativistic theory) -L. D. Landau and E. M. Lifshitz
9. Elementary Theory of Angular Momentum -M. E. Rose
10. Principles of Quantum Mechanic -P. A. M. Dirac
11. Quantum Mechanics, Concept and Applications-N Zettili

**Course Outcomes:**

Students will be able to:

1. Derive energy and wavefunction for physical system using time independent perturbation theory
2. Derive transition probability under time dependent perturbation theory
3. Explain Stark effect, origin of polarizability and dipole moment, fine structure of hydrogen atom and Zeeman effect
4. Tell dipole selections rules in various atomic transitions
5. Find out scattering cross-section for various scattering process such as black sphere scattering, hard sphere scattering and inelastic scattering
6. Apply variational principle to find out the ground state energy of the various physical system

**Core-8: Experimental Techniques (PPCPH204)**

**Course Objectives:**

Students will be able to:

1. Understand basic working principle to use various experimental techniques for studying structural, morphological, optical, electrical properties various types of materials
2. Familiar with strength and limitations of various experimental techniques used in condensed matter and materials physics

**Module-I**

***Structure and microstructure characterizations:***

X Ray Diffraction (XRD), Electron diffraction, Neutron diffraction, Synchrotron

**Module-II**

***Imaging techniques:***

Transmission electron microscope (TEM), scanning electron microscope (SEM), scanning Probe Microscope (SPM), Atomic Force Microscope (AFM), Scanning tunnelling Microscope (STM)

**Module-III**

***Spectroscopic techniques:***

UV-Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR) techniques, Raman, X-ray photoelectron spectroscopy, Energy Dispersive X-ray Fluorescence (EDXRF)

**BOOKS**

1. Semiconductor material and device characterization by Dieter K. Schroder

**Course Outcomes:**

Students will be able to:

1. Understand basic theory of
2. X-ray and electron diffraction
3. Neutron diffraction
4. Electron microscope
5. Atomic force microscope
6. Scanning Tunneling microscope
7. Spectroscopic techniques
8. Know strength and limitations of
9. X - ray diffraction
10. Neutron diffraction
11. Scanning electron microscope (SEM)
12. Transmission electron microscope (TEM)
13. Scanning probe microscope (AFM and STM)
14. UV-visible and FTIR spectroscopy
15. Raman spectroscopy
16. X-ray photoelectron spectroscopy (XPS)

**Core-9: Electronics (PPCPH205)**

**Course Objectives:**

Students will be able to:

1. Understand operational principle, model and analysis of various amplifiers
2. Understand operational principle, model and analysis of various operational amplifiers
3. Understand operational principle, model and analysis of various oscillators
4. Understand operational principle, model and analysis of various digital circuits
5. Understand model and analysis of radio communication and antenna
6. Understand working principles of fiber optics

**Module-I**

***Amplifiers:***

Frequency response of linear amplifiers, amplifier pass band, Direct, RC and Transformer coupled amplifiers, Frequency response, gain band-width product, Feedback amplifiers, effects of negative feedback, Boot-strapping the FET, Multistage feedback, stability in amplifiers, noise in amplifiers.

***Operational amplifiers:***

The differential amplifiers, rejection of common mode signals. The operational amplifier input and output impedances, application of operational amplifiers, Unity-gain buffer, summing, integrating and differentiating amplifiers, comparators and logarithmic amplifiers.

**Module-II**

***Oscillator Circuits:***

Feedback criteria for oscillation, phase shift, Wien’s bridge oscillator, crystal-controlled oscillator, Klystron oscillator, Principle of multivibrator.

**Module-III**

***Digital Circuits:***

Logic fundamentals, Boolean theorem, Logic gates RTL, DTL and TTL gates, CMOS switch, RS flip- flop, JK flip-flop.

***Radio Communication and Antenna:***

Ionospheric propagation, Antennas of different types,

***Fibre Optics:***

Optical fibre, various types of optical fibres, Principle of propagation of light through Optical fibre, classification, optical Acceptance angle and optical cone of the fibre, numerical aperture, fractional index change, skip distance and number of total internal reflection, light sources, attenuation and application of optical fibre in communication.

**Books:**

1. Electronic Fundamental and application, J. D. Ryder
2. Int. Digital Electronics, Heap and Martin
3. Integrated Electronics, Millman and Halkias
4. Optical Fibres; J A Buck
5. Foundation of Electronics Chattopadhyay; Rakshit, Saha and Purkait
6. Optical Fibre Communication; G Kaiser

**Course Outcomes:**

Students will be able to:

1. Explain frequency response of linear amplifiers, feedback amplifier
2. Explain and design differential amplifier, sum and integrator
3. Explain feedback criteria for oscillation, crystal-controlled oscillator, Klystron oscillator, principle of multivibrator
4. Explain basic logic operations of NOT, AND, OR, NAND, NOR, XOR and flip-flops
5. Explain basic principles of radio communications and antennas
6. Explain basic principles optical fibers and electromagnetic wave propagation in optical fiber

**Lab 3 (Core Lab-2): Electromagnetic and Optics Laboratory (PLCPH201)**

***List of Experiments:***

1. Michelson’s interferometer: determination of wavelength of sodium lines.
2. Study of Fabry-perot interferometer.
3. To study the Hall Effect in semiconductors and determine Hall coefficient and Hall voltage.
4. To study the Hall Effect in semiconductors and determine number density of charge carriers
5. To study the Hall Effect in semiconductors and determine Hall mobility and Hall angle.
6. To determine the wavelength of (1) sodium and (2) Spectral lines of mercury light using plane diffraction Grating.
7. Calibration of magnetic field using Hall apparatus.
8. To determine angular spread of He-Ne laser using plane diffraction grating
9. To study the interference using laser and a double slit and find the wavelength of He-Ne laser source
10. Determination of thickness of air wedge and Newton’s ring experiment
11. Measurement of magneto-optic effect using Faraday effect
12. Measurement of atomic spectra of discharge lamps (H2, He, Ne)
13. Diffraction of light by straight edge using He-Ne laser
14. Measurement of electro-optic coefficient using Kerr effect
15. Diffraction of light by circular aperture (Pinhole)

**Lab 4 (Core Lab-3): Basic Electronics Laboratory (PLCPH202)**

1. Frequency response of operational amplifier with and without feedback.
2. To study Astable multivibrator characteristics.
3. To study Bistable multivibrator characteristics.
4. To study Monostable multivibrator characteristics.
5. To design a phase shift oscillator using BJT.
6. To add two dc voltages using Op-amp in inverting and non-inverting mode
7. Verification of Thevnin and Norton theorems
8. To verify the superposition and maximum power transfer theorems
9. To design a precision Differential amplifier of given I/O specification using Op-amp.
10. To investigate the use of an op-amp as an Integrator.
11. To investigate the use of an op-amp as a Differentiator.
12. To study the V-I characteristics of a LED.
13. To study the analog to digital converter (ADC) IC
14. To study the digital to analog converter (DAC) IC
15. To study Sensitivity of Wheatstone bridge

**Semester-3**

**Core 10: Advanced Quantum Mechanics & Quantum Field Theory (PPCPH301)**

**Course Objectives:**

1. To impact knowledge of advanced quantum mechanics for solving relevant physical problems.
2. To deepen understanding of Quantum Mechanics.

**Module-I**

***Relativistic Quantum Mechanics:***

Klein-Gordon equation, its solution and drawbacks, need for Dirac equation, Properties of Dirac matrices, Non-relativistic reduction of Dirac equation, magnetic moment, Darwins term, Spin-Orbit coupling, Poincare transformation, Lorentz group, Covariant form of Dirac equation, Bilinear covariants, Gordon decomposition.

**Module-II**

***Dirac Equation for free particles and symmetry Properties:***

Free particle solution of Dirac equation, Projection operators for energy and spin, Physical interpretation of free particle solution, Zitterbewegung, Hole theory, Charge conjugation, space reflection and time reversal symmetries of Dirac equation. Continuous systems and fields. Transition from discrete to continuous systems, Lagrangian and Hamiltonian Formulations, Noether’s theorem.

**Module-III**

***Quantization of free fields:***

Second quantization, Quantization of scalar and Dirac fields, Propagators for scalar, spinor and vector fields, Equal Time Commutators, Normal Ordering, covariant quantization of electromagnetic field, Gauge Invariance.

**Books:**

1. Advanced Quantum Mechanics - J. J. Sakurai
2. Relativistic Quantum Mechanics - J. D. Bjorken and S. D. Drell
3. Relativistic Quantum Fields - J. D. Bjorken and S. D. Drell
4. Quantum Field Theory - F. Mandl and G. Shaw
5. Quantum Field Theory - C. Itzykson and J. Zuber
6. Quantum Field Theory - M. E. Peskin and D. V. Schroeder
7. Quantum Field Theory - L. H.Ryder
8. Quantum Field Theory - S. Weinberg

**Course Outcomes:**

The aim of the course is to advance the students' understanding of non-relativistic and relativistic quantum mechanics. Students will have achieved the ability to:

1. A working knowledge of non-relativistic and relativistic quantum mechanics including time-dependent perturbation theory, relativistic wave equations, and second quantization.
2. Explain the relativistic quantum mechanical equations, namely, Klein-Gordon equation and Dirac Equation.
3. Describe second quantization and relative concept
4. Explain the formalism of relative quantum field theory.
5. Derive a mathematical description of quantum motion in electromagnetic fields.
6. Apply the relativistic wave equations to simple single-particle problems.

**Core 11: Nuclear and Particle Physics (PPCPH302)**

**Course Objectives:**

Students will be able to:

* Introduce students to the fundamental principles and concepts governing nuclear and particle physics and have a working knowledge of their application to real-life problems.
* Provide students with opportunities to develop basic knowledge and understanding of: scientific phenomena, facts, laws, definitions, concepts, theories, scientific vocabulary, terminology, conventions, scientific quantities and their determination, order-of magnitude estimates, scientific and technological applications as well as their social, economic and environmental implications.

**Module-I**

***General nuclear properties:***

Radius, mass, binding energy, nucleon separation energy, angular momentum, parity, electromagnetic moments, excited states.

***Two Nucleon Problem:***

Central and non-central forces, deuteron and its magnetic moment and quadrupole moment; Force dependent on isospin, exchange force, charge independence and charge symmetry of nuclear force, mirror nuclei.

***Nuclear models & Structure:***

Liquid drop model, fission, magic numbers, shell model, analysis of shell model predictions, beta stability line, collective rotations & vibrations, Form factor and charge distribution of the nucleus.

**Module-II**

***Nuclear reaction:***

Energetics of nuclear reaction, conservation laws, classification of nuclear reaction, radioactive decay, radioactive decay law, production and decay of radioactivity, radioactive dating,

***Alpha decay:***

Gamow theory of alpha decay and branching ratios,

***Beta decay:***

Energetics, angular momentum and parity selection rules, compound nucleus theory, resonance scattering, Breit- Wigner formula, Fermi's theory of beta decay, Selection rules for allowed transition, parity violation.

**Module-III**

***Particle Physics:***

Particle classification, fermions and bosons, lepton favors, quark flavors, electromagnetic, weak and strong processes, Spin and parity determination, Isospin, strangeness, hypercharge, baryon number, lepton number, Gell-Mann-Nishijima Scheme,

***Quarks in hadrons:*** Meson and baryon octet, Elementary ideas of SU (3) symmetry, charmonium, charmed mesons and B mesons, Quark spin and need for colour degree.

**BOOKS:**

1. Nuclear physics, Satyaprakash.
2. Nuclear and Particle Physics, Mital, Verma, Gupta.
3. Nuclear Physics, Dr. S. N. Ghosal.
4. Atomic and Nuclear physics, Shatendra Sharma.

**Course Outcomes:**

The student should be able to

1. Explain the different forms of radioactivity and account for their occurrence
2. Master relativistic kinematics for computations of the outcome of various reactions and decay processes.
3. Account for the fission and fusion processes.
4. Explain effects of radiation in biological matter.
5. Classify elementary particles according to their quantum numbers and draw simple reaction diagrams.

**Core 12: Basic Condensed Matter Physics (PPCPH303)**

**Module-I**

***Crystallography:***

Crystal lattice, crystal structure, symmetry elements in crystal, proper rotation axis, plane of symmetry, inversion center, screw axis, glide plane, types of bravais lattices, crystal structure: simple cubic, body centre cubic face centred cubic, HCP structure, Diamond structure, Zinc blende structure, Fluorite structure, perovskite structure, Weigner –Seitz cell, Miller indices.

***Lattice Vibration:***

Born Oppenheimer Approximation, Hamiltonian for lattice vibration in the harmonic Approximation, Normal modes of system. Phonons and lattice vibrations Vibrations of monoatomic and diatomic lattices, dispersion, optics& acoustic modes, quantum of lattice vibrations and phonon momentum.

**Module-II:**

***Free electron Fermi gas:***

Wave equation for an electron in a periodic potential, Bloch functions, Brillouin zones E-K diagram under free electron approximation. Density of state in one dimension, effect of temperature on Fermi-Dirac distribution, Free electron gas in three dimensions, heat capacity of electron gas, electrical and thermal conductivity of metals. Nearly free electron approximation-Diffraction of electrons by lattice planes and opening of gap in E-K diagram. Effective mass of electrons in crystals, Holes, Kronig Penney model, Tight binding approximation,

**Module-III:**

***Magnetism and Ferro electricity:***

Langevin’s theory of dia- and para-magnetism, Landau diamagnetism and Pauli paramagnetism, Weiss theory of ferromagnetism, Curie Weiss law of susceptibility, Heisenberg model- condition for ferro and anti-ferromagnetic order, Anti ferro magnetic order, Neel temperature.

Ferroelectric crystals, classification of Ferroelectric crystals, Multiferroics-Elementary concept

***Transport Properties:***

The Boltzmann equation, Electrical conductivity, General transport coefficients, Thermal conductivity, thermoelectric effect, Hall Effect.

***Nanomaterials:***

Nano structured materials-Classification based on spatial extention (0-D, 1-D, 2-D). 0-D nanostructures-quantum dots, Widening of band gap in quantum dots, 1-D nano structures-Quantum wells-super-lattices.

***Superconductivity:***

Experimental survey,Meisners effect, Type-I & Type-II superconductors, Thermodynamics of superconductors, Londons theory,

**BOOKS:**

1. Introduction to solid state physics by C. Kittel
2. Solid state physics by Ashcroft and Mermin
3. Principles of Condensed Matter physics by P. M. Chaikin and T. C. Lubensky
4. Solid state physics by A. J. Dekker
5. Solid state physics by O. E. Animaler
6. Quantum Theory Solid State by J. Callaway
7. Solid state physics by C. G. Kuper
8. Solid state physics David by W. Snoke (LPE Publication)
9. Solid state physics Dan Wei (Cengauge Learning)

**Core 13: Physics of Semiconductor Devices (PPCPH304)**

**Course Objectives:**

Students will be able to:

* Understand basic semiconductor device physics.
* Analyse the charge conduction across p-n junctions and devices.
* Understand the application of Field-Effect Transistors and Bipolar Junction Transistors.
* Design experiments for measuring semiconductor parameters and properties.
* Know the physics of semiconductor junctions, metal-semiconductor junctions and metal-insulator-semiconductor junctions.

**Module-I:**

***Introduction to the quantum theory of solids:***

Formation of energy bands, K-space diagram (two and three-dimensional representation), conductors, semiconductors and insulators. Electrons and Holes in semiconductors: Silicon crystal structure, Donors and acceptors in the band model, electron effective mass, Density of states, Thermal equilibrium, Fermi-Dirac distribution function for electrons and holes, Fermi energy. Equilibrium distribution of electrons & holes: derivation of n and p from D(E) and f(E), Fermi level and carrier concentrations, The np product and the intrinsic carrier concentration. General theory of n and p, Carrier concentrations at extremely high and low temperatures: complete ionization, partial ionization and freeze-out. Energy-band diagram and Fermi-level, Variation of EF with doping concentration and temperature. Motion and Recombination of Electrons and Holes: Carrier drift: Electron and hole mobilities, Mechanism of carrier scattering, Drift current and conductivity. Motion and Recombination of Electrons and Holes: Carrier diffusion: diffusion current, Total current density, relation between the energy diagram and potential, electric field. Einstein relationship between diffusion coefficient and mobility. Electron- hole recombination, Thermal generation.

**Module-II**

***PN Junction:***

Building blocks of the pn junction theory: Energy band diagram and depletion layer of a pn junction, Built-in potential; Depletion layer model: Field and potential in the depletion layer, depletion-layer width; Reverse-biased PN junction; Capacitance-voltage characteristics; Junction breakdown: peak electric field. Tunnelling breakdown and avalanche breakdown; Carrier injection under forward bias-Quasi- equilibrium boundary condition; current continuity equation; Excess carriers in forward- biased pn junction; PN diode I-V characteristic, Charge storage.

**Module-III**

***The Bipolar Transistor:***

Introduction, Modes of operation, Minority Carrier distribution, Collector current, Base cur-rent, current gain, Base width Modulation by collector current, Breakdown mechanism, Equivalent Circuit Models - Ebers-Moll Model.

***Metal-Semiconductor Junction:***

Schottky Diodes: Built-in potential, Energy-band diagram, I-V characteristics, Comparison of the Schottky barrier diode and the pn-junction diode. Ohmic contacts: tunnelling barrier, specific contact resistance.

***MOS Capacitor:***

The MOS structure, Energy band diagrams, Flat-band condition and at-band voltage, Surface accumulation, surface depletion, Threshold condition and threshold voltage, MOS C-V characteristics, Q in MOSFET.

***MOS Transistor:***

Introduction to the MOSFET, Complementary MOS (CMOS) technology, V-I Characteristics, Surface mobilities and high-mobility FETs, JFET, MOSFETVt, Body effect and steep retrograde doping, pinch-o voltage.

**BOOKS:**

1. Physics of Semiconductor Devices - Donald A. Neamann
2. Physics of Semiconductor Devices - B. B. Swain
3. Physics of Semiconductor Devices - AnjanaAcharya
4. Physics of Semiconductor Devices - Calvin Hu.
5. Physics of Semiconductor Devices - Dilip K Roy
6. Fundamentals of Semiconductor Devices- M. K. Achthanand K. N. Bhatt
7. Solid state Electronics Devices Bhattacharya, Rajnish Sharma
8. Semiconductor Materials and Devices J. B. Gupta
9. Physics of Semiconductor Devices – Jivan Jyoti Mohanty.

**Course Outcome**

Students will be able to:

1. Understand the basic materials and properties of semiconductors with application to the pn junction and diode circuits.
2. Understand the application of Field-Effect Transistors with the application of the design of amplifiers.
3. Understand the application of Bipolar Junction Transistors with the application of the design of amplifiers.
4. Know the physics of semiconductor junctions, metal-semiconductor junctions and metal-insulator-semiconductor junctions.
5. Students will acquire a thorough understanding on the devices and be able to apply the knowledge to the development of new and novel devices for different applications.

**Major Project: Project (PPRPH301)**

***Project evaluation guidelines:***

Every student will have to complete project in Semester with 100 marks. Students can take one long project (especially for SSP / SSE / Material Sc. / Nanotechnology / Nuclear /Particle physics etc). However, for the project students have to submit dissertation consisting of the problem definition, literature survey and status, objectives, methodology, experimental work, results and analysis. The project can be a theoretical or experimental project, related to advanced topic, electronic circuits, models, industrial project, training in a research institute, training of handling a sophisticated equipment etc. Maximum three students can do a joint project. Each one of them will submit a separate project report with details/part only he/she has done. However, he/she can in brief (in a page one or two) mention in Introduction section what other group members have done. In case of electronic projects, use of readymade electronic kits available in the market should be avoided. The electronics project / models should be demonstrated during presentation of the project. In case a student takes training in a research institute/training of handling sophisticate equipment, he/she should mention in a report what training he/she has got, which instruments he/she handled and their principle and operation etc.

Each project will be of 100 marks by internal evaluation.

The project report should be le bound/spiral bound/hard bound and should have following format

* Title Page/Cover page
* Certificate endorsed by Project Supervisor and Head of Department
* Declaration
* Abstract of the project
* Table of Contents
* List of Figures
* List of Table
* Chapters of Content:
* Introduction and Objectives of the project Experimental/Theoretical
* Methodology/Circuit/Model etc. details Results and Discussion if any
* Conclusions
* References

Evaluation by Internal examiner will be based on following criteria:

|  |  |
| --- | --- |
| Criteria | Maximum Marks |
| Literature Survey | 10 |
| Objectives/Plan of the project | 10 |
| Experimental/Theoretical methodology/Working condition of project or model | 20 |
| Significance and originality of the study/Society application and Inclusion of recent References | 10 |
| Depth of knowledge in the subject / Results and Discussions | 20 |
| Presentation | 30 |
| Total marks | 100 |

**Lab 5 (Core Lab-4): Advanced Electronics Laboratory (PLCPH301)**

***List of Experiments:***

1. Study of basic configuration of OP-AMP (IC-741), simple mathematical operations and its use as comparator and schmidt trigger
2. Study and design of differentiator, integrator and active filter circuits using OP-AMP (IC-741)
3. Study and design of phase shift oscillator using OP-AMP (IC-741)
4. Study of various logic families (DRL, DTL and TTL)
5. Study of Boolean logic operations using ICs
6. Design and study of full adder and subtractor circuits
7. Design and study of various flip flop circuits (RS, D, JK, T)
8. Design and study of various counter circuits (up, down, ring, mod-n)
9. Design and study of astable multivibrators using IC-555 Timer
10. To design a monostable multivibrator of given specifications using 555 Timer.
11. To design a digital to analog converter (DAC) of given specifications
12. Design and performance study of a constant current source
13. Design and performance study of a voltage-controlled oscillator
14. To design a switch (NOT gate) using a transistor.
15. To design a Wien bridge oscillator for given frequency using an op-amp

**Lab 6 (Core Lab-5): Basic Condensed Matter Physics Laboratory (PLCPH302)**

***List of Experiments:***

1. Study of energy gap of Germanium by four-probe method.
2. To draw the B-H curve of Fe using Solenoid & determine energy loss from Hysteresis.
3. To study the magnetic field along the axis of a current carrying solenoid
4. Verification of Richardson’s T3/2 law.
5. Study of Platinum resistance thermometer using Calendar and Griffith’s bridge.
6. Determination of Young’s modulus of a given specimen by Coronus method
7. To determine the Coupling Coefficient of Piezoelectric crystal.
8. Determination of Planck’s constant by reverse photoelectric effect method.
9. To study the PE Hysteresis loop of a Ferroelectric Crystal.
10. To determine the complex dielectric constant and plasma frequency of metal using Surface Plasmon resonance (SPR)
11. Dielectric constant at microwave frequency
12. To study the reflection, refraction of microwaves
13. To study the current vs voltage characteristics of CdS photo-resistor at constant irradiance
14. To measure the photocurrent as a function of the irradiance at constant voltage
15. Determination of reverse saturation current of P-N junction

**Semester-4**

**Core-14: Nano Science & Technology (PPCPH401)**

**Module-I**

***Nanostructured Materials:***

Classification based on spatial extension (0-D, 1-D, 2-D), Surface to volume ratio and quantum confinement, Density of states, Preparation of quantum nanostructures (top-down and bottom-up approach), Size effects, Excitons, Single electron tunneling, Applications: infrared detectors, Quantum Dot Lasers

***Properties of individual Nanoparticles:***

Metal nanoclusters: Magic numbers, Theoretical modelling of nanoparticles, Geometric structure, Electronic structures, reactivity, fluctuations, magic clusters, Bulk to nanostriction

Semiconducting Nanoparticles: Optical properties, photofragmentation, Coulombic explosion, Photoluminescence, thermo luminescence

**Module-II**

***Carbon nanostructures***

Carbon molecules: Nature of the carbon Bond, New carbon structures Small Carbon Clusters, Discovery of C60, Structure of C60 and its crystal, Alkali doped C60, Larger and Smaller Fullerenes, Other Bucky ball

***Carbon nanotubes:***

Fabrication, Structure, Electrical properties, Vibrational properties, Mechanical properties

Applications of carbon nanotubes: Field emission and shielding, computers, Fuel cells, Chemical Sensors, Catalysis, Mechanical Reinforcement

**Module-III**

***Bulk Nanostructured materials:***

Solid Disordered Nanostructures: Methods of synthesis, Failure mechanism of Conventional Grain- Sized Materials, Mechanical properties, Nanostructured Multilayers, Electrical properties, Other properties, Metal Nanocluster Composite Glasses, Porous Silicon

Nanostructured Crystals: Natural Nanocrystals, Computational Prediction of Cluster Lattices, Arrays of nanoparticles in Zeolites, Crystals of Metal Nanoparticles, Nanoparticle Lattices in Colloidal suspensions, Photonic Crystals

Physical Properties of Nanostructured Materials: Effect of size reduction on magnetic and electric behavior of materials, Dynamics of nanomagnets, Ferro fluids

**BOOKS:**

1. Introduction to Nanotechnology: Charles P. Poole, Jr., Frank J. Owens
2. Nanocrystal Quantum dots by Victor I. Klimov (Second Edition)
3. Solid State Physics by C. Kittel (Eigth Edition)

**Core-15: Atomic and Molecular Physics (PPCPH402)**

**Module-I**

***One Electron Atom:***

Introduction: Quantum States; Atomic orbital; Parity of the wave function; Angular and radial distribution functions.

***Hyperfine structure:***

Review of Fine structure and relativistic correction, Lamb shift. Hyperfine interaction and isotope shift; Hyperfine splitting of spectral lines; selection rules.

***Many electron atoms:***

Independent particle model; He atom as an example of central field approximation; Central field approximation for many electron atoms; Slatter determinant; L-S and j-j coupling; Equivalent and non-equivalent electrons; Energy levels and spectra; Spectroscopic terms; Hunds rule; Lande interval rule; Alkali spectra.

**Module-II**

***Molecular Electronic States:***

Concept of molecular potential, Separation of electronic and nuclear wave functions, Born-Oppenheimer approximation, Electronic states of diatomic molecules, Electronic angular momenta, Approximation methods for the calculation of electronic Wave function, The LCAO approach, States for Hydrogen molecular ion, Coulomb, Exchange and Overlap integrals, Symmetries of electronic wave functions; Shapes of molecular orbital and bond; Term symbol for simple molecules.

***Rotation and Vibration of Molecules:***

Solution of nuclear equation; Molecular rotation: Non-rigid rotator, Centrifugal distortion, Symmetric top molecules, Molecular vibrations: Harmonic oscillator and the anharmonic oscillator approximation, Morse potential.

**Module-III**

***Spectra of Diatomic Molecules:***

Transition matrix elements, Vibration-rotation spectra: Pure vibrational transitions, Pure rotational transitions, Vibration-rotation transitions, Electronic transitions: Structure, Franck-Condon principle, Rotational structure of electronic transitions, Fortrat diagram, Dissociation energy of molecules, Continuous spectra, Raman transitions and Raman spectra.

***Vibration of Polyatomic Molecules:***

Application of Group Theory, Molecular symmetry; Matrix representation of the symmetry elements of a point group; Reducible and irreducible representations; Character tables for C2v and C3v point groups; Normal coordinates and normal modes; Application of group theory to molecular vibration.

**BOOKS:**

1. B. H. Bransden and C. J. Joachain: Physics of Atoms and Molecules
2. C. Cohen-Tannoudji, B. Dier, and F. Laloe: Quantum Mechanics vol. 1 and 2
3. R. Shankar: Principles of Quantum Mechanics
4. C. B. Banwell: Fundamentals of Molecular Spectroscopy
5. G. M. Barrow: Molecular Spectroscopy
6. K. Thyagarajan and A. K. Ghatak: Lasers, Theory and Applications
7. O. Svelto: Principles of Lasers
8. B. H. Eyring, J. Walter and G. E. Kimball: Quantum Chemistry
9. W. Demtroder: Molecular Physics
10. H. Herzberg: Spectra of Diatomic Molecules
11. J. D. Graybeal: Molecular Spectroscopy
12. M. C. Gupta: Atomic and Molecular Spectroscopy
13. B. Laud: Lasers and Non-linear Optics
14. A. Thorne, U. Litzen and J. Johnson: Spectrophysics

**PE 1: Advanced Condensed Matter Physics (PPEPH401)**

**Module –I**

***Fermi surface:***

Construction of Fermi surface, Experimental methods of study of Fermi surface, Cyclotron resonance, de Hass van Alphen effect.

***Electron Interaction:***

Perturbation formulation, Dielectric function of an interacting electron Gas (Lindhard’s expression), static screening, screened impurity, Kohn effect, Friedel oscillations and sum rule, dielectric constant of semiconductor, plasma oscillation.

***Transport properties:***

Elementary ideas about Quantum Hall effect, magneto resistance, giant magneto resistance and colossal magneto resistance,

**Module-II**

***Electronic and lattice defects:***

Lattice defects, Frenkel and schottky defects, Line defects, Edge and screw dislocations-Burger’s Vector, planner (stacking) Faults- twin planes and grain boundaries Color centers-mechanism of coloration of a solid, F-center, other color centers.

***Excitons:***

Loosely bound, tightly bound, Excitonic Waves, Electron –hole droplets. Exotic Solids

**Module-III**

***Superconductivity:***

Electron-phonon interaction, Second quantized form of Hamiltonian for electrons and phonons interaction, electron-electron attractive interaction due to virtual phonon exchange, Cooper pairs and BCS Hamiltonian, Solution of BCS Hamiltonian- spin analog method. Elementary ideas on High Tc Superconductors.

***Josephson Effect:***

Microscopic quantum mechanical effect, Dc Josephson effect, Effect of electric field Ac/Inverse Ac Josephson effect, Effect of magnetic field, SQUID and other applications of superconductors.

**Books:**

1. D. Pines: Elementary Excitations in Solids S. Raimes: Many Electron Theory
2. O. Madelung: Introduction to Solid State Theory
3. N. H. March and M. Parrinello: Collective Effects in Solids and Liquids
4. H. Ibach and H. Luth: Solid State Physics: An Introduction to Theory and Experiments J. M. Ziman: Principles of the Theory of Solids
5. C. Kittel: Quantum Theory of Solids
6. M. Tinkham: Group Theory and Quantum Mechanics
7. M. Sachs: Solid State Theory
8. A. O. E. Animalu: Intermediate Quantum Theory of Crystalline Solids
9. N. W. Ashcroft and N. D. Mermin: Solid State Physics
10. J. M. Ziman: Principles of the Theory of Solids
11. C. Kittel: Introduction to Solid State Physics

**PE 1: Advanced Particle Physics (PPEPH402)**

**Module-I**

***Symmetry:***

Different types of symmetries and conservation laws. Noethers theorem.

***Symmetry groups and Quark model:***

SU(2) and SU(3): root and weight diagrams, Composite representation, Youngs tableaux, quark model, colour, heavy quarks and their hadrons.

**Module-II**

***Lorentz Group:***

Continuous and discrete transformations, Group structure, Proper and improper Lorentz Transformations, SL (2, C) representations, Poincare group.

***Interacting fields:***

Interaction picture, covariant perturbation theory, S-matrix, Wicks theorem, Feynman diagrams.

**QED:**

Feynman rules, Example of actual calculations: Rutherford, Bhabha, Moeller, Compton, e+ e-→ µ+ µ -. Decay and scattering kinematics. Mandelstam variables and use of crossing symmetry.

**Module-III**

***Gauge theories:***

Gauge invariance in QED, non-abelian gauge theories, QCD (introduction), Spontaneous symmetry breaking, Higgs mechanism.

***Electroweak Theory:***

Standard Model, Gauge boson and fermion masses, Neutral current, Experimental tests. Calculation of FB asymmetry in e+e-→ µ+ µ - and decay widths of W and Z (only at tree-level), Higgs physics. (13)

**BOOKS:**

1. Introduction to elementary particles By David J Griffith
2. M. Peskin and F. Schroeder: Quantum Field Theory
3. J. D. Bjorken and S. D. Drell: Relativistic Quantum Fields
4. D. Bailin and A. Love: Introduction to Gauge Field Theory
5. Lahiri and P. B. Pal: A First Book of Quantum Field Theory
6. F. Mandl and G. Shaw: Quantum Field Theory
7. P. Ramond: Field Theory: A Modern Primer
8. C. Itzykson and J. B. Zuber: Quantum Field Theory
9. F. Halzen and A. D. Martin: Quarks and Leptons
10. J. Donoghue, E. Golowich and B. Holstein: Dynamics of the Standard Model
11. T. -P. Cheng and L. -F. Li: Gauge Theories in Particle Physics
12. E. Leader and E. Predazzi: An Introduction to Gauge Theories and Modern Particle Physics
13. F. E. Close: An Introduction to Quarks and Partons

**OE 1: Advanced characterization Techniques (POEPH401)**

**Module-I**

***X-ray diffraction and reciprocal lattices***

Choice of x-ray, electron and Neutron for crystal structure determination, Bragg diffraction, Reciprocal lattices, The Bragg‘s condition and Ewald construction, Brillouin zones, Brillouin zones of SC, BCC, FCC lattices, Atomic scattering factor, Geometrical Structure factor, Laue method, Rotating crystal method, powder method, Electron diffraction, Geometrical nature of electron diffraction patterns, Indexing of electron diffraction spot pattern, electron microscope, transmission electron microscopy, Debye Scherrer Technique, Analysis of the powder photograph, The determination of lattice type and space group, crystal structure determination.

**Module-II**

***Microscope techniques:***

Electron Microscope: SEM, TEM, FESEM, HRTEM

Scanning probe microscopy: Atomic Force microscopy, Scanning-tunnelling microscopy.

**Module-III**

***Spectroscopic Techniques:***

UV-visible Spectroscopy, Raman spectroscopy, Neutron scattering, X-ray scattering, x-ray photoelectron spectroscopy.

**BOOKS:**

1. Advanced Techniques for Materials Characterization, A. K. Tyagi, Mainak Roy, S. K. Kulshreshtha and S. Banerjee Vol 49-51

**OE 1: Vacuum science and Technology (POEPH402)**

**Module-I**

Behavior of gases; Gas Transport phenomenon, Viscous, molecular and transition flow regimes, measurement of pressure, Residual gas analyses.

**Module-II**

Production of vacuum-mechanical pumps, Diffusion pump, Getter and ion pumps, cryopumps, material in vacuum; high Vacuum and ultra-high vacuum systems; Leak detection.

**Module-III**

Properties of engineering material at low temperature; cryogenic fluids-Hydrogen, Helium3, Helium4, superfluidity, experimental method at low temperature: closedcycle, Refrigerators, single and double cycle He 3 refrigerator, He4 refrigerator, He3-He4 dilution refrigerator, pomeranchunk cooling, pulsed refrigerator system, magneticre frigerators, Thermoelectric coolers; Cryostat Design: Cryogenic level sensors, Handling of cryogenic liquids, Cryogenic thermometry.

**BOOKS:**

1. Handbook of Vacuum Science and Technology Edited by: Dorothy M. Hoffman, Bawa Singh, John H. Thomas III and John H. Thomas III, ISBN: 978-0-12-352065-4
2. The Art of Cryogenics, 1st Edition, Low-Temperature Experimental Techniques, Guglielmo Ventura Lara Risegari

**OE 1: Material Science (POEPH403)**

**Module-I**

***Mechanical Properties***

Mechanical, Thermal and electrical properties of materials, Tensile Strength, stress-strain behavior, Ductile and brittle material, Toughness, hardness, fatigue, creep and fracture.

***Thermal properties:***

Thermal conductivity, thermoelectric effects, Electrical properties: electrical conductivity, energy band structure of conductors, semiconductors and insulators, type-I and Type-II superconductors and their application, dielectric, ferroelectric and piezoelectric material and their application.

**Module-II**

***Laser Physics:***

Basic elements of a laser; Threshold condition; Four-level laser system, CW operation of laser; Critical pumping rate; Population inversion and photon number in the cavity around threshold; Output coupling of laser power.

Optical resonators; Cavity modes; Mode selection; Pulsed operation of laser: Q-switching and Mode locking; Experimental technique of Q-switching and mode locking Different aser systems: Ruby, CO2, Dye and Semiconductor diode laser;

***Optical materials:***

Optical properties scattering, refraction, reflection, transmission and absorption, optical fibres-principle and application.

**Module-III**

***Soft condensed matter:***

Polymeric materials: Types of polymers, Mechanism of polymerization, Mechanical behaviour of polymers, Fracture in polymers, Rubber types and applications, Thermosetting and thermoplastics, conducting polymers:

***Composite Materials:***

Micro composites & Macro composites; fibre reinforced composites; Continuous fibre composites; Short fibre composites, Polymer matrix composites, Metal-matrix composites: Ceramic-matrix composites; Carbon-carbon Composites; Hybrid composites.

***Ceramics:***

Types, structure, properties and application of ceramic materials

***Other materials:***

Brief description of other materials such as Corrosion resistant materials, Nano phase materials, Shape memory alloy, SMART materials.

**BOOKS:**

1. Material Science and engineering: An Introduction, by William D. Callister, Jr. David G. Rethwisch, Wiley
2. Materials Science by M Vijaya, Rangarajan G, McGraw Hill Education
3. Materials Science and Engineering, V. Raghavan, Phi Learning

**Seminar: Seminar (PSEPH401)**

**Course Objectives:**

1. To learn, practice, and critique effective scientific seminar skills. Students develop presentation skills that will be essential during their entire professional careers. These skills will improve as students respond to critical feedback, and seek to make scientific information understandable to scientists, peers, and the general public.

**Learning Outcomes:**

Students will be able to:

1. Communicate science in a 30-40-minute oral scientific presentation
2. Understand and critique scientific presentations

***General Aspects of Oral Presentation:***

Presented at level that is appropriate to the audience; clear and informative visual aids (simple, sufficient time); evident that presenter has practiced.

***Introduction:***

Overview of your problem area provided; unfamiliar terms introduced; appropriate literature abstracted and presented clearly; research hypothesis of the study identified.

***Methods:***

Brief overview of the equipment and materials used, and how obtained; brief overview of the experimental design used and any other parts of the methods employed; materials and/or equipment described; procedures followed to conduct the experiment presented

***Results:***

Anticipated and actual results reported; statistics clearly presented.

***Discussion:***

Implications if the hypothesis is supported clearly stated; implications if the hypothesis is not supported clearly stated; limitations of your study discussed; future research addressed

***Questions:***

Demonstrated knowledge of the material; poised and confident, but no bluffing; answered the question(s) asked (asked for clarification or restatement of the question)

**Lab 7 (Core Lab-6): Modern Physics Laboratory (PLCPH401)**

***List of Experiments:***

1. To determine Rydberg constant from the Balmer series of Hydrogen emission.
2. To determine the wavelengths of Balmer series in the visible region from Hydrogen emission.
3. To setup the Millikan oil drop apparatus and determine the charge of an electron.
4. To demonstrate quantum nature of charge using Millikan oil drop apparatus
5. Existence of discrete energy level by Frank Hertz experiment.
6. To study the effect of filament voltage and anode plate voltage on the Frank-Hertz characteristic curve for neon
7. Study of polarization using Malus Law.
8. Determination of Brewster’s angle.
9. To analyze elliptically polarized Light by using a Babinets compensator.
10. To study damping oscillations in various medium.
11. Determination of temperature co-efficient of current for LED by Planck’s constant method
12. Rectification by junction Diode using various filters.
13. Study of junction capacitance of P-N junction
14. To study Normal and Anomalous Zeeman effect
15. To determine the refractive Index of (1) glass and (2) a liquid by total internal reflection using a Gaussian eyepiece

**Lab 8 (PE Lab 1): Advanced Condensed Matter Physics Laboratory (PLCPH402)**

***List of Experiments:***

1. Determination of magnetic susceptibility by Guoy-balance.
2. Measurement of Lande’s g factor of DPPII by ESR at Microwave frequency.
3. To observe Meissner effect and determine transition temperature of a given superconductor.
4. To study MOSFET characteristics.
5. Determination of Thermo-EMF of a thermocouple.
6. Determination of Magnetoresistance of Bismuth.
7. To characterize Solar cell and find out its power conversion efficiency.
8. To determine Dielectric constant of solid (wax) by Lecher Wire
9. To study lattice vibrations in mono- and di-atomic lattice using lattice dynamics kit.
10. Preparation of thin film using spin coating techniques
11. Study of lattice parameter of agiven material using X-ray diffraction technique
12. Measurement of resistivity of semiconductor by four probe method
13. To determine magnetic moment of an electron using ESR equipment
14. To study dielectric properties of a given substance using Impedance analyzer
15. Characterization of a given nanomaterial by Scanning electron microscope

**Lab 8 (PE Lab 1): Advanced Particle Physics Laboratory (PLCPH403)**

***List of Experiments:***

1. Calibration of the x-ray spectrometer and determination of x-ray energy of unknown sources.
2. Determination of resolving power of x-ray spectrometers.
3. Study of β spectrum.
4. Determination of absorption co-efficient of Aluminum using G. M Counter.
5. X-test and operating point determination using G-N tube.
6. Characteristics of G. M. counter.
7. Study of surface barrier detector.
8. Study of counter technique.
9. Study of single channel analyzer.
10. Study of photo detector and photo multiplier.
11. Study of wide-band amplifier.
12. Emulsion photograph studies