M.Sc. Physics Syllabus

BODOLAND UNIVERSITY

(Master of Science in Physics)
Choice Based Credit System (CBCS)

(Effective from Academic Year 2019-20)

Table of Contents

M.Sc. Physics Syllabus

Choice Based Credit System (CBCS)

(Master of Science in Physics)
BODOLAND UNIVERSITY, KOKRAJHAR

Programme Structure

Semester - I				
Course type	**Paper Code**	**Name of the Course**	**Credits (L+T+P)**	**Marks**
Core Courses	PHY101	Mathematical Physics – I	3+1+0 = 4	100
	PHY102	Classical Mechanics	3+1+0 = 4	100
	PHY103	Quantum Mechanics – I	3+1+0 = 4	100
	PHY104	Electronics	3+1+0 = 4	100
	PHY105P	General Physics Laboratory – I	0+0+5 = 5	100
Open Elective – I	PHY106(OE)	Nanostructures	2+0+0 = 2	50
	PHY107(OE)	Surface Science	2+0+0 = 2	50
	PHY108(OE)	Basic tools for data visualization & typesetting	2+0+0 = 2	50
Total			23	550
A student will have to choose any one of the above Open Electives-I.				

Semester - II				
Course type	**Paper Code**	**Name of the Course**	**Credits (L+T+P)**	**Marks**
Core courses	PHY201	Classical Electrodynamics	3+1+0 = 4	100
	PHY202	Quantum Mechanics – II	3+1+0 = 4	100
	PHY203	Nuclear Physics – I	3+1+0 = 4	100
	PHY204	Condensed Matter Physics – I	3+1+0 = 4	100
	PHY205P	General Physics Laboratory – II	0+0+5 = 5	100
Open Elective - II	PHY206(OE)	Basics of Vacuum Science & Low temperature Physics	2+0+0 = 2	50
	PHY207(OE)	Basics of Material Science	2+0+0 = 2	50
Total			23	550
A student will have to choose any one of the above Open Electives-II.				

Semester - III				
	Paper Code	**Name of the Course**	**(L+T+P)**	**Marks**
Core Courses	PHY301	Mathematical Physics - II	3+1+0=4	20+80
	PHY302	Computational Physics	2+0+2=4	20+40+40
Discipline Specific Electives				
Module A	PHY 303	Advanced Nuclear Physics - I (Theory)	3+1+0=4	20+80
	PHY303P	Advanced Nuclear Physics - I (Lab)	0+0+4 =4	20+80
Module B	PHY304	Advanced Condensed Matter Physics – I (Theory)	3+1+0=4	20+80
	PHY304P	Advanced Condensed Matter Physics – I (Lab)	0+0+4=4	20+80
Module C	PHY305	High Energy Physics - I	3+1+0=4	20+80
	PHY306	Advanced Mathematical Physics	3+1+0=4	20+80
	PHY307	Experimental High Energy Physics	3+1+0=4	20+80
Module D	PHY308	Advanced Optics-I	3+1+0=4	20+80
	PHY308P	Advanced Optics Lab	0+0+4=4	20+80
Total			24	600

- *A student has to choose any* ***two*** *of the above Modules as Discipline Specific Elective.*
- *Students who choose Module C have to take either PHY 306 or PHY 307 along with the course PHY305.*

Semester - IV				
Paper Code	**Name of the Course**		**(L+T+P)**	**Marks**
Core Courses	PHY401	Statistical Mechanics	3+1+0 = 4	100
	PHY402	Atomic & Molecular Physics	3+1+0 = 4	100
Discipline Specific Electives	PHY403	Advanced Nuclear Physics - II	3+1+0 = 4	100
	PHY404	Advanced Condensed Matter Physics – II	3+1+0 = 4	100
	PHY405	High Energy Physics - II	3+1+0 = 4	100
	PHY406	Advanced Optics-II	3+1+0 = 4	100
Core Courses	PHY407	Research Methodology & Techniques in Physics	3+1+2 = 6	100
	PHY408P	Project/Dissertation/Advanced Practical	6	100
Total			22	500

- *A student has to choose any* ***two courses*** *from Discipline Specific Electives.*
- *A student has to choose either PHY407 or PHY408P.*

Programme Specific Outcome

The students studying the M.Sc course in Physics will be able to develop a strong foundation in Physical Sciences. The course will provide the students with all round knowledge resources, analytical and research skills needed for developing a career in advanced research in science and technology.

In specialized courses students will be made confident to pursue further advanced study and conduct scientific research in the field of materials and nuclear science and technology. That includes material discovery, synthesis, processing, as well as train them with the state of the art computational and analytical tools required for analysing the data related to high energy physics experiments. Students will get ample scope to learn about renewable energies, energy material applications and recent advances in nuclear science as well as identify societal challenges and engage in energy policy decisions.

M. Sc. program is designed covering most of the UGC syllabus in physical sciences enabling the students to prepare effectively for various national level competitive examinations like UGC-CSIR NET, JEST, GATE, SLET, etc.

Students will be able to recognize ethical and professional responsibilities in science and technology and make informed judgments to produce solutions that meet the scientific and socio-economic needs.

Semester – I

PHY-101: Mathematical Physics – I

Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *Mathematics is an indispensable tool in the study of physics. After learning the course, the learner will be able to (i) get the basic ideas of linear vector space including linear independence, dimensionality, orthogonality, etc. (ii) utilize the knowledge of complex plane and Cauchy's method to solve complicated integral equations (iii) solve higher order differential equations using different polynomial techniques such as Legendre, Bessel, Hermite etc. (iv) get the preliminary idea of probability distribution and curve fitting.*

Course Contents:

Unit - I: Vector spaces and Matrices (12 lectures)

Linear vector spaces – Axiomatic definition, linear independence, bases, dimensionality, orthogonality and completeness, norms, inner products, Hilbert spaces; Matrix representation of linear operators, Different kind of matrices – orthogonal, unitary and Hermitian matrices, eigenvalues and eigenvectors, diagonalization.

Unit - II: Complex Variables (14 lectures)

Recapitulation: Complex numbers, geometrical representation of complex number, functions of a complex variable – single and multiple-valued function, limit and continuity; Differentiation – Cauchy-Riemann equations and their applications; Properties of analytical functions; Complex integrals, Cauchy's Integral Formula and its corollaries; Series – Taylor and Laurent expansion; Classification of singularities; Branch point and branch cut; Cauchy residue theorem, Applications of residue theorem.

Unit - III: Differential equations and special functions (15 lectures)

Series solution and Fuch's theorem for second order equation, Bessel, Legendre, Hermite, Laguerre functions/polynomials-their equations, series solutions, recursion relations, orthogonality, generating functions, associated Legendre polynomials, Hypergeometric function, Confluent hypergeometric functions, gamma and beta function. (14 lectures)

Unit - IV: Elementary probability theory and Statistics (7 lectures)

Random variables; binomial, Poisson and Gauss' normal distributions, Error propagation, Fitting curves to data, χ^2 distribution.

Recommended Books:

1. **Mathematical Methods for Physicists**–*G.B. Arfken (Academic Press)*
2. **Mathematical Physics - Applications and Problems** – *V. Balakrishnan (Springer)*
3. **Matrices and Tensors in Physics**–*A.W. Joshi (New Age)*
4. **Complex Variables**–*Murray Spiegel (McGraw Hill Education)*
5. **Complex variables and Applications**– *R.V. Churchill and J.W. Brow (McGraw Hill Edu)*
6. **Differential Equations** –*S.L. Ross (John Wiley & Sons)*
7. **Special Functions for Scientists and Engineers** – *W.W. Bell (Dover Publications Inc)*
8. **Mathematical Methods of Physics** – *J. Mathews and R.L. Walker (Pearson Addison - Wesley; 2nd edition*
9. **Mathematical Physics**–*P.K.Chattopadhyay (New Age Pub., 2nd Ed.)*

10. **Mathematical Physics**–*H.K. Dass (S. Chand Publishing)*

Semester – I

PHY-102: Classical Mechanics
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *After learning this course, students will be able to (i) understand the basic principles of classical mechanics system using Lagrange and Hamiltons formalism (ii) apply methods of classical mechanics in solving various problems of like complicated oscillatory system, motion of rigid body, nonlinear dynamics.*

Course Contents:

Unit - I: An overview of Lagrangian and Hamiltonian formalism (10 lecture)

Lagrange's and Hamilton's equations-their applications to physical problems, Harmonic oscillator and central force problems, relativistic forms of Lagrangian and Hamiltonian equations of motion, covariant formulation of electromagnetic equations.

Unit - II: Rigid bodies (8 lectures)

Rigid body dynamics, Euler's theorem, concept of infinitesimal rotation, Euler's equation of motion, symmetric top motion.

Unit - III: Canonical transformations (8 lectures)

Generating functions, Properties of canonical transformations, Infinitesimal contact transformations, Poisson bracket, Hamilton's equation in terms of Poisson bracket, Jacobi's identity, Liouvillie's theorem.

Unit - IV: Hamilton–Jacobi theory (10 lectures)

Hamilton – Jacobi differential equation, application to harmonic oscillator problem, central force problem. Action–angle variables, application to simple harmonic oscillator, planetary motion.

Unit - V: Small Oscillations (7 lectures)

Theory of small oscillations, normal coordinates, normal modes, coupled oscillations, diatomic and triatomic molecules.

Unit - VI: Nonlinear dynamics and Classical Chaos (5 lectures)

Introduction to nonlinear systems, concept of catastrophe, bifurcation, chaos and strange attractors, fractals, physical examples.

Recommended Books:

1. **Classical Mechanics** – *H. Goldstein (Pearson; 3rd edition)*
2. **Classical Mechanics of Particles and Rigid Bodies** – *K.C. Gupta*
3. **Classical Mechanics** – *S.N. Biswas*
4. **Classical Mechanics** – *Rana and Joag*
5. **Mechanics** – *Landau and Lifshitz*
6. **Classical Mechanics** – *A.K. Raychaudhury*
7. **Chaos and Nonlinear Dynamics** – *R.C. Hibron*

Semester – I

PHY-103: Quantum Mechanics – I
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *After learning this course, the learners will be able to (a) solve Schrodinger's equation for bound state problems and calculate the tunneling probability through a potential barrier (b) use Dirac's bra-ket algebra to derive generalized uncertainty principle and solve 1D harmonic oscillator problem (c) compare the different pictures in Quantum Mechanics (d) apply various approximation methods such as time-independent perturbation theory, variational principle and WKB approximation to solve quantum mechanical problems which cannot be ose exact solutions are unavailable (e) write KG equation for spinless particles.*

Course Contents:

Unit - I: Schrödinger's Equation and its application (10 lectures)
Wave function and its physical interpretation, time-independent and time-dependent Schrödinger's equation, applications of Schrödinger equation: Particle in a box, tunnelling through a barrier, motion in a central potential (Hydrogen atom).

Unit - II: Operator method in Quantum Mechanics (10 lectures)
Introduction to linear vector space, Hilbert space, observables and operators, Dirac notations – Properties of state vectors – Ket and Bra vectors, Orthogonal and Orthonormal states. Projection Operators, Commutator Algebra, Uncertainty principle for two arbitrary operators, One dimensional linear harmonic oscillator problem by operator method.

Unit - III: Time evolution of states (6 lectures)
Evolution of states, unitary time evolution operator, Schrodinger and Heisenberg pictures. Heisenberg's equation of motion, Dirac interaction picture, Ehrenfest theorem.

Unit - IV: Approximation Methods (14 lectures)
Time independent perturbation theory: First and second order corrections to the energy eigenvalues; First order correction to the eigenvector; Degenerate perturbation theory; Applications to Zeeman Effect, isotopic shift and Stark effect. Variational methods and its applications. Wentzel - Kramers - Brillouin (WBK) Method and its application.

Unit - V: Relativistic Quantum Mechanics (8 lectures)
Concept of four-vectors in special theory of relativity and covariant forms in four dimensional Minkowski space, natural units and conversion factors; Relativistic Klein-Gordon equation, its physical significance and drawbacks.

Recommended Books:

1. **Introduction to Quantum Mechanics** – *David J Griffiths (2nd Ed. Pearson)*
2. **Principles of Quantum Mechanics** – *R. Shankar (3rd Ed. Springer)*
3. **Quantum mechanics** – *A. Ghatak and S. Lokanathan (Springer)*
4. **Quantum Mechanics – Concepts and Applications** *N. Zettili (2nd Ed. Wiley)*
5. **Quantum mechanics** – G. Auletta, M. Fortunato, G. Parisi *(Cambridge Univ. Press)*
6. **Quantum Mechanics: An Introduction** – *Walter Greiner (4th Ed. Springer)*
7. **Modern Quantum Mechanics** – J .J. Sakurai *(2nd Ed. Pearson)*
8. **The Principles of Quantum Mechanics** –*P. A. M. Dirac (B.N. Publishing)*

9. **The Feynman Lectures on Physics** –*R. Feynman, R. Leighton and M. Sands*
10. **Quantum Mechanics** –*C. Cohen-Tannoudji, B. Diu, and F. Lalo. (2nd Ed., Wiley-VCH)*
11. **Modern Particle Physics** - *Mark Thomson (Cambridge University Press)*

Semester – I

PHY-104: Electronics
Total Credit: 4 (3+1+0), Total Lecture: 48

***Course Learning Outcomes**: After completion of the course, the students will be equipped with required knowledge in electronic devices, circuits and their applications. The students will be able to learn about digital circuits and microprocessors. The students will get to know the basic concept of signal transmission, and the role of modulation and demodulation in signal transmission.*

Course Contents:

Unit - I: MOS and CMOS devices and applications (4 lectures)
Static & dynamic characteristics, depletion & enhancement modes, use of the devices in amplifiers and oscillators.

Unit - II: Tunnel Diode and Applications (2 lectures)
Tunneling effect, transfer coefficient, tunnel diode characteristics, use of tunnel diode as oscillator and amplifier.

Unit - III: Gunn Diode and Applications (2 lectures)
Transferred electron effect, modes of TE oscillations, Gunn diode in oscillation circuit.

Unit - IV: Impatt / Avalanche Diode and Applications (4 lectures)
Drift and scattering velocity, relation between field, current and terminal impedance, equivalent circuit of the diodes and their use in amplifiers and oscillators.

Unit - V: OP-AMP Applications (8 lectures)
Oscillators: Phase shift, Wien bridge and high frequency and voltage controlled oscillators, sawtooth generator. Filters: Active low and high pass filters, Butterworth filter (up to second order). Analog computation: Solution of differential equation (up to second order), solution of simultaneous equations.

Unit - VI: Digital Circuits (10 lectures)
Mapping of logic expression and function minimization: SOP, POS expressions and circuit configurations, Combinational Logic gates, working and configuration of TTL, DTL, RTL, CMOS, MOSFET, Sequential circuits: RS, JK, D and TFF; Register: serial, parallel and shift register-their design, Counter: synchronous counter and design (up to module–10 counter), Microprocessor: basic concept.

Unit - VII: Signal Transmission & Devices (10 lectures)
Transmission line: Basic concept of transmission of LF and HF in open wire and coaxial lines, wave equation, characteristic impedance, VSWR, Short and open circuit impedance, λ matching and stub matching, Waveguides: fundamental concepts of signal propagation through a waveguide, relation between cutoff frequency and waveguide dimension of rectangular waveguide, Antenna: monopole and dipole antenna, antenna parameter, antenna array.

Unit - VIII: Modulation and Demodulation: (8 lectures)
Amplitude modulation: Bandwidth and frequency spectra, Frequency modulation: narrow

band and wide band, power, bandwidth, improvement of S/N with emphasis and de-emphasis circuits, Pulse Modulation: PAM, PCM Basic idea of digital carrier modulation schemes and Channel capacity.

***Recommended Books*:**

1. Modern Digital Electronics – *R.P. Jain*
2. Electronic Communication Systems – *Kennedy, Davis*
3. Microwaves – *K.C. Gupta*
4. Op-Amps and Linear Integrated Circuits – *R.A. GayaKwad*
5. Digital Principles and Applications – *A.P. Malvino and D.J. Leach*
6. Electronic Devices – *Thomas L. Floyd*
7. Fundamentals of Digital Electronics – *A. Kumar*

Semester – I
PHY-105P: General Physics Laboratory - I
Total Credit: 5 (0+0+5)

Course Learning Outcomes: *General Physics Laboratory-I offers a number of optical and electronics practicals which enable the learners to understand the basic concept of electronic circuits through action and observation. After completion of this course, the students will have the ability to (i) understand the behaviour and operations of electronic components such as Integrated Circuit (IC), Operational Amplifier (OPAMP), Logic Gates etc. (ii) analysis and design various oscillators and electronic circuits for mathematical operations, (iii) calculate and determine self-inductance of a coil, unknown resistance of a wire etc. (iv) determine the wavelength of monochromatic light, radius of curvature of convex surface.*

Course Contents:

List of Experiments:

1. To determine the wavelength of sodium light with the help of Fresnel Bi-prism.
2. Study the formation of Newton's rings in the air-film in between a plano-convex lens and a glass plate using nearly monochromatic light from a sodium-source and hence to determine the radius of curvature of the plano-convex lens.
3. To determine the value of an unknown resistance by using Carey-Foster bridge.
4. To determine the self-inductance of a coil using Anderson Bridge.
5. To design a Phase shift oscillator and compare its theoretical and practical frequency.
6. To design a Wien bridge oscillator and compare its theoretical and practical frequency of oscillation.
7. Using an IC 741C (a) design an integrating & differentiator circuit, (b) draw the input and output waveform, (c) measure the rise and fall time, (d) Compare the theoretical and practical value.
8. To solve a given simultaneous equation using OPAMP.
9. To design and study (a) Monostable Multivibrator, (b) Astable Multivibrator using IC 555 timer.
10. To design and study Schmitt Trigger using IC 555 timer.
11. To design a CE amplifier circuit and obtain the frequency response curve of the amplifier and determine the mid frequency gain, lower and upper cut-off frequency and bandwidth of amplifier.
12. To design (a) RS flip flop (b) Gated RS flip flop and (c) D flip flop using logic circuits and verify their truth tables.

(List of practicals given above should be considered as suggestive of the standard. New practicals of similar standard may be added and old problems may be deleted whenever considered it necessary)

Semester – I
PHY-106(OE): Nanostructures
Total Credit: 2 (2+0+0), Total Lecture: 24

Course Learning Outcomes: At the end of the course the students will be able to

1. *Know the promising area of nanomaterials, understand the nature and prospects for the field.*
2. *Learn about the various types of nanomaterials such as semiconducting nanomaterials and carbon based nanomaterials*
3. *Learn about various synthesis and characterization techniques of nanomaterials*

Course Contents:

Unit - I: Introduction to nanostructured materials (13 lectures)

Quantum well, -wire and –dot; metal-oxide nanoparticles, nanorods and nanotubes; core-shell nanostructures: inorganic-inorganic, inorganic-organic, organic-organic and polymer-inorganic core shell structures; metal nanostructures; carbon fullerenes and single and multi-walled carbon nanotubes; micro and mesoporous materials: ordered mesoporous structure, random mesoporous structure, zeolites; Nanostructure fabrication techniques, Morphological studies of nanostructures.

Unit - II: Synthesis techniques (11 lectures)

Introduction to top-down and bottom-up techniques, sol-gel method, solution growth and hydrothermal method, lithography technique, mechanical milling and solid state reaction techniques, thermal evaporation and e-beam evaporation methods, molecular beam epitaxy.

Reference Books

1. **Nanostructures and Nanomaterials, World Scientific** – *Guozhon Cao*
2. **Nanotechnology: Principles and Practices, Springer** – S*ulbha Kulkarni*
3. **Introduction to Nanotechnology,** Wiley – *Jr. C. P. Poole, and F. J. Owens*

Semester – I
PHY-107(OE): Surface Science
Total Credit: 2 (2+0+0), Total Lecture: 24

***Course Learning Outcomes**: This course provides the physics of surfaces and interfaces in an atomic-scale understanding with experimental and theoretical aspects. Students are expected to gain knowledge on physico-chemical properties of a surfaces, surface structure, surface energy states, thin film properties and surface analysis techniques*

Course Contents:

Unit - I: Introduction to physics of surface and interfaces (10 lectures)

Surface specificity, surface structure, Terrace-Ledge-Kink model, binding sites and diffusion, surface diffusion model, bulk electronic state, surface electronic state, Energy levels at metal interfaces, structural defects at surfaces - point defects, steps, faceting, adatoms, dislocations.

Unit - II: Surface properties (10 lectures)

Non-equilibrium growth, Langmuir-Blodgett films, self-assembled monolayers, thermodynamics and kinetics of adsorption and desorption, binding energies and activation barriers, adsorption isotherms, rate of desorption, lateral interaction, Chemisorption, physisorption and dynamics.

Unit - III: Surface analysis: (4 lectures)

Scanning probe microscopy, photoelectron spectroscopy, Auger electron spectroscopy.

Reference Books:

1. **Surface Science: An Introduction** – *K. Oura, V.G. Lifshits*
2. **Surface Science: Foundations of Catalysis and Nanoscience** – Wiley-*K. W. Kolasinski*
3. **Surface Analysis Methods in Materials Science**, Springer – *D. J. O'Connor, B.A. Sexton*
4. **Concepts in Surface Physics, Springer** – *M.C.* Desjonqueres, *and D.Spanjaard,*
5. **Kinetics of Heterogeneous Solid State Processes** Springer – *P. Deb*

Semester – I

PHY-108(OE): Basic tools for data visualization & typesetting
Total Credit: 2 (2+0+0), Total Lecture: 24

Course Learning Outcomes: *After learning this course, the learners will be able to (a) use Gnuplot and Origin to plot ASCII files and functions and fit experimental data with suitable function (b) write article, report, letter, book, and beamer presentation using latex.*

Course Contents:

Unit I: Introduction to plotting graphs with Gnuplot (7 lectures)

Plotting functions & data files, plotting data with error bars, customizing plots, gnuplot scripts, fitting data using gnuplot's fit function, spread-sheet like calculation on data, plotting piecewise functions, Combining graphs with multiplot mode, parametric plots, surface and contour plots, exporting graphs to file, Common terminal options (Size, Fonts, Enhanced text mode), standard graphics file formats, animated plots.

Unit II: Introduction to Origin (7 lectures)

Origin file type, Import data, Workbooks Worksheets column, Graphing Customizing Graphs, Graphical Exploration of Data, Data Analysis, Statistics, Publishing and Export.

Unit III: Typesetting with LaTeX (10 lectures)

Understanding LaTeX compilation: Basic Syntax, Writing equations, Matrix, Tables. LaTeX editor: Texmaker; configuration, feature and use. Classes: Introduction to basic classes like article, book, report, beamer. Packages: Geometry, Hyperref, amsmath, amssymb, algorithms, algorithmic graphic, color, lstlisting, BibLaTeX. Page Layout: Titles, Abstract Chapters, Sections, Theorems, Proofs. Table of contents, List of figures, List of tables, Generating index. Applications: Writing Resume, articles/research papers, Presentation using beamer, Multi-file LaTeX projects.

Reference books:

1. **Gnuplot 5.2 Manual: An Interactive Plotting Program** – *T Williams, C, D Crawford*, 12th Media Services
2. **Gnuplot in Action: Understanding Data with Graphs** – P*hilipp K. Janert, Manning Publication*
3. **LaTeX: A document preparation system**, User's guide and reference manual – *Leslie Lamport,* 2nd Edition, Addison Wesley.
4. **The LaTeX Companion, 2nd edition (TTCT series)** – *F. Mittelbach, M. Goossens, J. Braams, D. Carlisle, C. Rowley*, Addison-Wesley Professional.

Semester – II

PHY-201: Classical Electrodynamics
Total Credit: 4 (3+1+0), Total Lecture: 48

***Course Learning Outcomes**: This course imparts the concepts of electrodynamics and Maxwell equations and their applications in various situations. After perusing this course, students will be able to (i) use basic mathematical tools to solve problems in electrodynamics, (ii) describe the nature of electromagnetic wave and its propagation through different media and interfaces, (iii) Simplify charged particle dynamics and radiation from moving charge particles, (iv) extend their understanding on relativistic electrodynamics.*

Course Contents:

Unit I: Electrostatic boundary value problems and Magnetostatics (6 Lecture)

Method of images, multipole expansion, Poisson and Laplace equations, solution of Laplace equations in spherical, cylindrical and Cartesian coordinates, use of Green's function approximation.

Unit II: Maxwell's Equations (5 Lecture)

Review of Maxwell's equations, electromagnetic potentials, gauge transformation, gauge invariance, Lorentz and Coulomb gauge.

Unit III: Electromagnetic wave (10 Lecture)

Wave equation, Propagation of EM waves in free space, non-conducting and conducting media, reflection and transmission at the boundary of two non-conducting media, reflection from a metal surface, absorption and dispersion, wave-guides and cavity resonance, EM wave propagation of various types of EM modes in different types of waveguides.

Unit IV: Radiation (8 Lecture)

Retarded potential, Lienard–Wiechart potential, fields of a point charge in motion, radiation fields, radiation from a point charge in motion, power radiated by a point charge, Larmor formula, electric and magnetic dipole radiations.

Unit V: Scattering of electromagnetic waves (7 Lecture)

Scattering of EM waves due to free electrons, Thomson scattering, scattering from bound electrons, Rayleigh scattering and resonance fluorescence.

Unit VI: Relativistic Electrodynamics (6 Lecture)

Four vectors, transformation of electromagnetic fields under Lorentz transformation, covariance of Maxwell's equations, electromagnetic field tensor, Lagrangian for electromagnetic fields.

Unit VII: Motion of a charged particle in electromagnetic field (6 Lecture)

Non relativistic motion of a charged particle in uniform constant fields, in a slowly varying field, gradient drift, magnetic mirror.

Book Recommended:

1. **Introduction to Electrodynamics** – *David J. Griffiths*
2. **Foundation of Electromagnetic Theory** – *J. R. Reitz, F.J. Milford and R.W. Christy*
3. **Electricity and Magnetism** – *M.H. Nayfeh and M.K. Brussel*
4. **Classical Electrodynamics** – *J.D. Jackson*
5. **The Feynman Lectures on Physics**- *Vol-II*
6. **Elementary Plasma Physics**–*C.L. Longmire*
7. **Introduction to Plasma Physics** – *F.F. Chen*
8. **Electromagnetics** – *B B Laud*
9. **Electrodynamics** – *Uma Mukherjee*
10. **Classical theory of fields** – *Landau*
11. **Introduction to plasma physics and control fusion**- *Francis F. Chen*

Semester – II

PHY-202: Quantum Mechanics - II

Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *After learning this course, the learners will be able to (a) write matrix representation of angular momentum and calculate eigenfunctions of orbital angular momentum (b) analyze orbital and spin angular momentum matrices and calculate Clebsch-Gordan coefficients, (c) illustrate continuous and discrete symmetries in QM and apply the identical particle QM to the collision of identical particles (d) use time-dependent perturbation theory for constant and harmonic perturbations and derive Fermi's Golden rule (d) derive KG and Dirac equation equation in presence of electromagnetic field.*

***Course Contents*:**

Unit - I: Angular Momentum (13 lectures)

The orbital angular momentum operator, general formalism of angular momentum, matrix representation of angular momentum, eigenfunctions of orbital angular momentum, angular momentum in differential representation using spherical coordinates, spherical harmonics; Raising and lowering operators for angular momentum using Bra and Ket algebra. Spin angular momentum, experimental evidence for spin (Stern-Gerlach Experiment), spin-half and Pauli matrices. Addition of angular momenta and Clebsch-Gordon coefficients.

Unit - II: Symmetry and Invariance principle and conservation (5 lectures)

Symmetry and conservation laws, Translation in space: conservation of linear momentum, Translation in time: Conservation of energy, Rotation in space: Conservation of angular momentum, Space Inversion: parity conservation, Time reversal.

Unit - III: Identical Particles (5 lectures)

Meaning of identity and consequences; Symmetric and antisymmetric wave functions; Slater determinant; Symmetric and antisymmetric spin wave functions of two identical particles; Collisions of identical particles.

Unit - IV: Time-dependent Perturbation Theory (9 lectures)

Time-dependent perturbation theory, interaction picture; constant and harmonic perturbations, Fermi's Golden rule; Sudden and adiabatic approximations.

Unit - V: Scattering theory (10 lectures)

Differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Partial wave analysis and phase shifts; attractive or repulsive nature of the potential; Scattering by a rigid sphere and square well; Coulomb scattering; Born approximation.

Unit - VI: Relativistic Quantum Mechanics (6 lectures)

Klein-Gordon equation in the presence of electromagnetic field and its non-relativistic approximation, Pauli-Schrodinger equation, Dirac's equation for electron, Dirac equation in the presence of electromagnetic fields and the prediction of spin and magnetic moment of electron.

***Books recommended*:**

1. **Introduction to Quantum Mechanics** – *David J Griffiths*

2. **Principles of Quantum Mechanics** – *R. Shankar* (3rd Ed. Springer)
3. **Modern Quantum Mechanics** – *J.J. Sakurai*
4. **The Principles of Quantum Mechanics** – *P. A. M. Dirac*
5. **Quantum Mechanics** – *N. Zettili*
6. **The Feynman Lectures on Physics** – *R. Feynman, R. Leighton and M. Sands*
7. **Quantum mechanics** – *A. Ghatak and S. Lokanathan*
8. **Relativistic Quantum Mechanics** – *J.D. Bjorken and S.D. Drell*
9. **Introductory Quantum Mechanics** – *Richard L. Liboff.*
10. **Quantum Mechanics** – *C. Cohen-Tannoudji, B. Diu, and F. Lalo.*
11. **Modern Particle Physics** - *Mark Thomson* (Cambridge University Press)

Semester – II

PHY-203: Nuclear Physics - I
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *After learning this course, the students will be able to (i) apply the shell model and collective model to describe some basic nuclear properties, (ii) understand basics of nuclear reactions, optical model, compound nuclear reactions (iii) get familiar with the various particle accelerators and radiation detectors, (iv) understand the role of symmetries in elementary particle interactions, (v) get elementary idea of quark model, quark confinement, asymptotic freedom and standard model of particle physics*

***Course Contents*:**

Unit - I: Nuclear Properties (4 lectures)
Basic nuclear properties: nuclear size, Rutherford scattering, charge distribution, nuclear form factor, angular momentum, spin, parity, Magnetic dipole moment and electric quadrupole moment.

Unit - II: Two nucleon system (8 lectures)
Bound State Problem: Deuteron ground state with square well potential, electric quadrupole and magnetic dipole moments – experimental values. Scattering problem: Low energy n-p scattering, partial wave analysis, scattering length, magnitude of scattering length and strength of scattering, significance of the sign of scattering length.

Unit - III: Nuclear Models (8 lectures)
(a) Liquid drop Model: Semi empirical mass formula and its applications Nuclear stability, mass parabolas – prediction of stability against beta decay and alpha decay, stability limits against spontaneous fission. (b) Shell Model: Evidence of shell structure, magic numbers, effective single particle potentials – square well, harmonic oscillator, Wood-Saxon with spin-orbit interaction, extreme single particle model – its successes and failures in predicting ground state spin, parity, Nordheim rule.

Unit - IV: Nuclear Reactions (8 lectures)
Types of Nuclear Reactions, Conservation principles, Laboratory and CM frame of reference - energy and angle relationship for non-relativistic cases, kinematics and Q-values, exo-ergic and endo-ergic reactions, threshold energy. Basic concepts of flux and cross-sections, attenuation, the compound nucleus hypothesis and Ghoshal experiment.

Unit - V: Nuclear beta decay (8 lectures)
Pauli's neutrino hypothesis, Fermi's theory of beta decay, comparative half-lives and forbidden decays, Kurie plot, selection rules for Fermi and Gamow-Teller transitions, neutrino physics, Reins & Cowen experiment, Concept of double beta decay and Majorana neutrino.

Unit - VI: Nuclear Radiation Detectors (4 lectures)
Gas filled detector: Ionization chambers, Proportional counters, and Geiger-Muller counters. High energy particle (such as gamma) detection: scintillation counters.

Unit - VII: Elementary particles (8 lectures)

Classification of fundamental forces, elementary particles and their quantum numbers (charge, spin, parity, isospin, strangeness, etc.) Gell-Mann--Nishijima scheme, Quark Model

<u>Recommended Books</u>:

1. **Introductory Nuclear Physics** – *Kenneth S Krane*
2. **Introductory Nuclear Physics** – *Samuel SM Wong*
3. **Atomic and Nuclear Physics (Vol.2)** – *SN Ghoshal*
4. **Concepts of Nuclear Physics** – *Bernard L Cohen*
5. **Techniques for Nuclear & Particle Physics Experiments** – *WR Leo*
6. **Nuclear Radiation Detectors**- *S.S. Kapoor & V.S. Ramamurthy*
7. **Nuclear and Particle Physics:** *An Introduction – B.R. Martin*
8. **Concepts of Modern Physics**- *Arthur Beiser, S. Mahajan, S. Rai Choudhury*
9. **Introduction to Elementary Particles** – *David Griffiths*
10. **Modern Particle Physics** - Mark Thomson (Cambridge University Press)

Semester – II

PHY-204: Condensed Matter Physics - I
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *Condensed Matter Physics is one of the broad branches of physics that deals with fundamental science of solids and liquids. This course provides a foundation for future advanced studies in solids. On successful completion of this course students will be able to learn the fundamental topics in solids such as (i) crystal structure and crystal systems, and lattice dynamics of solids, (ii) energy band theory for electrical conduction, and basic type, materials and properties of semiconductors, and (iii) concept of different phenomena in electric and magnetic substances.*

Course Contents:

Unit - I: Crystalline Solids (12 lectures)
Fundamentals of crystal structure, symmetry operations, point groups and space groups, X-ray diffraction, reciprocal lattice, atomic scattering factor, geometrical structure factor, Imperfection in solids, Fick's law.

Unit - II: Lattice dynamics (4 lectures)
Dispersion relations in monoatomic and diatomic linear lattices, normal modes, phonons.

Unit - III: Dielectric and ferroelectric properties (7 lectures)
Complex dc dielectric constant and dielectric loss, dielectric relaxation, Debye equations, dipole theory of ferroelectric domains, antiferroelectricity.

Unit - IV: Energy bands in solids (7 lectures)
Bloch function, Kronig-Penney model, Brillouin zones, effective mass of charge carriers. Tight binding and Wigner-Seitz method (Only qualitative).

Unit - V: Semiconductors (8 lectures)
Intrinsic and extrinsic semiconductor, number density of carriers in intrinsic and extrinsic semiconductors, expression for Fermi levels, recombination processes, photoconductivity, Hall effect in metals and semiconductors.

Unit - VI: Magnetic properties (10 lectures)
Fundamental concepts, quantum theory of diamagnetism and paramagnetism, diamagnetic and paramagnetic susceptibilities of free electrons, molecular field theory of ferromagnetism, antiferromagnetism and ferrimagnetism, anisotropic energy, electron paramagnetic resonance and nuclear magnetic resonance, Bloch equations.

Books recommended:

1. Introduction to Solid State Physics – *C. Kittel.*
2. Solid State Physics – *A.J. Dekker.*
3. Introductory Solid State Physics – *H.P. Myers.*
4. Solid State Physics – *N.W. Ashcroft and N.D. Mermin.*
5. Magnetism in solids – *D. H. Martin*
6. Physics of Magnetism – *S. Chikazumi*

Semester – II

PHY-205P: General Physics Laboratory - II
Total Credit: 5 (0+0+5)

Course Learning Outcomes: *General Physics Laboratory-II is focusing on advanced techniques and experiments drawn from overall physics classes consisting of advanced electronics, solid state physics, nuclear physics and optics. The student will be able to grasp the role of experimental design, data analysis, error analysis, and the use of computers while investigating physical phenomena.*

Course Contents:

1. Design a triangular wave generator & compare its theoretical and practical frequency.
2. To Study Adder, Subtractor & Comparator circuit using IC-741 & verify theoretical and practical output.
3. Measure the resistivity & hence the band gap of a semiconductor sample with the use of four probe apparatus.
4. Determine the Hall-coefficient, carrier density & carrier mobility of a given semiconductor by using Hall-coefficient apparatus.
5. Using IC-741 (a) Design a 1^{st} order & 2^{nd} order low pass filter (b) Draw the frequency response curve (c) Find the roll off rate (d) Determine the gain & cut-off frequency theoretically and practically.
6. Verify the inverse square law for Gamma rays with the help of G.M. counter.
7. Measure the specific charge (e/m) of an electron using Helical method.
8. Determine the specific charge i.e. charge to mass ratio (e/m) of an electron using Thomson's bar magnet method.
9. Determine the value of Planck's constant with the help of a photoelectric cell and monochromatic filter.
10. Study the bending loss in an optical fibre with different angles of bending of the fibre.
11. To measure the power-loss at a splice between two multi-mode fibre and study the power-loss for longitudinal and angular shift.
12. To sort a string of a number of bytes in descending/ascending order using the 8086 microprocessor.
13. Using microprocessor 8086 (a) Write a program to Add two binary numbers each 8 bytes long (b) Write a program to find maximum no. in a given string & store it in location 0310.
14. Using microprocessor 8085 (a) Write a program for Hexadecimal addition of two numbers (b) Write a program for decimal addition of two decimal numbers.

(List of practicals given above should be considered as suggestive of the standard. New practicals of similar standard may be added and old problems may be deleted whenever considered it necessary)

Semester – II

PHY-206(OE): Basics of Vacuum Science & Low temperature Physics
Total Credit: 2 (2+0+0), Total Lecture: 24

Course Learning Outcomes: *This course serves as an open elective course. This course provides the complete understanding of vacuum technology, vacuum measurements and low temperature physics. After learning this course students will be able to construct vacuum system to create high vacuum and to do experiments in low temperature physics.*

Course Contents:

Unit - I: Pumps for High Vacuum (HV) and Ultra High Vacuum (UHV) (12 lectures)
Important and fields applications of vacuum, Principles of pumping concept, Types of vacuum pumps: Rotary, Molecular drag, Diffusion, Cryogenic, Getter, Titanium sublimation, Sputter ion, Orbitron

Unit - II: Vacuum Measurements (7 lectures)
Vacuum Gauges: Mc Leod, Thermocouple (Pirani), Penning, Hot cathodeionization (triode type), Bayard- AlpertLeak detection, Vacuum system design.

Unit - III: Low Temperature Technique (5 lectures)
Low temperatures techniques: Refrigeration principle (including thermo dynamical aspects) and low temperature production techniques (Throttling process)

***Books recommended*:**

1. **HandBook of Thin Film Technology** – *Maissel and Glange (Springer)*
2. **Vacuum Physics and Techniques** – *T. A. Delchar (Springer)*
3. **Vacuum Technology** – *A. Roth (Elsevier)*
4. **High Vacuum Techniques** – *J. Yarwood (Wiley)*
5. **Experimental Principles and Methods below 1K** – *O. U. Lounasmaa (Elsevier)*
6. **Thermometry at Ultra Low Temperatures** – *W. Weyhmann (Elsevier)*
7. **Methods of Experimental Physics, Vol. II** – *R. V. Coleman (Elsevier)*
8. **Cryophysics** – *K. Mendelssohn (Springer)*

Semester – II

PHY-207(OE): Basics of Material Science
Total Credit: 2 (2+0+0), Total Lecture: 24

***Course Learning Outcomes**: This course serves as an open elective course. This course provides the complete understanding of the properties of materials, their structures, band theory of solids and different techniques of material preparations and their characterization techniques.*

***Course Contents*:**

Unit - I: Introduction to materials science (10 lectures)
Classification of engineering materials–Structure-property relationships-stability and metastability-Basic thermodynamic functions and related processes-Introduction to phase diagrams-Phase rule-Leverrule-One and two components-Solids solution-Eutectic binary mixtures-Micro structural changes during cooling-Typical phase diagrams and their applications.

Unit - II: Introduction to band theory of solids (8 lectures)
Classification of metals, insulators and semiconductors-Forbidden gap-Mechanical properties of materials-Elastic deformation-Fracture-Plastic deformation Slip-Critical shear stress-Effect of lattice defects on mechanical properties.

Unit - III: Material preparation and characterization (6 lectures)
Different techniques of growing crystals-Melt growth of thin films-Characterization by X-ray and optical methods.

***Books recommended*:**

1. Material Science and Engineering *V. Raghavan (Prentice-Hall)*
2. Material Science and Engineering, *W.D. Callistin* (John Wiley Sons)
3. Handbook of thin film technology,*Meissel and Glong*, (McGraw Hill)

Semester – III

PHY-301: Mathematical Physics - II
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *After learning this course, the students will be able to (i) understand properties of Tensor like Transformation of coordinates, contravariant and covariant tensors, indices rules for combining tensors,Christoffel symbols and their transformation laws, (ii) solve partial differential equations like 1D, 2D wave equations, 1D heat transfer equation, Laplace equation by using separation of variable method, (iii) apply Fourier and Laplace transforms in solving differential equations, (iv) solve the integral equations by Iterative Technique, separable kernels, (v) apply the concepts of Group Theory to solve numerical problems in Physics.*

Course Contents:

Unit - I: Tensor Analysis (15 lectures)
Curvilinear coordinate systems, transformation properties of covariant and contravariant tensors, covariant and contravariant tensors; addition, subtraction, outer product, inner product and contraction; Symmetric and antisymmetric tensors; Quotient law; metric tensor; conjugate tensor; Raising and lowering of indices; The Christoffel symbols of first and second kind and their transformation laws; covariant differentiation of tensors, tensoral expression for gradient, divergence, curl and Laplacian operator.

Unit - II: Partial Differential equations (8 lectures)
One-dimensional and two-dimensional (rectangular and circular) wave equation, separation of variables method, one-dimensional heat transfer equation (finite and infinite rod), incorporation of initial and boundary conditions, Laplace's equation and its solution.

Unit - III: Integral transformation (6 lectures)
Fourier transform of Dirac-delta function, Laplace transform, inverse Laplace transform, shifting theorem, convolution, solution of differential equations using Laplace transform and Fourier transform.

Unit - IV: Integral Equations (7 lectures)
General classification of integral equations Voltera and Fredholm equations of first and second kind. Solution of integral equations: Iterative technique (successive approximation or Neumann series), separable kernels (degenerate kernel).

Unit - V: Group Theory (12 lectures)
Definition of group, subgroup, coset, classes, factor groups, homomorphism, isomorphism, direct and semi-direct products, group representations – reducible and irreducible representations; symmetry group, unitary group, Lie groups, SU(2) and SU(3), elements of point groups and simple applications.

Books recommended:

1. **Mathematical Methods for Physicists** - *G.B. Arfken*
2. **Vector Analysis and an Introduction to Tensor Analysis** – *Murray Spiegel*

3. **Mathematical Physics**–*H.K Dass*
4. **Group Theory and its Application to Physical Problems**–*M. Hamermesh*
5. **Classical Groups for Physicists**–*B.G. Wybourne*
6. **Group Theory and Quantum Mechanics** – *M. Tinkham*
7. **Mathematical Methods of Physics** – *J. Mathews and R.L. Walker*
8. **Integral Equations** - *Shanti Swarup*

Semester – III

PHY-302: Computational Physics
Total Credit: 4 (2+0+2), Total Lecture: 24

Course Learning Outcomes: *After learning this course, the students will be able to (i) solve nonlinear equations such as Bisection method regula, falsi method and Newton raphson method. (ii) solve system of linear equations using both Gauss elimination and Gauss-Jordan method with and without pivoting, (iii) perform polynomial interpolation such as Newton-Gregory and lagrange interpolation method and least square curve fitting (iv) compute numerical integration using trapezoidal rule, Simpson's one third rule in Monte Carlo method (v) solve first and second order linear differential equation using Euler method and Runge-kutta method.*

Course Contents:

Part – I : Numerical Methods (Theory)

Unit - I Introduction (3 lecture)
The need for numerical analysis and its limitations, sources of errors, round off and truncation errors.

Unit - II: Solution to nonlinear equations (3 lectures)
Bisection method, Regula-Falsi Method, Newton-Raphson method, advantages and disadvantages, errors in each of these methods.

Unit - III: Solution of linear systems (3 lectures)
Gauss elimination and Gauss-Jordan elimination, pivoting.

Unit - IV: Interpolation and curve-fitting (5 lectures)
Polynomial interpolation using Lagrange's method, construction of Newton-Gregory forward difference and backward difference tables, error estimation in these methods, curve-fitting and the principle of least square.

Unit - V: Numerical Integration: (5 lectures)
Integration by trapezoidal and Simpson's rule, Montecarlo integration

Unit - VI: Solution of differential equations (5 lectures)
Euler's method for solving first order linear differential equations (initial value problem): limitations and discussion on its accuracy, Runge-Kutta method and its comparison with Euler's method, 4^{th} order R-K method.

Part – II : Computational Lab

- Introduction to Linux and Computer Programming Language (FORTRAN /C++ / Python), Plotting with GNUPLOT/Matplotlib.
- **Solution of nonlinear equations:** Bisection Method, Regula-Falsi Method, Newton-Raphson Method.
- **Interpolation:** Newton interpolation, Lagrange interpolation
- **Curve fitting and regression:** Least squares fitting, polynomial curve fitting
- **Numerical integration:** Trapezoidal rule, Simpson's rule, Gaussian quadrature

method

- **Differential equation:** Solution of 1st and 2nd order differential equation using Euler's and Runge-Kutta method: Simple harmonic oscillator problem with and without damping effects, Solution of Schrodinger's equation under various standard potentials. Solution of partial differential equations (PDEs) with finite difference method.
- **Matrix methods**: Determination of Eigenvectors of a system of linear equations, Finding eigenvalue and corresponding eigenvector, Solution of linear systems of equations through matrix inversion.
- **Monte Carlo Technique:** Generation of random numbers, Monte Carlo evaluation of integrals, determination of the value of π. Monte Carlo technique to simulate nuclear decay phenomena.

(List of programming given above should be considered as suggestive of the standard. New problems of similar standard may be added and old problems may be deleted whenever considered it necessary)

***Recommended Books*:**

1. Introductory Methods of Numerical Analysis –*S. S. Sastry (*PHIL *Pvt. Ltd.)*
2. Numerical Methods –*E. Balagurusamy (McGraw Hill Ed.)*
3. Computer Oriented Numerical Methods – *V. Rajaraman* (PHIL *Pvt. Ltd.*)
4. Numerical Recipes – *W. H. Press (Cambridge University Press)*
5. Programming with C++ – *Ravichandran (McGraw Hill Ed.)*
6. Schaum's Outline of Programming with C++ – *John Hubbard (McGraw Hill Ed.)*

Semester – III

PHY-303: Advanced Nuclear Physics - I
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *After learning this course, the students will be able to (i) apply the shell model and collective model to describe some basic nuclear properties, (ii) understand basics of nuclear reactions, optical model, compound nuclear reactions (iii) get familiar with the various particle accelerators and radiation detectors, (iv) understand the role of symmetries in elementary particle interactions, (v) get elementary idea of quark model, quark confinement, asymptotic freedom and standard model of particle physics*

***Course Contents*:**

Unit I: Nuclear Models (10 lectures)
(i) Shell Model: Review of shell model, Applications of SPSM: Magnetic dipole moments of nucleon and nuclei - C-N Catastrophe, Schmidt's calculation of total angular momentum and total magnetic moment, electric quadrupole moments of various nuclei in the light of extreme single particle shell model. (ii) Collective Model: Failure of the nuclear shell model, Vibrational Model: Deformation parameters, Nuclear shapes with quadrupole, octupole and hexadecapole deformations, Nuclear shape vibrations, vibrational model predictions; Rotational Model: rotational energy states of a deformed nucleus.

Unit II: Nuclear Reaction (8 Lecture)
Different types of reactions, Optical model for elastic scattering, average interaction potential for nucleon, energy dependence of the potential, imaginary and absorption, analysis of scattering experiment. Direct Reaction, Kinematics of stripping and pick-up reactions, inelastic scattering. Resonance scattering and reactions: Breit-Wigner dispersion formula. Compound nucleus reaction, Statistical theory of nuclear reactions and evaporation probability.

Unit III: Particle Accelerators (6 lectures)
Type of accelerators (Tandem, Linear accelerator, Cyclotron, Synchrocyclotron, Synchrotron and Storage Rings) and their basic principle, Fixed target versus collider experiments, overview of accelerator facilities in the world.

Unit IV: Nuclear Radiation Detectors (15 lectures)

General Properties of Radiation Detectors: Detector sensitivity, Energy Resolution, Detection Efficiency, Dead Time. Energy loss of charged particles: Mechanism, Stopping power and range, Bethe-Bloch formula, energy dependence of the stopping power, particle identification, Bragg curve, Radiation length. Interactions of photons in matter. Solid State Detectors: Semiconductor detectors, Surface-barrier detectors. Scintillation counter, SSNTD, Nuclear emulsions, Cloud chambers, Bubble chambers. Advanced Detectors: Multi-wire proportional counters (MWPC), Cerenkov counter, Time Projection Chamber (TPC), Micropattern Gas Detectors: Gas Electron Multiplier (GEM), Resistive Plate Chamber (RPC).

Unit V: Particle physics (9 Lectures)
C, P, and T invariance, the $\theta - \tau$puzzle, Parity non-conservation in weak interaction: Wu

experiment, CPT theorem, Quark model, Properties of quarks and their classification, Color degree of freedom, Elementary ideas of SU(2) and SU(3) symmetry groups, Gell-Mann – Okubo mass relation, Introduction to Standard Model, quark confinement, asymptotic freedom.

Recommended Books:

1. Introductory Nuclear Physics – *Kenneth S Krane*
2. Atomic and Nuclear Physics (Vol.2) – *SN Ghoshal*
3. Radiation Detection and Measurement - *Glenn F. Knoll*
4. Techniques for Nuclear & Particle Physics Experiments – *WR Leo*
5. Introduction to Nuclear & Particle Physics –*A Das & T Ferbel.*
6. Nuclear Radiation Detectors- *S.S. Kapoor & V.S. Ramamurthy*
7. Introduction to Elementary Particles – *David Griffiths*
8. Nuclear and Particle Physics: *An Introduction – B.R. Martin*
9. Concepts of Nuclear Physics – *Bernard L Cohen*
10. Nuclear Physics: Theory and Experiment, – *Roy and Nigam.*
11. Introduction to Nuclear Reactions – *GR Satchler*
12. Nuclear Physics – Principles & Applications (*John Lilley)*
13. Nuclear & Particle Physics – *WE Burcham & M Jobes.*
14. *Physics & Engineering of Radiation Detection, S. N. Ahmed (Academic Press 2007)*

Semester – III

PHY-303P: Advanced Nuclear Physics - I (Lab)
Total Credit: 4 (0+0+4)

***Course Learning Outcomes**: After learning this course, the students will be able to (i) Use GM counter in order to calculate the dead time and efficiency of the counter, (ii) use scintillation counter and analyze various peaks using single and multi channel analyzer, (iii) handle microscope (a) to calculate the average diameter of α-particle tracks, (b) will able to scan nuclear emulsion plates and can calculate mass of pion, scattering cross section, and range of tracks.*

Course Contents:

List of Experiments

1. To determine the dead time of a GM counter using a single source.
2. To determine the efficiency of a G.M. counter for β and γ-rays.
3. To study the absorption of beta rays emitted from different radioactive sources in Al, and hence to find the range-energy relation for beta particles by Feather's method.
4. (a) To study the complete spectrum of different gamma sources and to locate the corresponding photo peak, Compton edge, using NaI (Tl) scintillation counter and single channel analyzer (SCA) and draw calibration curve. (b) To find the resolution R for different energies and hence to draw logR vs. logE curve.
5. To study the complete spectrum of different gamma sources and to locate the corresponding photo peak, Compton edge, using NaI (Tl) scintillation counter and Multi channel analyzer (MCA).
6. (i) To study the complete spectrum of Mn-54, using NaI (Tl) scintillation counter and multichannel analyser. (ii) To calibrate and determine the resolution R using the sources Cs-137, Ba-133 and Co-60 taking Na-22 as the unknown source.
7. To create the rough vacuum in a given small stainless steel chamber and find out the resolution of an SSB detector inserting inside it using a 241Am α-source.
8. To determine the average diameter of α-particle tracks in SSNTD.
9. To study the "Thorium stars" produced in the nuclear emulsion and to measure the range of the tracks and to draw energy histograms.
10. To determine the mass of the pion by studying π-μ decay in nuclear emulsion.
11. (i) To scan a given nuclear emulsion plate to determine the number of prongs of the stars. (ii) To draw the Nn distributions of the interaction stars and hence calculate the excitation energy of the interaction. (iii) To determine the scattering cross-section for interaction.

(List of practicals given above should be considered as suggestive of the standard. New practicals of similar standard may be added and old experiments may be deleted whenever considered it necessary)

Semester – III

PHY-304: Advanced Condensed Matter Physics - I
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *The objective of this course is to expand the knowledge of condensed matter physics and to provide a deep understanding of how condensed matter is characterised on the atomic scale. After completing this course, students will be able to (i) comprehend the opto-electronic and scattering phenomena in solids, (ii) analyse the electrical and transport properties as well as device applications of semiconductor materials (ii) understand the critical phenomena in low-dimensional physics at nanoscale* ***and the key role in the technological*** *advances.*

Course Contents:

Unit I: Phonon Spectrum: (6 Lectures)

Phonon creation and annihilation operators, elastic scattering of electrons, inelastic scattering by phonons, inelastic scattering of neutrons by phonons, phonon scattering: normal and umklapp processes.

Unit II: Optical Properties of Solids: (10 Lectures)

Optical constants, dispersion relation of optical constants from Maxwell's equations, Optical absorption and emission in semiconductors, Exciton absorption, Impurity and interband transitions, Luminescence, Activators, Frank Condon principle, Photoluminescence and thermo-luminescence.

Unit III: Thin Solid Films: (12 Lectures)

Thin films and preparation by physical and chemical methods, Condensation, nucleation and growth of thin films, size effect in electrical conductivity: Fuchs and Sondheimmer theory and comparison with experiments; Two-dimensional electron gas (2DEGS) systems, 2DEGS in hetero-structures, integral quantum hall effect (QHE) and fractional quantum hall effect.

Unit IV: Semiconductor devices: (12 Lectures)

Carrier transport phenomena in semiconductors, Junctions: p-n junction in equilibrium, contact potential, space charge at the junction, forward and reverse biasing, p-n junction capacitance: depletion and charge storage capacitance, I-V characteristics; Metal-semiconductor junctions: Ohmic and Schottky junction, semiconductor homo and heterojunctions, Optoelectronic devices: Solar cell, photodetector, LEDs, Laser, Semiconductor Laser.

Unit V: Nanophysics: (8 Lectures)

Idea of nano-structured materials; Quantum confinement: Quantum well Quantum dots and quantum wires, Density of states, Opto-electronic properties of semiconductor nanomaterials, Structural properties of nanomaterials.

Reference books:

1. Solid State Physics – *A. J. Dekker*

2. Fundamentals of Solid State Physics – *J. Richard Christman*
3. Introduction to Solid State Physics – *C. Kittel*
4. Physics of Semiconductor Devices – *S. M. Sze*
5. Solid State Electronic Devices – *B.G. Streetman, S.K. Banerjee*
6. Nanotechnology: Principles and Practices, Springer – *Sulbha Kulkarni*
7. Nanostructures and Nanomaterials, World Scientific – *Guozhon Cao*

Semester – III

PHY-304P: Advanced Condensed Matter Physics - I (Lab),
Total Credit: 4 (0+0+4)

Course Learning Outcomes: *This course offers the advanced hand on experiments of advanced condensed matter physics. After completion of this course students will have a deeper understanding on the subject and they will be able to understand the phenomena practically.*

Course Contents:

List of Experiments:

1. To determine the Lande g-factor of electrons by using the ESR set up.
2. To study the temperature dependence of Hall coefficient.
3. To determine magnetoresistance of the supplied material.
4. To determine the (i) Susceptibility arising due to water in the solution of $MnCl_2$ (ii) magnetic moment of Mn_{++} ions in terms of Bohr magneton and (iii) the ionic molecular susceptibility of Mn^{++} ions by using Quink's method.
5. To study the I-V characteristics of the supplied solar cell and find its spectral response.
6. To determine the transition temperature of the supplied ferroelectric materials. ($BaTiO_3$).
7. To determine the power law dependence of photocurrent on intensity of illumination in a thin film sample.
8. To measure the transmission and absorption coefficients of a given liquid and a solid thin film with spectrophotometer.
9. To study the thermoluminescence of F-centres of alkali halides.

Semester – III

PHY-305: High Energy Physics - I
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *Using this course the learners will be able to (a) get the idea of the role of symmetry in elementary particles physics (b) get the basic concept of quantum fields and field quantization, (d) compute various QED processes such as Rutherford, Bhabha, Moeller, Compton scattering etc.*

<u>Course Contents</u>:

Unit - I: Introduction to elementary particles and quark model (12 Lectures)
Classification of elementary particles, spin and parity determination of pions and strange particles, properties of particles: C, P, G-conjugation, Gell-Mann and Nishijima scheme, the eightfold way classification (Gell-Mann and Neeman classification), quark hypothesis of Gell-Mann and Zweig, properties and types of quarks, elementary idea of Lie groups, spin SU(2) and flavour SU(3) symmetry, colour quantum number, hadron wave functions and classification (spin and flavour), Parton model. Four fundamental interactions and their characteristics in terms of decay lifetimes, strengths, ranges; conservation laws and decay modes, charged leptonic weak interactions, decay of muon, neutron and charged pions, neutral weak interactions.

Unit - II: Quantum Field Theory (10 Lectures)
Introduction: Concept of fields and field quanta, various kinds of fields and their characteristics, Inadequacies of quantum mechanics and the necessity of field theory. Concept of fields, classical fields as generalized coordinates, Lagrangian of a field, Euler-Lagrange equation, Canonical quantization of a one-dimensional classical system, Fock space, the method of second quantization;

Unit - III: Canonical quantization of free fields (6 Lectures)
Real and complex scalar fields, electromagnetic field, Dirac field;

Unit - IV: Interacting fields (6 Lectures)
Interaction picture, Covariant perturbation theory, S-matrix, Wick's theorem, Feynman diagram.

Unit - V: Quantum Electrodynamics (QED) (8 Lectures)
Feynman rules in momentum space, reduction of time-ordered products, Example of actual calculations: Rutherford, Bhabha, Moeller, Compton, $e^+e^- \rightarrow \mu^+\mu^-$ scattering. Decay and scattering kinematics, Mandelstam variables.

Unit - VI: Higher order corrections (6 Lectures)
One-loop diagrams. Basic idea of regularization and renormalization. Degree of divergence. Calculation of self-energy of scalar in ϕ^4 theory using cut-off or dimensional regularization. Elementary discussions on running couplings and renormalization groups.

<u>Books Recommended</u>:

1. **Introduction to Elementary Particles**–*David Griffiths*
2. **Quarks and leptons: An introductory course in Modern Particle Physics**–*F. Halzen & A.Martin*
3. **Gauge Theory of Elementary Particle Physics**– *Ta-Pei Cheng & Ling-Fong Li*
4. **Quantum Field Theory**– *L.H.Ryder*
5. **Relativistic Quantum Mechanics (Vol-I , Vol-II)** *James D.Bjorken and Sidney D.Drell.*

Semester – III

PHY-306: Advanced Mathematical Physics
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *After successful competition of the course, the learner will be able to (i) transform differential equations to integral equations, figure out the various methods of solving integral equations (ii) apply the knowledge of group theory in various branch of physics (iii) use the concept of path integral in various system like free particle and harmonic oscillator.*

Course Contents:

Unit – I: Integral Equations (20 lectures)

General classification of integral equations, Volterra and Fredholm equations of first and second kind, linear, non-linear and homogeneous equations, advantages of integral equations over differential equations, transformation of differential equation to integral equations, example - Schröndinger equation, linear harmonic oscillator equation. Solution of integral equations: Iterative technique (successive approximation or Neumann series), separable kernels (degenerate kernel), eigenvalue and eigenfunction problem, Fredholm method of solution, resolvent kernel (reciprocal kernel) in method of successive approximation, illustrative examples with problems and solutions.

Unit: II: Group Theory (14 lectures)

Schur's lemmas and the orthogonality theorem, characters of representation, reducibility criteria, direct product of representations, Lorentz group, Lie algebra and representations of Lie group, Young tableau in reduction of direct product of representations, adjoint representation, regular representation, fundamental representation.

Unit – III: Path Integral Method (14 lectures)

Functional calculus, path integral method for a free particle, path integral for a general quadratic action, equivalence with Schrödinger equation, simple applications to a free particle and harmonic oscillator, path integral for a partition function and partition function for an SHO system.

Recommended Books:

1. **Mathematical Methods for Physicists** - *George Arfken.*
2. **Integral Equations** - *Shanti Swarup.*
3. **Group Theory and its application to physical problems** - *Morton Hamermesh.*
4. **Elements of Group Theory for physicists** - *A W Joshi.*
5. **Introduction to Topology, Differential Geometry, and Group Theory for Physicists** -*S. Mukhi and N. Mukunda.*
6. **Quantum Mechanics and Path Integrals** - *R P Feynman and A R Hibbs.*
7. **Techniques and applications of Path Integrals** - *L S Schulman.*
8. **Path Integral Methods and their applications** - *D C Khandekar, S V Lawande, and K V Bhagawat.*

Semester – III

PHY-307: Experimental High Energy Physics

Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *After successful competition of the course, the learner will be able to (i) apply the basic principles of Relativistic Kinematics to solve problems in connection with scattering and decay of elementary particles, (b) get the basic knowledge of the Physics of Heavy-ion collisions and the observable, (c) learn the indirect signatures of Quark-Gluon Plasma, (d) to run various MC event generators in computer, (e) get the basic idea of detector simulation and data analysis.*

Course Contents:

Unit - I: Relativistic kinematics (8 Lectures)

Lorentz transformation; Mandelstam variables, Detailed derivation of kinematic variables and their transformations. Collision & Decay kinematics. Rapidity, pseudo-rapidity, invariant cross-section, space-like and time-like. Some examples where relativistic kinematics play an important role for understanding of data.

Unit - II: Introduction to relativistic heavy-ion collisions (8 Lectures)

Nuclear stopping power and nuclear transparency, Space-time picture of collisions, Central plateau and fragmentation region, Time history of ultra-relativistic AA collisions, Geometry of heavy ion collisions; Past, current and future accelerators

Unit - II : Observables & QGP signatures (12 Lectures)

Asymptotic freedom and Confinement in QCD, Quark-Gluon Plasma, Production of Hot and dense matter in the laboratory; Global Observables: Multiplicity, (pseudo)rapidity distributions, invariant yields; Centrality of events: Glauber Model, experimental methods. Quarkonia suppression: dynamics of quarkonium production in elementary collisions, cold nuclear matter effects, Debye screening, experimental observables and interpretation; Collective Flow: Radial flow, anisotropic flow: different flow harmonics and methods of extraction; Physics of Jets: Formation, Energy loss of jets, jet quenching, nuclear modification factor.

Unit - III: Event Generators (8 Lectures)

Introduction to monte carlo (MC) event generators: HIJING, PYTHIA, UrQMD, AMPT.

Unit - IV: Detector Simulation High Energy Physics: (6 Lectures)

Requirement of detector simulation, Introduction to GEANT3/GEANT4, Illustration with an example.

Unit - V: Raw Data processing: (6 Lectures)

Introduction to data analysis: Luminosity, Event rate, beam parameters, hits, primary vertex, tracks, secondary vertex, trigger and pileup. Concept of detector and electronic noise, Detector calibration, Acceptance and Efficiency estimation, event and physics trigger selection, analysis for physics objectives. Particle identification in high energy experiments: dE/dx, Range, TOF technique, Transition radiation.

Recommended Books:

1. The Physics of the Quark-Gluon Plasma - S. Sarkar, H. Satz, B. Sinha (Springer)

2. Relativistic Kinematics; a guide to the kinematic problems of High Energy Physics by R. Hagedorn
3. Introduction to high energy Heavy-Ion Collisions - C. Y. Wong
4. Quark Gluon plasma from Big Bang to Little Bang - K. Yagi, T. Hatsuda and Y. Miake
5. Phenomenology of Ultra-Relativistic Heavy-Ion Collisions - Wojciech Florkowski
6. A Short Course on Relativistic Heavy Ion Collisions - Asis Kumar Chaudhuri
7. Ultrarelativistic Heavy-Ion Collisions - Ramona Vogt
8. TheExperimental Foundations of particle physics - R.N.Cahn and G.Goldhaber
9. Techniques For Nuclear And Particle Physics Experiments : How to approach - W. R. Leo (Springer)
10. Experimental Techniques in High Energy Nuclear and Particle physics - T. Ferbel (WorldScientific)
11. Introduction to Experimental particle physics - R. C.Fernow
12. Data Reduction and Error analysis for the physical sciences - P. Bevington and D.K. Robinson
13. Data analysis Techniques for High Energy physics - R. Frunwirth, M. Regler, R. K. Bock and H. Grote

Semester – III

PHY-308: Advanced Optics - I

Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes:

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

1. Familiarize with different branches of spectroscopy
2. Learn to use spectroscopic methods to apply in various areas
3. Understand theoretical background of laser, its importance

---

***Course Contents*:**

Unit I: Interaction of Matter-radiation (Lecture 12)
Various spectroscopic techniques (Overview), absorption, spontaneous and stimulated emission of radiation, Einstein's coefficients, Coherent properties of radiation fields, Transition probabilities- weak and strong field approximation, Cavity radiation-counting the number of cavity modes, Plank's law for cavity modes, widths and profiles of spectral lines, overview of spectroscopic instrumentations-detection of light, interferometers, photo emissive detectors

Unit II: Basics of Lasers (Lecture 12)
Basic elements of lasers, saturation intensity, growth factor, properties of lasers- coherency, directionality, monochromaticity light amplification, threshold condition for laser oscillation, laser amplifiers, spectral characteristics, laser rate equations- three and four level systems, laser resonators-longitudinal and transverse cavity modes

Unit III: Types and applications of Lasers: (Lecture 13)
Types of lasers with examples: solid state, gas laser, Dye laser, and semiconductor lasers, liquid and chemical lasers, free-electron lasers, excimer lasers, X-ray laser, applications of lasers- Physics, Chemistry, Environmental Research, Material Science, Biology, Medical Science, communication, Atmospheric optics, industry, Holography

Unit IV: Time resolved laser spectroscopy (Lecture 11)
Q-switched lasers, mode locking of lasers, laser amplifiers, femtosecond pulses, measurement of ultrashot pulses, life-time measurements with lasers, pump and probe techniques

***Recommended Books*:**

1. Principles of Lasers, O Svelto, Springer
2. Molecular Structure and Spectroscopy, G Aruldhas, PHI Learning Pvt Ltd, Delhi
3. Fundamental of Molecular Spectroscopy, Banwell and McCash, Tata McGraw Hill
4. Lasers and Non-linear Optics, B B Laud, New age international limited, publishers

5. Elements of Laser and Non-Linear Optics, G D Baruah, Prakashan, Meerut

Semester – III

PHY-308P: Advanced Optics (Lab)

Total Credit: 4 (0+0+4)

***Course Learning Outcomes*:**

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

1. *Use and handle spectroscopic instruments in laboratory*
2. *Understand the principles of laser spectroscopy through performance of experiments*
3. *Provide exposure in practical application of spectroscopic instruments.*

***Course Contents*:**

List of Experiments:

1. To measure the excitation potential of mercury using the Franck-Hertz method.
2. To study the emission spectra of Hydrogen (Balmer series) and determination of Rydberg's constant
3. To determine the value of e/m by Zeeman effect
4. To record the absorption spectra of an optically active sample and hence determine the extinction coefficient and optical depth or path length of the sample
5. To record the photoluminescence spectra of an optically active sample and hence calculate the radiative parameters
6. To study the vibrational spectra of I_2 molecule

***Recommended Books*:**

1. Laser Spectroscopy II, Experimental Techniques, W. Demtröder, Springer
2. Introduction to IR and Raman Spectroscopy, N. Colthup, L. Daly, S. Wiberley, Elsevier
3. Topics in Applied Physics, Vol-14, Laser Monitoring of the Atmosphere, Editor- E. D. Hinkley, Springer Berlin Heidelberg.
4. Physics of Atoms and molecules, B.H. Brasden and C.J. Joachain, Prentice Hall.

Semester – IV
PHY-401: Statistical Mechanics
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *This course gives the insight of postulates of statistical physics and calculating probability for various statistical systems of particles. After completing this course students will be able to (i) distinguish between the types of ensembles and explain the behaviour of classical and quantum statistics, (ii) establish the connection between statistics and thermodynamics, and (iii) understand the concept of the Ising model and phase transitions.*

***Course Contents*:**

Unit I: Classical Statistical Mechanics (15 lectures)
Classical Statistical mechanics: Statistical basis of Thermodynamics, the micro and macro states, postulates of equal a priori probability, connection between statistical mechanics and thermodynamics. Elements of ensemble theory: Micro canonical, canonical and grand canonical ensembles, partition and grand partition functions, particle density, energy fluctuations in grand canonical ensemble, equivalence to other ensembles.

Unit - II: Quantum Statistical Mechanics (14 lectures)
Basic principle, inadequacy of classical theory, quantum mechanical ensemble theory, density matrix, ensembles in quantum statistical mechanics. Maxwell-Boltzmann, Bose-Einstein and Fermi-Dirac statistics, properties of ideal Bose gas system and ideal Fermi gas system, their equations of state, some applications – Black body radiations, white dwarf, Bose-Einstein condensation (BEC) and experimental evidence.

Unit - III: Fluctuations (7 lectures)
Thermodynamic fluctuations, Gaussian distribution, random walk and Brownian motion, approach to equilibrium, Fokker-Planck equation; introduction to non-equilibrium processes.

Unit - IV: Phase transition (8 lectures)
Formulation of the problem, the theory of Lee and Yang. First and second order phase transitions; diamagnetism, paramagnetism and ferromagnetism; Liquid Helium, Two fluid hydrodynamics, second sound, theories of Landau and Feynman.

Unit - V: Special topics (4 lectures)
Ising model: partition function for one dimensional case; Chemical equilibrium and Saha ionisation formula.

***Recommended Books*:**

1. **Statistical mechanics** –*K. Huang*
2. **Statistical Mechanics** – *R. K. Pathria*
3. **Statistical Mechanics** – *B. K. Agarwal and M. Eisner*
4. **Statistical Mechanics** – *S. K. Singh*
5. **Statistical Physics** – *J. K. Bhattacharya*
6. **Statistical Mechanics** – *R. Feynman*

7. **Statistical Physics:** *L. Landau and E. Lifshitz*

Semester – IV

PHY-402: Atomic and Molecular Physics
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *At the end of the course the students will be able to: 1. ascertain the atomic and molecular structures 2. learn the interaction of electromagnetic spectra with matter 3. use spectroscopic techniques to identify elements present in a sample 4. familiarize with the mechanism of laser spectroscopy and its importance 5. familiarize with the mechanism of Fibre optics and its importance in various areas*

***Course Contents*:**

Unit - I: Atomic Physics (lectures: 15)
Pauli exclusion principle: spectral terms from two equivalent electrons, calculation of Zeeman pattern, Paschen-Back effect, Stark effect in hydrogen, hyperfine structure and determination of nuclear spin and nuclear g factors, radiative transition probabilities, line width: Doppler broadening, natural broadening, collision broadening and Stark broadening.

Unit - II: Molecular Physics (lectures: 15)

(a) **IR spectra**: Rotation, vibration and rotation-vibration spectra of diatomic molecules, selection rules, determination of rotational constants.

(b) **Electronic spectra:** Born-Oppenheimer approximation, (i) vibrational structure of electronic transition, progressions and sequences of vibrational bands, Intensity distribution, Franck-Condon principle, (ii) rotational structure of electronic transition, band head formation.

(c) **Raman spectra:** Quantum and classical theory of Raman Effect, Vibrational Raman spectrum, selection rules, Stokes and anti-Stokes lines, Rotational Raman spectrum, selection rule.

(d) **NMR & ESR spectra:** Magnetic properties of nuclei, nuclear resonance, Spin-spin & spin-lattice interaction, chemical shift, nuclear coupling.

Unt -III: Laser (lectures: 9)

Basic elements of laser; properties of laser light: directionality, intensity, monochromaticity, coherence; spontaneous and stimulated emission: Einstein coefficients; population inversion, threshold condition, rate equation; Laser resonator and modes, optical and electrical pumping; solid state laser, gas laser, semiconductor laser, applications of laser spectroscopy

Unit -IV: Fibre optics (lectures: 9)
Dielectric slab waveguide, modes in the symmetric slab waveguide, TE and TM modes, modes in the asymmetric slab waveguide, coupling of the waveguide (edge, prism, grating), dispersion and distortion in the slab waveguide, integrated optics components (active, passive), optical fibre waveguides (step index, graded index, single mode), attenuation in fibre, couplers and connectors

Suggested readings:

1. Introduction to Atomic Spectra – H. E. White (McGraw-Hill Inc)
2. Physics of atoms and molecules – B. H. Bransden, C J. Joachain.
3. Modern Atomic Physics (Vol I) – B. Cagnac and J. C. Pabey.
4. Fundamentals of Molecular Spectroscopy – C. N. Banwell, E. M. McCash.
5. Spectra of Diatomic Molecules (Vol. 1) – G. Herzberg.
6. Optical Fiber Communications Principles and Practice – John M. Senior, M. Yousif Jamro, Pearson
7. Atomic Spectra – JB Rajam
8. Principles of Lasers – O. Svelto
9. Lasers: Theory and Applications – K. Thyagarajan, A. K. Ghatak

Semester – IV

PHY-403: Advanced Nuclear Physics– II

Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *After learning this course, the students will be able to (i) apply angular momentum and parity selection rules to predict gamma transition, (ii) apply the basic principle of Mossbauer effect to measure the Isomer shift, determination of gravitational red shift. (iii) calculate important nuclear fission reactor parameters such as slowing down power, moderating ratio & diffusion length (iv) derive & solve Fermi Age Equation (v) compute fission and fusion barrier (vi) distinguish between stellar nucleosynthesis and big bang nucleosynthesis and Controlled fusion reaction (vii) apply basic QM to explain the neutrino oscillation (viii) Accumulate some radiological protection knowledge like effective Biological effect (RBE), shielding, Radiation safety in the laboratory for nuclear physics (ix) apply the basic idea of magnetic nuclear resonance (NMR) to determine nuclear spin & chemical shift.*

***Course Contents*:**

Unit I: Gamma Rays (8 lectures)

Multipole expansion of Radiation field, multipolarity, gamma-ray transition probability, Angular momentum and Parity selection rules, Nuclear Isomerism, Internal Conversion of gamma-rays; Mossbauer spectroscopy: Mossbauer effect, Experimental techniques, Applications of Mossbauer effect – Isomer shift, determination of gravitational red shift.

Unit II: Nuclear fission and reactor physics (14 lectures)

Fission: spontaneous and induced fission, Q-value of fission, fission barrier, activation energy, condition for spontaneous fission, characteristics of fission - energy and mass distribution of fission product, number of emitted neutrons, cross-section of neutron induced fission, Bohr-Wheeler theory of fission; Reactor Physics: Sources of neutron, detection of neutrons, classification of neutrons, slowing down of neutrons, slowing down power, diffusion of thermal neutrons, Fermi Age equation, moderating ratio, fission chain reaction & multiplication factor, four-factor formula, reactor theory; Nuclear reactor programme in India.

Unit III: Nuclear fusion (8 lectures)

Nuclear fusion: Basic fusion process, characteristics of fusion - Energy release, Coulomb barrier, cross-section, reaction rate, thermonuclear fusion in stars -pp chain & CNO cycle, big bang nucleosynthesis, nucleosynthesis beyond iron, r- and s-processes. Controlled fusion reaction, Debye length, Confinement of plasma - magnetic confinement and Toroidal confinement, Lawson criterion – Tokamak.

Unit IV: Neutrino Physics (8 lectures)

Solar and Atmospheric neutrino anomaly, neutrino oscillation, neutrino mass hierarchy, overview of neutrino oscillation experiments.

Unit V: Radiation protection (10 lectures)

Dosimetric units: The Roentgen, absorbed dose, relative biological effects (RBE), equivalent dose, effective dose; typical doses from sources in environment; Biological effects: high doses received in short time, low-level doses; dose limits; shielding; radiation safety in the nuclear physics laboratory.

Recommended Books:

1. **Introductory Nuclear Physics** – *Kenneth S Krane (Wiley)*
2. **Atomic and Nuclear Physics (Vol. 2)** – *SN Ghoshal (2nd Ed. S Chand)*
3. **Neutrino Physics** – *Kai Zuber (2nd Edn. CRC Press)*
4. **Techniques for Nuclear & Particle Physics Experiments** – *WR Leo (2nd Ed. Springer)*
5. **Radiation Detection and Measurement** – *Glenn F Knoll (4th Ed. Wiley)*
6. **Nuclear Moments** – *H Kopferman*
7. **Nuclear Magnetic Resonance Spectroscopy** – *F. A. Bovey, P. A. Mirau and H. S. Gutowsky (2nd Edn. Academic Press)*

Semester – IV

PHY-404: Advanced Condensed Matter Physics - II
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *This course aims at giving the students the advances in material science that most directly be confronted with experiments in future. At the end of the course students will be able to (i) perceive the magnetic behaviour, magnetic interactions in bulk as well as at nanoscale, (ii) explain the fascinating phenomenon of superconductivity and its potential applications, (iii) demonstrate the understanding of soft material dynamics and interactions.*

Course Contents:

Unit I: Magnetic properties of Solids (12 Lectures)

Exchange interaction and exchange integral for a two-electron system, Heisenberg Hamiltonian for exchange interaction, relationship between exchange energy and molecular field, ferromagnetic spin waves and antiferromagnetic spin waves and their dispersion relations, magnons.

Unit II: Electrons in magnetic field (6 Lecture)

Magneto-conductivity, Fermi surface, cyclotron resonance, Landau levels and Landau cylinders, de Hass-Van Alphen effect.

Unit III: Superconductivity (12 Lectures)

Thermodynamics of superconducting state, Type-I and Type-II superconductors, Meissner effect, London equations, Isotope effect, Frohlich interaction, London equation, BCS theory of superconductivity, flux quantization, Giaever tunneling and Josephson effects (d.c. and a.c.), superconducting quantum interference device (SQUID), Ginsburg-Landau theory, introduction to high temperature superconductors.

Unit IV: Nanomagnetism (10 Lectures)

Origin of nanomagnetic behavior, magnetic anisotropy, magnetic domain structure and magnetism in ferromagnetic nanomaterials, superparamagnetism. Spin dependent scattering.

Unit V: Soft condensed matter physics (8 Lectures)

Introduction to conducting polymers, Liquid crystal, Van der Waals interaction and forces, colloidal dispersion.

Reference books:

1. Fundamentals of Solid State Physics – *J. R. Christman*
2. Magnetism in Solids – *D. H.Martin*
3. Introduction to Solid State Physics – *C. Kittel*
4. Physics of Magnetism – *Soshin Chikazumi*
5. Theory of Superconductivity – *J. R. Schriffer*
6. Nanotechnology: Principles and Practices, Springer – *Sulbha Kulkarni*

7. Principles of Nanomagnetism, Springer – *Alberto P. Guimaraes*
8. Soft Condensed Matter, Oxford (2002) – *R. A. L. Jones*
9. Intermolecular and surface forces, Academic, New York (1985) – *J. N. Israelachvili*
10. Introduction to soft Matter – *Ian W. Hamley*

Semester – IV

PHY-405: High Energy Physics - II
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *At the end of this course, the students will be able to (a) learn about the role played by symmetries in studying Quantum Field theories (b) get the preliminary idea of SSB and Higgs mechanism, (c) acquire the in-depth knowledge of the Standard Model of particle Physics (d) grasp the necessity for physics beyond SM, (e) know the solar & Atmospheric neutrino puzzle and realize its solution through a quantum mechanical process called neutrino oscillation.*

Course Contents:

Unit - I: Gauge Theories: (8 lectures)
Introduction to Gauge symmetries – global and local gauge transformations, Abelian group U(1) (QED), Yang-Mills (Non-Abelian) groups – SU(2) (isospin), SU(3) C (QCD).

Unit - II: Spontaneous Symmetry Breaking (SSB) (10 lectures)
Ground state with spontaneous symmetry breaking, some examples; global symmetry breaking and Goldstone bosons, proof of Goldstone theorem, local symmetry breaking and Higgs mechanism for giving masses to vector bosons, examples-U(1), SU(2).

Unit - III: Standard Model (SM): (8 lectures)
Standard model of electroweak unification, gauge bosons $W^{\pm}$, Z^{0}, charged weak current and neutral current, Higgs particle, experimental status.

Unit - IV: Beyond Standard Model (15 lectures)
(a) Introduction to Grand Unified Theories (GUTs) – SU(5) and SO(10), and proton decay predictions; (b) Minimal Supersymmetric Standard Model (MSSM) and its extension, its predictions; (c) Introduction to String Theories and Planck scale physics.

Unit - V: Neutrino physics (7 lectures)
Solar and atmospheric neutrino puzzles, theory of neutrino oscillations in vacuum and medium (MSW mechanism), neutrino masses and leptonic mixings, survey of various neutrino oscillation experiments, seesaw mechanism for small neutrino masses.

Books recommended:

1. Gauge Theory of elementary particle physics - Ta–Pei Cheng & Ling-Fong Li, (Oxford University Press, 1983)
2. Quarks and leptons: An introductory Course in Modern Particle Physics, by Francis Halzen & Alan D. Martin (John Wiley & Sons, 1984)
3. Introduction to Elementary Particles - David Griffiths (John Wiley & Sons, 1987)
4. A First Course in String theory, by Barton Zwiebach, (Cambridge Univ. Press, 2004)
5. Grand Unified theories - Graham G. Ross, (Oxford Univ. 1984)
6. Massive Neutrinos in Physics and Astrophysics – by R.N. Mohapatra & P.B. Pal (World Scientific, Singapore)

Semester – IV
PHY406: Advanced Optics-II
Total Credit: 4 (3+1+0), Total Lecture: 48

Course Learning Outcomes: *At the end of the course, the students will be able to*

1. *Learn the basic principles of non linear spectroscopy*
2. *Familiarize with principles and instrumentations in non linear spectroscopy*
3. *Learn the different techniques of laser Raman spectroscopy and applications*
4. *Familiarize with recent developments in Laser Spectroscopy*

Course Contents:

Unit I: Nonlinear Optics (Lecture 11)
Nonlinearities of the polarization, generation of second harmonic, D.C., sum and difference frequency generation, anharmonic oscillator model, Miller's rule, crystal symmetry, coupled amplitude equations, Manley-Rowe relation.

Unit II: Phase Matching (Lecture 12)
Basic idea of phase matching, quasi-phase matching method, various methods of phase matching (angle, temperature, birefringence etc.) critical and noncritical phase matching, collinear and non-collinear phase matching, expression of angle band-width ($\Delta\theta$) and wavelength band-width ($\Delta\lambda$) in phase matched second harmonic generation, idea of tangential phase matching.

Unit III: Second Harmonic Generation (Lecture 11)
Basic equation, conversion efficiency and parameters affecting doubling efficiency, various methods of enhancing conversion efficiency, second harmonic generation with Gaussian beam, intracavity second harmonic generation.

Unit IV: Higher Order Nonlinear Processes (Lecture 14)
Four wave mixing processes-third harmonic generation, resonance enhancement of nonlinear susceptibilities, different phase matching techniques, generation of tunable deep UV and IR radiation, Tunable Raman lasers, Nonlinear Raman spectroscopy- stimulated Raman scattering, Coherent Anti-Stokes Raman Spectroscopy (CARS), hyper Raman effect, inverse Raman scattering, photo-acoustic Raman spectroscopy, Applications of Laser Raman Spectroscopy.

Suggested Readings:

1. Lasers and Non-linear Optics, B B Laud, New age international limited, publishers
2. Principles of Lasers, Orazio Svelto,
3. High Resolution Spectroscopy of Transient Molecules, Eizi Hirota
4. Tunable Lasers and Applications, A. Mooradian.T., Jaeger and P. Stockseth
5. Tunable Solid State Lasers-II, A.B. Budgor, L. Esterowitz and L.G. Deshazer

Semester – IV

PHY-407: Research Methodology & Experimental Techniques in Physics
Total Credit: 6 (4+2+0), Total Lecture: 48

Course Learning Outcomes: *This course will provide a basic understanding about the scientific research and various techniques. After completion of the course, students will be able to identify the research gap and various research methodologies to address the contemporary research problems, investigate the data by using different scientific techniques and develop their presentation skills.*

Course Contents:

Unit I: Introduction to research methods: (15 lectures)

Introduction to scientific journals and articles, identification of research problems, research gap and literature survey, experimental findings and interpretations, manuscript writing and publishing a scientific paper, plagiarism, scientific ethics and tools, Intellectual Property Right.

Unit II: Error Analysis and Numerical Methods: (10 lectures)

Uncertainties in measurement: measuring errors, uncertainties, parent & sample distributions, mean & standard deviation; Probabilities distributions: binomial, Poisson, Gaussian, & Lorentzian distribution; Error analysis: instrumental & statistical uncertainties, propagation of errors; Estimates of mean & errors: statistical fluctuations, probability tests, reliability χ^2 test of a distribution; Least-Squares Fit: Method of Least Squares & uncertainties in parameters, Limitations of the Least-Squares Method; Maximum likelihood.

Unit III: Experimental tools and techniques for material science (11 lectures)

Vacuum technology, material preparation: chemical and physical techniques, characterization techniques: x-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic force microscopy (AFM), scanning tunnelling microscopy (STM).

Unit IV: Advanced nuclear techniques (12 lectures)

Nuclear Magnetic Resonance (NMR): Resonance condition, Experimental technique – Purcell and Bloch method, Applications of NMR – Determination of nuclear spin, Chemical shift. Nuclear Electronics: Overview of pulse processing, pulse pile-up, electronic noise, baseline shift, triggers, Preamplifiers - voltage & charge sensitive configurations, noise characteristics, detector bias voltage. Pulse shaping; Pulse counting: Discriminator, scalars or counters; Pulse height analysis, Linear amplifier, ADC, TDC, MCA, Coincidence; Background and Detector Shielding: Sources of background, background in different detectors, Shielding materials, active methods of background reduction.

Unit V: Literature survey report and presentation

References:

1. Research Methodology: Methods and Techniques – C. R. Kothari (Newage Publishers)
2. Data Reduction and Error Analysis for the Physical Sciences – P.R. Bevington and K.DRobinson (McGraw Hill, 2003)
3. Thin film Fundamentals –A Goswami
4. Thin film Phenomena – K L Chopra
5. Elements of X-ray diffraction – B D Cullity
6. Modern Vacuum Practice – N. S. Harris (McGraw Hill, 1989)
7. Vacuum Technology – A. Roth (2nd Edition North Holland, 1982)
8. Cryogenics Systems – R. F. Barron (2nd Edition, Oxford university Press 1985)
9. Nanotechnology: Principles and Practices – Sulbha Kulkarni (Springer)
10. Introduction to Nanotechnology – Jr. C. P. Poole, and F. J. Owens (Wiley)
11. Nanostructures and Nanomaterials: Synthesis, Properties and Applications – Guozhong Cao (Imperial College Press, 2004)
12. Radiation Detection and Measurement – *Glenn F Knoll (4th Ed. Wiley)*
13. Techniques for Nuclear & Particle Physics Experiments – *WR Leo (2nd Ed. Springer)*

Semester – IV
PHY-408P: Project/Dissertation/ Advanced Practical
Total Credit: 6

Course Learning Outcomes: *The outcome of this course is the completion of a dissertation / project report. The dissertation reports a research project conducted with the guidance of a supervisor. The dissertation / project reports should make a contribution to education knowledge. This course will motivate the students to take up research in their future.*

***Course Contents*:**

- This course comprises a total of 6 credits. A student will have to do their project/dissertation either on theoretical or experimental topics and in the end of semester a project report/dissertation report has to be submitted to the University.

- Usually the faculty members of the Department are supervisors for this course. A student will do their work under the guidance of any one of the faculty. The faculty members from the associated departments/ other institutes may also supervise some of the projects/dissertations.

- In case a student opts for advanced practical, he/she will have to perform some advanced practicals and later a detailed report has to be submitted on the basis of his/her experiment(s).

- At the end of the semester, the students need to face the viva-voice on their projects/dissertations/advanced practical

****