

Syllabus for M.Sc. in Physics

University of North Bengal

Introduced from the academic year 2022-23

Course Name: M.Sc. in Physics
Number of Semesters : 4

Structure of the syllabus (Course of 4 Semesters)

Applicable from the academic year 2022-23

Paper Code	Paper title	Paper type	Credit
Semester I			
PHYSCCT0101N	Mathematical Methods in Physics	Core	4
PHYSCCT0102N	Classical Mechanics	Core	4
PHYSCCT0103N	Electronics	Core	4
PHYSCCT0104N	Computational Methods in Physics I	Core	2
PHYSCCP0105N	Laboratory Course I	Core	2
Semester II			
PHYSCCT0201N	Classical Electrodynamics	Core	4
PHYSCCT0202N	Statistical Mechanics	Core	4
PHYSCCT0203N	Quantum Mechanics I	Core	4
PHYSCCP0204N	Computational Methods in Physics II	Core	4
Semester III			
PHYSCCT0301N	Quantum Mechanics II	Core	4
PHYSCCT0302N	Condensed Matter Physics	Core	4
PHYSCCT0303N	Nuclear and Particle Physics	Core	4
PHYSGET0301N	Atomic and Molecular Spectroscopy	GE	4
Semester IV			
PHYS-CP-401	Laboratory Course II	Core	4
PHYS-ET-402	DSE1-A : Magnetism	DSE	2
	DSE1-B : Nuclear Models, Two-body Problem and Nuclear Reactions		
	DSE1-C : Electronic Communication		
PHYS-ET-403	DSE2-A : Field Theoretical Techniques in Condensed Matter Physics	DSE	2
	DSE2-B : Nuclear and Particle Astrophysics		
	DSE2-C : Microwave		
PHYS-ET-404	DSE3-A : Topology in Condensed Matter Physics	DSE	2
	DSE3-B : Quantum Electrodynamics		
	DSE3-C : Digital System and Communication		
PHYS-ET-405	DSE4-A : Soft Condensed Matter Physics	DSE	2
	DSE4-B : Symmetries and Gauge fields		
	DSE4-C : Physics of Liquid Crystals		
	DSE4-D : Project and Dissertation		
PHYS-GE-406	General Theory of Relativity, Astrophysics and Cosmology	GE	4

Salient features:

1. The M.Sc. Physics curriculum consisting of 4 semesters includes 13 Core courses, 4 Department Specific Elective (DSE) courses. In addition, the Department at present offers 2 Generic Elective (GE) courses, one in Semester III and the other in Semester IV, where students from other departments can join subject to the consent from the respective department and Department of Physics. The university as a whole offers 2 Ability Enhancement (AEC) and 2 Skill Enhancement (SEC) courses.
2. To qualify in the M.Sc. in Physics examinations of the University a student must pass in all the Core, DSE and GE courses with at least 40% marks and/or equivalent credit points.
3. PHYSCCP0105N and PHYS-CP-401 are laboratory based courses. Both have a pool of experiments. The Department may change/update the experiments from time to time, as and when required.
4. The course PHYSCCP0204N is also a laboratory course based on Computer Programming in Fortran.
5. Each of the DSE courses will have more than one options, namely DSE1-A, DSE1-B, etc.. The students will be allowed to choose one paper/module from each DSE course. Project dissertation or guided reading may be offered as an option in one of the DSE courses.

Programme Outcomes

- ✓ Instill among the students an attitude of being inquisitive, so that they are capable of independent and critical thinking.
- ✓ Equip the students with such skills as to make them understand the mysteries of nature at different scales of space and time, from sub-nuclear to cosmological.
- ✓ Enable the students to analyze problems starting from first principles, evaluate and validate experimental results, and draw logical conclusions thereof.
- ✓ Imbibe effective scientific and/or technical communication abilities among the students.
- ✓ Inspire them in such a way that they can demonstrate and maintain the highest standard on ethical issues in their professional lives.
- ✓ Create an awareness among the students to be persons of integrity, to be responsible and enlightened citizens with a commitment to deliver good to the society within the scope of the bestowed rights and privileges.

Programme Specific Outcomes

- ✓ Train-up the students in such a way that they can objectively carry out investigations, scientific and/or otherwise, without being biased or without having any preconceived notions.
- ✓ Prepare the students to pursue research careers, careers in academics, in industries and in allied fields.

Semester I

PHYSCCT0101N: Mathematical Methods in Physics

Course Outcome

Knowledge gained : Knowledge gained in areas like Complex analysis, integral transform, differential algebras, linear vector space and operators, tensors, matrix and group theories which are useful in basic science, particularly in physics.

Skill gained : Skill acquired in various mathematical techniques required in physics and research in basic science.

Competency developed : The students gain competencies in mathematical techniques which enable them to solve problems in various branches of physics, and interdisciplinary fields like biological science, economics, etc.

Course Content

A. Complex analysis: Functions of complex variables. Analytic functions, Cauchy- Riemann conditions, Cauchy's theorem, Cauchy's integral formulae. Classification of singularities, Taylor and Laurent series, Branch points and branch cuts, Residue theorem and its application in evaluating integrals and series summations, Principal value of an integral, Conformal mappings and its physical applications.

B. Differential equations and special functions: Series solution of linear second order ordinary differential equations; Wronskian method of obtaining a second solution, Solution of Bessel, Legendre, Hermite and Laguerre equations. Properties of Bessel functions, Legendre polynomials, Hermite polynomials, Laguerre polynomials, Hypergeometric functions. Solution of linear second order partial differential equations by separation of variable method, solution of Legendre and associated Legendre equations, Spherical harmonics.

B. Integral transforms: Fourier and Laplace transforms, Convolution and deconvolution, Resolution function, Transform of derivative and integral of a function, Solution of partial differential equations using integral transforms.

D. Linear vector space and matrices: Definition of a vector space, dimension, basis, subspace, inner product, orthogonality and completeness. Linear operators, matrix representation of operators. Change of basis. Matrices, eigenvalue problem, diagonalization of matrices, series of matrices.

E. Tensors: Covariant, contravariant and mixed tensors. Tensor algebra, tensor product, contraction, quotient law, conjugate tensor, dual tensor, pseudo-tensor, Christoffel symbols. Metric tensor and covariant derivative of tensors, geodesics.

F. Group theory: Introduction, group multiplication table, discrete and continuous groups. Reducible and irreducible representations, equivalent representation, invariant sub-spaces. Schur's lemma, orthogonality theorem. Direct product representations and their reduction. Lie groups, generator – parameter representation, Lie algebra, orthogonal, unitary and special unitary groups.

G. Green's function: Inhomogeneous boundary value problem and Green's function, eigenfunction expansion of Green's function, Fourier transformation method of constructing Green's function, application to physical problems.

Reference books

Mathematical methods for physicists – G. B. Arfken and H. J. Weber
Mathematical methods in classical and quantum physics - Tulsı Dass & S. K. Sharma
Mathematical Physics – H. K. Dass
Mathematical Physics – P. K. Chattopadhyay

Complex variables – M. R. Spiegel

Linear Algebra – S. Lipschutz

Matrices and Tensors – A. W. Joshi

Elements of Group Theory for Physicists – A. W. Joshi

PHYSCCT0102N:: Classical Mechanics

Course Outcome

Knowledge gained : Knowledge gained in areas like Lagrange's and Hamiltonian formalisms, two-body problems, Kepler's problems, rigid-body kinematics, small oscillations, canonical transformations, special theory of relativity (STR), nonlinear dynamics and chaos.

Skill gained : Skill acquired in basic mechanics and STR which will help to understand advanced physics like quantum mechanics, general relativity, etc.

Competency developed : The students gain competencies in mechanics which enable them to solve problems in classical physics, STR and the courses in the subsequent semesters.

Course Content

A. Lagrange's formalism: Generalized co-ordinates, constraints, Virtual work, D'Alembert principle, Euler-Lagrange equation of motion and its applications, cyclic co-ordinates and conserved quantities.

B. Two-body central force problem: Central force, definition and characteristics; effective potential technique; study of Keplerian systems, graphical analysis.

C. Rigid body kinematics: Kinematics of rigid body motion; degrees of freedom; Euler angles; The Cayley-Klein parameters and spinors; Rigid rotator, Motion of a symmetrical top, motion of a symmetrical top under gravity.

D. Hamilton's principle: Calculus of variations, Hamilton's principle, Legendre transformation, Hamilton's equation of motion and its applications, phase space and space trajectories, Principle of least action, Routh's procedure, Noether's theorem, symmetry and conservation rules.

E. Canonical transformations: Equation of canonical transformation, generating functions, Lagrange and Poisson brackets (PB); canonical invariance of Poisson brackets; equation of motion in PB notation; infinitesimal canonical transformation and constants of motion, angular momentum PB relations; Liouville's theorem.

F. Hamilton-Jacobi theory: Hamilton-Jacobi equation, separation of variables; Hamilton's principal and characteristic functions; action angle variables.

G. Small oscillations: Stable and unstable equilibria; small oscillations; vibration and normal co-ordinates.

H. Continuous systems: Transition from a discrete to a continuous system; Lagrangian formulation of continuous systems and fields; Hamiltonian formulation – applications.

I. Non-Linear dynamics: Fixed points and stability, linear stability analysis, one- and two-dimensional flows, logistic maps, route to chaos and Lyapunov exponent.

J. Special theory of relativity: Lorentz transformation of coordinates for motion of frames in any direction, Minkowski space, world point, world line and light cone. Time dilation and length contraction in Minkowski space, Four vectors and metric element. Lagrangian formulation of relativistic mechanics; covariant formulation of Maxwell's equations.

Reference books

Mechanics (Course of Theoretical Physics, Vol. I) – L. Landau & E. Lifshitz

Classical Mechanics – H. Goldstein, C. Poole & J. Safko

Classical Mechanics, Vol. II – E. A. Desloge

Classical Mechanics – N. C. Rana & P. S. Joag

Nonlinear Dynamics & Chaos – S. H. Strogatz

Chaotic Dynamics - An Introduction – G. L. Baker & J. P. Gollub

Classical Mechanics – S. N. Biswas

Special theory of relativity – Banerjee & Banerjee

PHYSCCT0103N:: Electronics

Course Outcome

Knowledge gained : Knowledge gained in areas amplifiers, oscillators, regulators, networks and lines. Also analysis of digital and logic circuits will help student to understand modern electronics.

Skill gained : Skill acquired in various electronic circuits and devices, and digital electronics.

Competency developed : The students would be competence to design and analyze various electronic circuits.

Course Content

A. Physics of semiconductor devices: Metal semiconductor junctions – Schottky barriers; Rectifying contacts; Ohmic contacts. Characteristics of some semiconductor devices – Quantum mechanical phenomenon and tunnel diode; LDR; p-n-p-n switch, SCR; Uni-junction transistor (UJT). Noise in electronic devices.

B. Power circuits and systems: Audio power amplifier requirements, Class A, Class B and Class C power amplifiers, Efficiency, Second - Harmonic Distortion, Push pull and tuned power amplifiers.

C. Power supplies and electronic regulators: Linear Power supply, Electronic voltage regulators, variable voltage supplies using Silicon Controlled Rectifier (SCR), IC etc. Switch Mode Power Supply (SMPS), Uninterrupted Power Supply (UPS), Step up and Step down Switching Voltage Regulators.

D. Special circuits using OP AMP: Square wave and triangle wave generators, voltage regulators, fixed and adjustable voltage regulators, active filters, 555 timer, voltage - controlled oscillator.

E. Digital logic families : Introduction to digital IC parameters (switching time, propagation delay, fan out, fan in etc.). Transistor- Transistor Logic (TTL), Metal Oxide Semiconductor (MOS) Logic and Complementary MOS (CMOS) Logic, CMOS Logic families, Emitter-coupled logic, MOSFET as transmission gate. A/D and D/A converters. Basics of micro-processor and micro-controller.

F. Combinational logic design: Standard representation for logical functions, Karnaugh map representation of logical functions, simplification of logical functions using K-map, minimization of logical functions specified in Minterms /Maxterms or truth table, Don't care conditions, five and six variable K-maps. Quine- McCluskey Minimization Technique. Hazards in Combinational Circuits.

G. Coupled circuits: Terms used in coupled circuits, air core transformer, behaviour of resonant circuits tuned to the same frequency and coupled together, fidelity of receivers

H. Filters : Passive filters, Propagation constant; Constant-K low pass and high pass filters; Active filters: Butterworth polynomials; Butterworth filter, low pass and high pass filters; RC band pass filter; Band rejection Filter.

I. Transmission line: Voltage and current relations on radio frequency transmission line; attenuation constant and phase constant; characteristic impedance; reflection and transmission coefficient; Standing wave and standing wave ratio; open and short-circuited lines and lines terminated with finite impedance; behaviour of lines of different lengths. Impedance matching in high frequency lines, Transmission lines as resonant circuits, Q of a transmission line; Transmission line measurements. Smith chart.

Reference books

Electronics fundamentals and application--John D. Ryder

Electronic Principles -- Malvino

Principles of Electronics-- Mehta and Mehta

Networks lines and fields-- John D. Ryder

Solid state electronic devices-- G. Streetman

Physics of semiconductor Devices-- S. M. Sze

Electronic circuits and systems-- Y. N. Bapat

Integrated Electronics-- Millman and Halkias

Electronics fundamentals and application-- Chattopadhyay and Rakshit
Electronics (Classical and modern)-- R. Kar
Fundamentals of digital circuit-- Anand Kumar

PHYSCCT0104N:: Computational Methods in Physics I

Course Outcome

Knowledge gained : Students learned computer programming language Fortran and the techniques on numerical analysis.

Skill gained : Acquired skill in writing Fortran program based on various numerical algorithms and physics problems.

Competency developed : The students gain competence in handling computers and working systems. Student learned to solve real world physics and mathematical problems using computer programming.

Course Content

A. Basic Fortran: Introduction to Fortran, Data types, Constants and variables, Expressions and assignment statements, Input /Output statements, Program structure, Logical operations and Do loops, Arrays, Formats, File Processing, Programming units—main program, models, subprograms.

B. Approximations and errors in computing: Introduction; data errors; round off errors; truncation errors, significant digits; absolute and relative errors; general formula of errors; error estimation.

C. Numerical methods: Solutions of algebraic and transcendental equations—Bisections method, regular false method, Newton-Raphson method, roots of polynomial, Iterative methods-simultaneous equations; Solutions of linear simultaneous equations—Gauss elimination method and Gauss-Jordan method; matrix inversion method, Solution of differential equations-Euler's method and Runge-Kutta method; Data fitting and Interpolation—Least square method, linear and polynomial; Lagrange's interpolation and Newton's interpolation; Numerical differentiation, Numerical integration-Trapezoidal method and Simpson's method, Newton-Cotes numerical quadratures.

Reference books

Fundamentals of Computers V. Rajaraman
Computer programming in Fortran IV V. Rajaraman
Computer oriented numerical methods V. Rajaraman
Fortran 77: A structured, disciplined style: G B Davis and T R Hoffmann
Numerical methods for mathematics, science and engineering: J H Mathews
Numerical recipes in Fortran: W H Press, S A Teukolski, W T Vetterling and B P Flannery.

PHYSCCP0105N:: Laboratory Course I

(List of experiments should be regarded as suggestive of the standard and may not be strictly adhered to. New experiments of similar standard may be added and old experiments may be deleted whenever felt it necessary)

Course Outcome

Knowledge gained : Knowledge gained in electronic devices and in functionality of various circuit modules – regulators, power supply, amplifiers, Clipping and Clamping circuits, Digital/Analog converters, Adder-subtractor, etc.

Skill gained : Skill acquired in analog and digital electronics and making electronic circuits with components and learned to use ICs.

Competency developed : The students gain competence in designing analog and digital circuits that are useful in real life operations.

Course Content

1. To design and construct a stabilized power supply (Constant Voltage Source) using discrete devices and to study the variation of load voltage with load current. Show also the variation of load voltage with load current using IC 78XX.
2. To design and construct constant – K-type (a) low pass (b) high pass (c) band pass filters and to study the variation of attenuation and phase constants of these filters with input frequency. To determine the cut off frequencies and to compare with theoretical values.
3. To study OPAMP as a Sample and Holding circuit. Feed the sinusoidal input and apply a clock through a gate of NMOS (IRF150). Observe the input and out voltage wave forms on a CRO and plot the wave forms on the same axis with reference to clock pulse.
4. To study the variation of output voltage with frequency and load resistance for a given class-B Push Pull amplifier and to obtain the variation of output power with frequency and load resistance.
5. To design and construct clipping and clamping circuits using diodes and to study the variation of output amplitude and wave form using CRO.
6. To design a square wave generator using OPAMP. Measure the frequency and amplitude of the output wave form and to study its output waveform and frequency for various RC values.
7. To design and construct a variable power supply using SCR. Plot the V-I characteristics under different gate current conditions and obtain maximum forward break over voltage.
8. To design a uni-junction transistor (UJT) circuit and draw its characteristic curves for different values of supply voltage. Use it as a saw - tooth wave generator and determine the frequency of oscillation.
9. To study the various feedback amplifier using OPAMP: Voltage series feedback amplifier (VCVS), Voltage shunt feedback amplifier (CCVS), Current series feedback amplifier (VCCS) and Current shunt feedback amplifier (CCCS)
10. To design and construct an amplifier circuit using MOSFET. Study different characteristics of the amplifier.
11. To construct Half-Adder and Full-Adder circuits using only NAND gates and to perform some simple 2's complement Adder-subtractor operations (two decimal digits).
12. Experiments on Transmission line.

Reference books

Laboratory Experiments and PSPICE Simulations in Analog electronics—L. K. Maheswary and M.M.S. Anand
Fundamentals of digital circuit-- Anand Kumar

Semester II

PHYSCCT0201N : Classical Electrodynamics

Course Outcome

Knowledge gained : Knowledge gained in Maxwell equations, Gauge transformations, retarded potential, electromagnetic radiations and covariant formulation of electrodynamics

Skill gained : Skill acquired in basic electrodynamics and plasma physics.

Competency developed : The students gain competence in solving problems on electrodynamics and plasma physics and other branches of physics like nuclear physics. Also the competence helps to understand the quantum field theory.

Course Content

A. Review of electromagnetic theory: Boundary value problems in different geometries; Multipole expansion of the scalar and the vector potentials in the static scenario; Gauge transformations; Poynting theorem; Stress tensor; Maxwell's equations; Dispersion; Kramer's-Kronig relations; Resonant cavity and wave guide.

B. Localized time varying sources: Solution of inhomogeneous wave equation using Green's function technique; Retarded potentials; Electromagnetic radiation from time dependent localized charge and current distributions; Multipole expansion in the radiation zone; Radiation from center-fed linear antenna; Quadrupole radiation.

C. Moving point charge : Lienard-Wiechert potentials; Electromagnetic fields due to a point charge in uniform motion; Radiation from an accelerated point charge; Generalized Larmor formula for total power radiated by an accelerated point charge in relativistic motion; Angular distribution of radiated power in the linear and circular motion; Bremsstrahlung; Synchrotron radiation; Cherenkov radiation; Radiation reaction; Abraham-Lorentz formula, Scattering and absorption of radiation.

D. Covariant formulation of electrodynamics : Four vectors; Lorentz transformation of electromagnetic fields; Electromagnetic field tensor; Dual field tensor; Covariance of Maxwell's equations; Lagrangian formulation of the motion of a charged particle in an electromagnetic field; Covariant equation of motion; Covariant formulation of Lorentz force; Introductory Classical Field Theory: Lagrangian density, Field momentum, Hamiltonian density, Poisson brackets for the fields, Hamiltonian for a system of charged particles in an electromagnetic field.

E. Basic plasma physics : Definition of Plasma and its occurrence in nature; Saha's ionization formula; Plasma approximation; Debye shielding; Motion of a charge particle in non-uniform and time dependent electromagnetic fields; Curvature drift; Polarization drift; Adiabatic invariants; Plasma confinement; Fluid description of plasma; Plasma oscillations; Electron plasma waves; Ion waves; Propagation of electromagnetic waves in plasma in a magnetic field; Cut-off and resonance phenomena.

Reference books

Classical Electrodynamics – J. D. Jackson

Classical Theory of Fields- L. D. Landau and E. M. Lifshitz

Introduction to Electrodynamics – D. J. Griffiths

Classical Electromagnetic Theory- J. Vanderlinde

Classical Electricity and Magnetism – W. K. H. Panofsky and M. Phillips

Plasma physics & Controlled Fusion – F. F. Chen

Fundamentals of Plasma Physics- J. A. Bittencourt

PHYSCCT0202N : Statistical Mechanics

Course Outcome

Knowledge gained : Knowledge gained in basic postulates of classical statistical mechanics, partition functions, probability and distribution functions, and quantum statistical mechanics and its applications.

Skill gained : Skill acquired in solving problems in statistical mechanics and thermodynamic systems in equilibrium.

Competency developed : The students would be competent to connect the principle of statics with the law of mechanics, and their knowledge to complicated thermodynamic systems in and beyond the domain of physics.

Course Content

A. Classical statistical mechanics: Macro and micro states. Gibbs' ensemble, phase space, density function, Liouville's theorem, equipartition theorem. Postulates of classical statistical mechanics.

B. Ensembles and classical gas: Microcanonical ensemble, statistical mechanics and thermodynamics classical ideal gas, Gibbs paradox, relativistic ideal gas. Canonical and grand canonical ensembles, conditions for statistical equilibrium, thermodynamic functions, partition function and grand partition function, relation to thermodynamic quantities fluctuations, equivalence of different ensembles. Maxwell-Boltzmann distribution, applications. Inadequacy of the classical theory.

C. Quantum statistical mechanics: Density matrix and its properties, density matrix in different ensembles, applications of density matrix. Indistinguishable particles, bosonic and fermionic states, Bose-Einstein and Fermi-Dirac statistics.

D. Ideal Bose gas: Thermodynamics of an ideal Bose-gas. Application to photons, Planck's formula. Phonons in solids. Bose-Einstein condensation, liquid Helium II.

E. Ideal Fermi gas: Thermodynamics of an ideal Fermi gas. Degenerate Fermi gas, white dwarfs. Specific heat of crystalline solids. Thermal ionization, Saha's formula. Pauli's theory of paramagnetism, Landau diamagnetism.

F. Ising model: Idea of exchange interaction and Heisenberg Hamiltonian. Solution of Ising model using the mean field theory, critical temperature. Thermodynamic properties of Ising model in the mean field theory. Expansion of free energy in the mean field approximation. Exact solution of one-dimensional Ising system.

G. Phase transition and elements of lattice statistics: Landau theory of phase transitions. First and second order phase transitions. Spontaneous and explicit symmetry breaking in Landau Theory. Onset of hysteresis in first order phase transitions. Critical phenomena, critical exponents, universality and scaling relations.

Reference books

Statistical Mechanics – R. K. Pathria

Statistical Mechanics – K. Huang

Fundamentals of statistical and thermal physics – F. Reif

Statistical Mechanics - an elementary outline – A. Lahiri

An Introductory Course of Statistical Mechanics – P. B. Pal

Statistical Physics, Vol. 5 in Course in Theoretical Physics – L.D. Landau and E.M. Lifshitz.

PHYSCCT0203N : Quantum Mechanics I

Course Outcome

Knowledge gained : Knowledge gained in areas like general formalism of quantum physics, various approximation methods which are useful in nuclear physics and condensed matter physics.

Skill gained : Acquired skills in solving problems physics systems like particle in a potential, hydrogen atom problem, tunneling, etc. and approximations like perturbations and WKB methods

Competency developed : The students would be competent to connect the principle of statics with the law of mechanics, and their knowledge to complicated thermodynamic systems in and beyond the domain of physics.

Course Content

A. General formalism: States, observables and operators in quantum mechanics. Dirac's notation, measurement, eigenstates and mixed states, expectation values, wave-packets, Ehrenfest's theorem. Basic postulates of quantum mechanics, uncertainty principle, Schrodinger's equation, coordinate and

momentum representations. Schrodinger, Heisenberg and interaction pictures, Heisenberg's equation of motion.

B. Eigenvalue problems: Three-dimensional bound state problems, particle in a rigid box, central potentials, free particle solution in spherical polar coordinates, orbital angular momentum, Hydrogen atom, degeneracy and order of degeneracy.

C. Matrix mechanics: Linear harmonic oscillator, creation and annihilation operators, energy eigenvalue and normalized eigenstates. Unitary operator and evolution of the energy states. Angular momentum, spin angular momentum and Pauli matrices, eigenvalues and eigenstates of spin-1/2 particles, addition of angular momenta, Clebsch-Gordon coefficients.

D. Time independent perturbation theory: Non-degenerate perturbation theory, general formulation, first-order and second-order energy and state corrections. Degenerate perturbation theory, two-fold degeneracy, higher-order degeneracy, removal of degeneracy. Applications, Zeeman effect, Hyperfine splitting, Stark effect etc.

E. Variational method: Rayleigh-Ritz theorem, applications – linear harmonic oscillator, helium atom, hydrogen molecule etc.

F. Time dependent perturbation theory: General formulation, interaction picture, constant and harmonic perturbations, transition probability, emission and absorption of radiation, Fermi's golden rule, applications.

G. WKB Approximation: Eikonal approximation, semi-classical reduction of Schrödinger equation, WKB equation, turning points and connection formulae, bound state solutions in the WKB approximation, barrier penetration.

Reference books

Quantum Mechanics – B. H. Bransden and C. J. Joachain

Quantum Mechanics, Vol. I & II – C. Cohen-Tannoudji, B. Diu and F. Laloe.

Introduction to Quantum Mechanics – D. J. Griffiths

Quantum Mechanics, Vol. I & II – A. Messiah Modern

Quantum Mechanics – J. J. Sakurai

Quantum Mechanics – S. N. Biswas

Quantum Mechanics – S. Devnathan

PHYSCCP0204N: Computational Methods in Physics II

(List of problems given below should be regarded as suggestive of the standard and may not be strictly adhered to. New problems of similar standard may be added and old problems may be deleted whenever felt necessary)

Course Outcome

Knowledge gained : Knowledge gained in numerical analysis, data sampling and Monte-Carlo techniques of simulation of simple physical systems. Know how to solve numerical and physical problems.

Skill gained : Acquired skills in writing algorithm, flow charts, and programming on Fortran, handle data of large volume.

Competency developed : The students would be competent to write program and apply their programming knowledge in higher studies and research even in multidisciplinary fields like biophysics and econophysics.

Course Content

Numerical/Physics problems

1. Roots of polynomials – Newton-Raphson method, Baristow's Method
2. Solution of a set of simultaneous linear equations – Jacobi's method, Gauss-Seidal method, matrix inversion method, Gauss-elimination method and Gauss-Jordan method.
3. Matrices – Characteristic polynomial by Fadeev-Leverrier method. Determination of eigenvalue and eigenvector by Power method.
4. Interpolation and extrapolation.
5. Solution of differential equations – Euler's method and Runge-Kutta method, First and Second order differential equations.
6. Simple harmonic oscillator problem with and without damping effects, Coupled harmonic oscillators, charge and current oscillation in an LCR circuit.
7. Motion of projectiles and satellites.
8. Random numbers and Monte Carlo methods – Uniformly distributed, exponentially distributed and Gaussian distributed random numbers, evaluation of integration within finite/infinite limits.
9. Monte Carlo technique to simulate physics problems like the alpha-decay problem, Buffon's needle problem, random walk problem, diffusion problems etc.
10. Solution of Schrodinger's equation in a simple potential.
11. Use of standard libraries – LAPACK and LINPACK.

Reference books

Classical FORTRAN Programming for Engg. & Scientific Applications – M. Kupferschmid

Numerical Methods – S. Balachandra Rao & C. K. Shantha

Computational Physics - FORTRAN Version – S. E. Koonin & D. C. Meredith

Computational Physics – Nicholas J. Giordano and Hisao Nakanishi

Numerical Recipes in FORTRAN 77: W. H. Press, S. A. Teukolsky, W. T. Vetterling, B. P. Flannery

Semester III

PHYSCCT0301N: Quantum Mechanics II

Course Outcome

Knowledge gained : Limitations of non-relativistic quantum mechanics, Dirac's theory electron, field quantization, symmetries and identical particles in quantum systems and scattering theory.

Skill gained : Acquired skills in solving problems on relativistic quantum mechanics, scattering problems and interactions between elementary particles. Also various consequences of symmetry transformations.

Competency developed : The students learned the formalisms of advanced quantum mechanics which will be useful in other branches of physics, and while pursuing research career in fundamental physics.

Course Content

A. Symmetries: Symmetries and conservation laws in quantum mechanics, continuous symmetries, space and time translations, rotation, infinitesimal and finite transformations, Wigner-Eckart theorem, discrete symmetries, parity and time reversal.

B. Many particle system: Identical particles, exchange degeneracy, symmetrization postulate, symmetric wave function and identical bosons, asymmetric wave function and identical fermions, Pauli's exclusion principle, BE and FD statistics.

C. Scattering theory: Partial-wave analysis, phase-shift, optical theorem, shadow scattering. Green's function in scattering theory, Born's approximation. Applications of scattering theory, Coulomb scattering.

D. Relativistic quantum mechanics: Klein-Gordon equation, Dirac equation and its plane wave solutions, Pauli-Dirac and other representations, orthonormalization and completeness relations, spin and magnetic moment of an electron, negative energy state and its interpretation, massless Fermions, helicity and chirality. Large and small components of Dirac spinor, Pauli's theory as non-relativistic approximation of Dirac's equation, higher order corrections, central potential, H-atom. Lorentz group, transformation properties of Dirac spinors, covariance of Dirac equation, construction of bilinear covariants.

E. Field quantization: Limitations of ordinary quantum theory. Principle of least action and Lagrangian formulation of field theory, Noether's theorem and conserved currents. Quantization of free scalar field, and complex scalar field.

Reference Books

Relativistic Quantum Mechanics – J. D. Bjorken & S. D. Drell

Quantum Mechanics – E. Merzbacher

Advanced Quantum Mechanics – J. J. Sakurai

Quantum Physics – S. Gasiorowicz

Quantum Mechanics – A. K. Ghatak & S. Lokanathan

Quantum Field Theory – F. Mandl & G. Shaw

PHYSCCT0302N: Condensed Matter Physics

Course Outcome

Knowledge gained : Crystallography, lattice vibrations, thermal, dielectric and electrical properties of solids. Also students will gain knowledge on magnetism and superconductivity and semiconductors.

Skill gained : Acquired skills in crystallography and symmetries in lattice which help to determine the structure of a crystal. Also skilled to solve problems on the above mentioned topic with the help of quantum mechanics and statistical physics.

Competency developed : The students will be competent to apply the techniques of quantum physics and statistical physics to solve the problems in condensed matter physics. The competency gained therein will be useful in research and/or higher studies in material science and applied science.

Course Content

A. Elementary Crystallography: Symmetry operations and classification of 2- and 3- dimensional Bravais lattices, point group and space group. Common crystal structures: NaCl and CsCl structures, close-packed structure, Zinc blende, Wurtzite structure; reciprocal lattice and Brillouin zone, reciprocal lattice for SC, BCC and FCC structures, x-ray diffraction. Bragg's law; Laue diffraction; atomic scattering factor; crystal structure factor, Ewald construction, neutron diffraction; electron diffraction. Surface crystallography; Graphene; Non-crystalline solids.

B. Lattice vibration and thermal properties: Vibrations of monatomic and diatomic chains; acoustical and optical lattice vibrations in crystals; dispersion relation; Characteristics of different modes, long wavelength limit, quantization of lattice vibrations, phonon momentum, inelastic scattering of neutrons by phonons, Lattice heat capacity, models of Debye and Einstein, comparison with electronic heat capacity, anharmonic effects in crystals, thermal expansion and thermal conductivity.

C. Band theory: Bloch theorem; motion of electrons in a periodic lattice; Brillouin zones for simple lattices; crystal momentum; effective mass; Electronic band structures in solids- nearly free electron approximation; tight binding approximation- application to simple cubic lattices; Band structures in copper, GaAs and silicon.

D. Magnetic properties of solids: Quantum theory of diamagnetism, paramagnetism, Hund's rules, behaviour of the rare earths and iron group of metals, Magnetic Exchange Interaction, ferromagnetism and anti-ferromagnetism, Frustrated Magnetism, Domain theory, Heisenberg's exchange energy, Spin waves.

E. Semiconductors and their properties: Intrinsic and extrinsic semiconductors; mechanism of conduction in semiconductors; motion of hole-electron pair-carrier transport equation, Boltzmann equation, Hall effect, Quantum Hall Effect.

F. Superconductivity: Meissner effect, type I and II super conductors; London's equations; Ginzburg-Landau theory of superconducting transition, Coherence length, Cooper instability, Josephson effect.

Reference Books

Introduction to Solid State Physics – Charles Kittel,
Solid State Physics – N.W. Ashcroft and N.D. Mermin,
Introductory Solid State Physics – H. P. Myers,
Elementary Solid State Physics – M. Ali Omar,
Magnetism in Condensed Matter Physics- Stephen Blundell.
The Oxford Solid State Basics- Steven H. Simon.
Solid State Physics – A. J. Dekker

PHYSCCT0303N: Nuclear and Particle Physics

Course Outcome

Knowledge gained : Students gained knowledge in nuclear structure and reactions like fission and fusion, and in elementary particle physics. It helps to choose for an advanced studies in nuclear and particle physics.

Skill gained : Acquired skills in basic nuclear physics, in nuclear reactor, and accelerators and detectors.

Competency developed : The students will be competent to apply the techniques of quantum physics and statistical physics to solve the problems in nuclear physics. The competency gained therein will be useful in research and/or higher studies in nuclear physics, particle physics, accelerators and detectors.

Course Content

A. Shell model and basic properties of nuclei: Experimental evidences of the shell model, spin-orbit coupling; spin, parity, quadrupole moment, and magnetic moment of nuclear ground states, Schmidt lines; limitations of the shell model.

B. Interaction of radiation with matter: Passage of heavy particles through matter, specific ionization, Bethe's theory, straggling. Passage of electrons through matter, range energy relations, Bremsstrahlung, Passage of gamma radiation through matter, photoelectric effect, Compton scattering and pair production. Passage of neutrons through matter: slowing down, absorption and diffusion.

C. Two-body problem and nuclear reactions: Ground state of deuteron; nucleon-nucleon scattering (low energy), spin dependence and charge independence of the nuclear force. Different types of nuclear reactions. Quantum mechanical theory. Principle of detailed balance. Compound nuclear reaction. Ghosal's experiment.

D. Particle accelerators: Principle of phase stability and phase oscillation. Synchro-cyclotron, Synchrotron and Linear accelerators. Focusing of particle beams.

E. Nuclear decays: (i) Alpha-decay, Gamow's theory and systematics; (ii) Beta-decay, Fermi's theory, beta spectrum, selection rules for Fermi and Gamow-Teller transitions, parity non-conservation in beta-decay, Coulomb effect, Wu's experiment; (iii) Gamma decay, multipole transition and selection rules.

F. Particle Physics: Classification of elementary particles, spin and parity of pions, Symmetries and conservation laws, isospin measurements, CP violation, SU(2) and SU(3) multiplets. Quantum chromodynamics, quark model, magnetic moment of nucleons, Gellman-Okubo mass formula, quark confinement, asymptotic freedom.

Reference Books

Nuclear Physics – K. Krane

Physics of Nuclei and Particles, Vol. I – P. Marmien & E. Sheldon.

Atomic & Nuclear Physics, Vol. II – S. N. Ghosal.

Particle Accelerators – M. S. Livingstone & J. P. Blewett

Introduction to elementary particles – D. Griffiths

Introduction to high energy physics – D. H. Perkins

Fundamentals of Nuclear Physics – B. D. Srivastava

PHYSGET0301N: Atomic and Molecular Spectroscopy

Prerequisite - Approximations of Quantum Mechanics

Course Outcome

Knowledge gained : In spectroscopy and structure of one-electron, two-electron and many-electron atoms and diatomic molecules. Gained knowledge in interactions of atomic systems with external electric and magnetic fields.

Skill gained : Acquired skills in applying quantum mechanical approximations in simple physical systems like atoms with a few electrons and molecules. Also the skills gained in this course will help to operate some spectroscopic devices like interferometers, Zeeman effect and Raman effect setups, and laser related experiments.

Competency developed : The students will be competent to apply the quantum mechanical calculations in simple atomic and molecular systems. Competency developed in solving problems on atomic and molecular spectroscopy and laser.

Course Content

A. One-electron atoms: Hydrogen-atom spectrum, fine structure of H-atom, Lamb shift, hyperfine structure.

B. Interaction with external fields: Time dependent perturbation treatment, electric dipole approximation, stimulated and spontaneous emission, absorption coefficients, selection rules, line broadening, Zeeman effect, Paschen-Back effect, Stark effect.

C. Two-electron atoms: Spectral terms, exchange degeneracy, singlet and triplet states; LS, JJ and mixed coupling schemes.

D. Many-electron atoms: Independent particle model, central field approximation, Slater's determinant, alkali spectra, fine and hyperfine structure in alkali spectra.

E. Laser: Basic requirements, population inversion and stimulated emission, three and four level lasers, N₂, CO₂ and He-Ne lasers. Rate equation in three level system, optical resonators, mode locking, pulse lasers, line broadening, collision and Doppler broadening, Holography.

F. Molecular spectra: Rotation of a diatomic molecule, rotational transition, selection rules, rotational spectra of diatomic molecules as rigid rotor and non-rigid rotors. Diatomic molecules as linear symmetric and asymmetric tops. Vibration of diatomic molecules, harmonic oscillator, anharmonicity, selection rules and spectrum, symmetry property of molecular vibration, intensity of spectral lines. Rotation-vibration spectra of diatomic molecules, PQR branching, Raman spectroscopy, pure rotational spectra and vibrational spectra. Electronic spectra of diatomic molecules, Frank-Condon principle. Born-Oppenheimer approximation, vibrational and rotational structure.

Reference Books

Physics of Atoms and Molecules – B. H. Bransden & C. J. Joachain

Fundamentals of Molecular Spectroscopy – C. N. Banwell and E. M. McCash

Molecular Spectra and Molecular Structure, Vol. I – G. Herzberg

Laser Fundamentals and Applications – K. Thyagarajan and A. Ghatak

Laser Fundamentals – W. Silfvast

Semester IV

PHYS-CP-401 : Laboratory Course-II

Course Outcome

Knowledge gained : Students gained knowledge in various apparatus usually used in atomic and molecular spectroscopy, nuclear physics, condensed matter physics and electronics.

Skill gained : Acquired skills in assembling various apparatus and interfacing systems for data acquisition. Skill developed in data analysis using computer softwares, and in error analysis.

Competency developed : The students would be able to apply the competence developed in their research works in experimental physics. Also the knowledge in data analysis helps to work in data science.

Course Content

Short experiments

1. Determination of ultrasonic velocity in liquids using an ultrasonic interferometer.
2. Study of absorption lines of Iodine vapour using a spectrograph.
3. To study the spatial and temporal coherence of laser using Fabry-Perot interferometer.
4. Determination of Curie temperature of a ferromagnetic material.
5. Determination of the change of Refractive Index by Pockel's Cell.
6. Simulation of the lattice vibration in a crystal using electrical analogue circuit.
7. To study the characteristics curve of a G.M. Counter and to study the statistical fluctuation in cosmic ray background radiation.

8. To study the decay of activity of an artificially activated source using a G.M. counter.
9. To study the gamma counting efficiency of a G.M. tube.
10. Measurement of Hall coefficient of a given sample and calculation of its carrier concentration.
11. Measurement of the energy gaps of (i) silicon and (ii) germanium.
12. Determination of spin-spin relaxation time of a given sample and the value of the spectroscopic splitting factor (g) by the ESR method.
13. To determine the transverse magneto-resistance coefficient of a given sample and find the mobility of the carriers.
14. To study the beta spectrum of different beta sources.
15. (a) To design and study an amplitude modulator circuit using transistor and determine the percentage of modulation by (i) envelope method, (ii) trapezium method.
(b) To construct a detector circuit for AM waves and study its performance.
16. (a) To construct and study a four-bit ripple counter, (b) To construct and study a decade counting unit.

Long experiments

1. To study beta absorption in Aluminium and determine the maximum beta energy of a beta-active source using Feather's method.
2. To study the pulse height spectra of different gamma-sources using a scintillator detector, calibrate the gamma-spectrometer and to determine its efficiency and resolution.
3. To study gamma-absorption in lead using a gamma ray spectrometer.
4. To design and construct Butterworth first order, second order and fourth order low-pass, high-pass filters, to plot the frequency response curves for the low-pass filters, and to determine the phase-angles and the cut-off frequencies.
5. To construct the following circuits using IC-555 and study them: (a) astable multivibrator, (b) Schmitt trigger (c) saw-tooth wave generator (d) voltage controlled oscillator generator.

To be incorporated

1. To study the spatial and temporal coherence of laser using Michelson's and Jamin's interferometer.
2. To study the Zeeman effect.
3. To calibrate a Pirani gauge.
4. To measure the charge of an electron using Millikan's oil drop experiment
5. To study the high temperature superconductivity (at liquid nitrogen temperature)
6. Measurement of the decay lifetime of the muons using Scintillation detector (organic) – TAC assembly, and to calculate the fundamental weak coupling constant.
7. Measurement of the coercive field and saturation polarization of a ferroelectric sample.
8. Measurement of the anisotropy of magnetic susceptibility of a crystal by (i) Krishnan's method and (ii) Oscillation method.
9. Determination of the concentration of colour centres in an alkali halide crystal.
10. To determine the value of the lattice parameter and Bravais lattice type of a cubic crystal by Debye-Scherrer method.
11. To take the Laue photograph of a single crystal and drawing gnomonic projections and index the spots.
12. To determine the cell dimensions of a single crystal from a rotation photograph.
13. Measurement of Compton scattering cross-section and photoelectric effect cross-section.
14. To study Rutherford's scattering of alpha particles.
15. To study the Compton effect using scintillator.
16. To study (i) hadronic interactions, (ii) nucleus-nucleus interactions, (iii) pi-mu decay, and (iv) to measure charge of nuclear fragments in nuclear emulsion.
17. To design and switching of a switching mode power supply.

18. To detect frequency modulated waves using the IC phase-locked loop
19. Experiments with Fibre-optics
20. Experiments with microwaves
 - (a) To study the characteristics of wave propagation in a waveguide by studying the standing wave pattern and hence to plot the ω - β diagram.
 - (b) To verify the relationship between guide wavelength λ and free-space wavelength using a waveguide slotted section.
 - (c) To study the mode characteristics reflex Klystron and hence to determine the mode number, transit time, electronic tuning range (ETR) and electronic tuning sensitivity (ETS).
 - (d) To study the Gunn oscillator as a source of microwave power and hence to study (a) I-V characteristics, (b) power-frequency versus bias characteristics, and (c) power-frequency characteristics.
 - (e) To study the properties of E and H-plane waveguide tee junctions, and to determine isolations, coupling coefficients and input VSWRs.
 - (f) To study isolation. Coupling coefficients and input VSWRs of an E-H tee or Magic tee.
 - (g) To study the E-plane and H-plane radiation pattern of a pyramidal horn antenna and compute the (i) beam width and (ii) directional gain of the antenna.
 - (h) To study the characteristics of a directional coupler.
 - (i) To study the operation of a ferrite circulator and hence measure the (a) insertion loss, (b) isolation (c) cross coupling (d) input VSWR at a given frequency and study their variation with frequency.

Reference Books

Experiments in Electronics – S.V. Subrahmanyam
 Basic microwave Techniques and Laboratory Manual – M. L. Sisodia & G.S. Raghubanshi
 Lab. Manual for Introductory Electronics Experiments – L. K. Maheshwari & M.M.S. Anand
 Techniques of Nuclear & Particle Physics Experiments – W. R. Leo
 Nuclear Physics Experiments – J. Verma
 Nuclear Physics, Vol. II – S. N. Ghosal
 Radiation Detection & Measurements – G. F. Knoll

PHYS-ET-402 (DSE1)

DSE1-A : Magnetism

Course Outcome

Knowledge gained : The course on magnetism provides the students an advanced understanding on magnetic properties of matter, spin-spin interactions and also on the principle spin-spin and spin-lattice resonances and NMR.

Skill gained : The students will gain skill on how the knowledge of quantum and statistical mechanics will be combined in describing the fundamental properties of magnetism and its application in devices like NMR.

Competency developed : The students would develop competence in theoretical physics related to magnetism and magnetic properties of matter, and will be able to apply the techniques in modern age application devices like ESR and NMR.

Course Content

A. Ferromagnetism: Exchange interaction and Heisenberg's theory of ferromagnetism; Bloch's theory of free electron ferromagnetism; collective electron theory; magnons; magnon dispersion relation for ferro- and anti-ferromagnetic substances; Bloch's $T^{3/2}$ law; neutron scattering by magnons; Ising model.

B. Magnetic resonance: Basic theory; spin-spin and spin-lattice relaxation processes; Bloch equations; steady-state solutions; Bloch susceptibilities; line width; motional narrowing; nuclear magnetic resonance (NMR); Knight shift in metals; electron spin resonance (ESR); crystal field theory; ENDOR; Overhauser effect; methods for measuring relaxation times; SWR, RME, AFFMR, Mossbauer effect; Mossbauer's experiment, Mossbauer coefficient, classical and quantum theory, red shift, isomer shift, quadrupole coupling, magnetic hyperfine structure.

Reference Books

Intermediate Quantum Theory of Solids: A O E Animalu

Principles of theory of solids: J M Ziman

Quantum theory of solids: C Kittel

Elementary excitations in solids: D Pines

Quantum theory of solid state Part A and B: J Callaway

Electron energy bands in solids: J Callaway

Nuclear magnetic resonance (Advances in solid state physics series): G E Pake

DSE1-B : Nuclear Models, Two-body Problem and Nuclear Reactions

Course Outcome

Knowledge gained : The students gained knowledge in advanced nuclear physics, nuclear force and its spin dependence and nuclear reactions at low energies.

Skill gained : Acquired skills in solving problems in nuclear models and reactions.

Competency developed : The competency gained by a student would help him/her to explain the experimental data on nucleus-nucleus interactions at MeV energies. Also student would be competent to undertake research work in nuclear physics.

Course Content

A. Nuclear models: Collective model, rotational spectra of the nucleus, deformed nuclei, Nilsson model.

B. Two-nucleon system: Low energy nucleon-nucleon scattering and effective range theory. Deuteron problem – ground state of deuteron with non-central force, quadrupole moment and magnetic moment, exchange force.

C. Nuclear reactions: Statistical model. Optical Model and optical potential. Phenomenological calculations. Direct reactions. Plane-wave and distorted-wave Born approximations

Reference Books

Theoretical Nuclear Physics – J. M. Blatt & V. F. Weisskopf

Atomic & Nuclear Physics – S. N. Ghosal, Vol. II

Nuclear Physics – R. R. Roy & B. P. Nigam

Nuclear Physics - An Introduction – H. V. Buttler

Structure of the Nuclei – M. A. Preston & R. K. Bhaduri

Nuclear Models – Greiner Maruhn

Nuclear Physics: Energy and Matter – J. M. Pearson

DSE1-C : Electronic Communication

Course Outcome

Knowledge gained : Gained knowledge in areas like radio wave propagation, microwave propagation, fiber-optics communications, satellite communication and antenna.

Skill gained : Acquired skills to design and analyze various electronic circuits used in communication systems.

Competency developed : The competency developed would be applicable in communication system engineering and modern electronics which will create employability in the growing industries of communications.

Course Content

A. Antennas : Electromagnetic radiation; The elementary doublet; Current and voltage distributions for wired radiator in space; Directive gain; Radiated power and radiation resistance; Dipole antenna; Vertical antenna of different lengths; Arrays of antennas Loop, Yagi and other special purpose antennas.

B. Radio wave propagation : Space wave propagation; atmospheric effects; the ionosphere and its layers; effect of magnetic field of the earth; reflection and refraction of sky waves by the ionosphere; skip distance and maximum usable frequency; fading; Chapman's theory of formation of ionospheric layers; measurement of ionospheric height and electron concentration; Solar activity and its effect on radio wave propagation.

C. Microwave communications : Advantages and disadvantages of microwave transmission; propagation of microwaves, loss in free space; atmospheric effects and propagation; Fresnel zone problem, ground reflection, fading sources. Microwave communication system - Multiplexing, repeaters, detectors, components and antennas.

D. Fibre Optical communication : Types of optical fibre, numerical aperture, acceptance angle, single and multimode optical fibres, splicing and fibre connectors, fibre optic communication system, fibre sensor, optical sources and optical detectors. Planar wave guide, concept of mode, V-parameter, Multipath and material dispersion; Power budget equation; Wavelength Division Multiplexing; Quantum limit; Bit error rate and maximum bit rate.

E. Satellite communication : Orbital and Geostationary satellites, orbital patterns, Satellite system link models, Satellite system parameters, and Link equations. Multiple access techniques; Transponders; Effects of nonlinearity of transponders. Satellite radio navigation, NAVSTAR Global Positioning System. Radar, Radar block diagram, Radar performance: range equation, noise; radar frequencies, Pulse system, antenna and scanning, display.

Reference Books

Basics of electronic communications: NIIT

Electronic communication: Robert L. Shrader

Electronic communication systems: George Kennedy

Electronic communications: D. Roody J. Coolen Pearson

Optoelectronics and fiber optics Communication: C.K.Sarkar and D.C.Sarkar

Advanced Electronics: T. P. Chattopadhyay

PHYS-ET-403 (DSE2)

DSE2-A : Field Theoretic Techniques in Condensed Matter Physics

Course Outcome

Knowledge gained : Students gained knowledge on various techniques for theoretical calculations in condensed matter physics, like the second quantization, real time Green's function and imaginary time Green's function

Skill gained : Acquired skills on mathematical methods and quantum mechanics emphasizing on the applications in condensed matter physics.

Competency developed : Attending the course students would be competent in their research works in condensed matter physics and understand the working principles of materials in modern applications.

Course Content

A. A brief review of quantum mechanics: Postulates, single particle states, electron gas, Bloch states, Wannier functions, two dimensional electron gas in a magnetic field; Landau levels.

B. Second quantization: Formulation, creation and annihilation operators, single and two-particle operators, quantum field operators.

C. Degenerate electron gas: Hamiltonian in the jellium model, high-density limit.

D. Real-time Green's and correlation functions: Physical significance, spin-dependent Hamiltonians, translational invariance, Linear response theory and its applications.

E. Imaginary-time Green's function: Matsubara Green's function; application to nondegenerate electron gas and Landau problem.

F. Superconductivity: Electron-phonon interaction, BCS theory, mean field approach, Green's function approach to superconductivity, Nambu formalism.

Reference Books

Feynman Diagram Techniques in Condensed Matter Physics - Radi A. Jishi

Many-Body Quantum Theory in Condensed Matter Physics- An Introduction, H. Bruus and K. Flensberg

Many-Particle Physics- G. D. Mahan

Quantum theory of Many-Particle Systems- Alexander L. Fetter and John D. Walecka

Condensed Matter Field theory- Alexander Altland and Ben Simons

Quantum theory of electron liquid- G. F. Giuliani and G. Vinale

DSE2-B : Nuclear and Particle Astrophysics

Course Outcome

Knowledge gained : The knowledge gathered from this course would make the student understand that how modern nuclear physics try to answer the questions about the birth and dynamics of the Universe.

Skill gained : Acquired skills on theoretical and experimental nuclear astrophysics and the physics of the quark gluon plasma.

Competency developed : Attending the course students would be competent in their research works in astroparticle physics and quark gluon plasma and heavy ion interactions.

Course Content

A. Nuclear Astrophysics: Sources of stellar energy, gravitational collapse, fusion reactions (p-p chain, CNO cycle, triple α reactions). Stellar nucleosynthesis and formation of heavy elements beyond the Fe-peak. Production of nuclei in stars through r-, s- and γ -processes.

B. Astroparticle Physics: Origin of primary cosmic rays. Acceleration and propagation of cosmic ray particles in ISR(M). Extensive air-showers, characteristic air shower observables and their measurements. Cosmic-ray energy spectrum, the knee and ankle, Greisen-Zatsepin-Kuzmin cut-off. Astrophysical neutrinos and gamma rays.

C. Quark-gluon Plasma: MIT bag model and QGP formation in terrestrial laboratory. QGP at high-temperature and low baryon density and its relevance in cosmology. QGP at high baryon density and its relevance in astrophysics.

Reference Books

Theoretical Astrophysics Vol III – T. Padmanabhan
High-energy Astrophysics – M. S. Longair
Extensive Air Showers – P. K. F. Grieden, Vol. II
Introduction to high-energy heavy-ion collisions – C.-Y. Wong

DSE2-C : Microwave

Course Outcome

Knowledge gained : Gained knowledge on transmission lines, microwave sources, microwave integrated circuits and antenna.

Skill gained : Identifying different active and passive microwave components, compare the structural parameters, operations, gains, power efficiencies of various microwave sources. Analyze various microwave transmission lines.

Competency developed : Attending the course students would be competent in designing microwave devices for practical applications and communications.

Course Content

A. Transmission lines and waveguides: Lossless and low loss transmission lines, Impedance matching in high frequency lines, Smith Chart, Impedance matching by stubs- single stub and double stub matching, Transmission lines as resonant circuits, Q of a transmission line. Rectangular wave guide: TE and TM modes, cut-off frequency, group and phase velocities; power transmission, excitation of modes. Circular waveguide: TE and TM modes, power transmission, excitation of modes. Microwave cavities: Rectangular and circular cavity resonator, Quality factor and Q-value of a cavity resonator, Q-value of a coupled cavity.

B. Microwave Sources: Conventional sources and their limitations. (i) *Vacuum tube sources:* Klystron, reflex klystron, travelling wave tubes, Magnetrons, Multicavity travelling wave magnetrons; Noises in microwave tubes. (b) *Solid state sources:* Microwave transistors and FETs, Gunn diodes.

C. Microwave Circuit components: Scattering matrix representation of microwave network, properties of S-parameter, Wave guide Tees, Magic Tee, Hybrid ring, Directional coupler, Ferrites and Faraday's rotation, Microwave ferrite devices: gyrator, circulator, isolator and terminator; $\frac{\lambda}{4}$ section filter, tuner and sliding short.

D. Microwave antennas: Aperture antennas, Radiation from electromagnetic horns, reflector antennas.

E. Microwave integrated circuit: Materials and fabrication technique; MOSFET fabrication, memory construction, thin film formation, planar resistor, planar inductor and planar capacitor formation; Hybrid integrated circuit formation.

Reference Books

Microwave Devices and Circuits – Samuel Y. Liao
Microwave Principles: Herbert J. Reich
Foundation for Microwave Engineering – R. E. Collin
Microwaves - M. L. Sisodia & V.L. Gupta
Microwave Propagation and Techniques – D. C. Sarkar
Microwaves – K. C. Gupta

Physics of Semiconductor Devices- S.M. Sze

Microwave Circuits and passive Devices – M. L. Sisodia & G. S. Raghubanshi

Circuit Theory - Waveguide and Radiowave Propagation – S. N. Sen

Antenna: J. D. Kraus

PHYS-ET-404 (DSE3)

DSE3-A : Topology in Condensed Matter Physics

Course Outcome

Knowledge gained : The course focuses on some theoretical aspects of condensed matter physics, and hence students will gain knowledge in Hamiltonian formulation and symmetries in solid state physics, quantum Hall effects, etc.

Skill gained : Students will be skilled to apply the concept of basic quantum mechanics in solids, model the problems and interpretation of the results with experimental observations.

Competency developed : The students will be competent in research and higher studies in theoretical condensed matter physics, customize the theory to interpret the experimental data.

Course Content

A. Topology, Hamiltonian, and Symmetry: Topology and Band theory, symmetries of the Hamiltonian, sub-lattice, particle-hole and time reversal symmetries, Kramer's theorem, one-dimensional systems.

B. The Su-Schrieffer-Heeger (SSH) Model: The SSH Hamiltonian, Bulk Hamiltonian, Edge states, Bulk-edge correspondence, topological invariant.

C. Berry phase, connection, and curvatures: Discrete and continuum case, Adiabatic dynamics, Chern theorem, two level system.

D. Hall conductance and Chern number: Quantum Hall Effect, TKNN invariant, Anomalous QHE, Haldane Model, Chern insulators.

E. Time-Reversal Invariant Topological Insulators: Kane-Mele model, Quantum Spin Hall insulator in Graphene, Z₂ invariant.

Reference Books

Topological insulators: Shun-Qing Shen.

Topological insulators and topological superconductors: B. Andrei Bernevig, and T. L. Hughes.

Topological insulators: Marcel Franz, and L. Molenkamp.

A short course on topological insulators: J. K. Asboth.

Berry Phases in electronic structure theory: David Vanderbilt.

DSE3-B : Quantum Electrodynamics

Course Outcome

Knowledge gained : The course focuses on the free field and interacting field theory. Understanding of these theories are essential to understand the fundamental interactions in the standard model.

Skill gained : Students will be skilled to compute the interaction cross section of various two-body interactions between fundamental particles. Also the basic concept of renormalization will be introduced.

Competency developed : The students will be competent in research and higher studies in fundamental theoretical physics and particle physics.

Course Content

A. Free fields: Quantization of Dirac field, Pauli's principle and anti-symmetric nature of Dirac field operators. Quantization of electromagnetic field, gauge condition and related issues, Gupta-Bleuler formalism. Covariant commutators and Feynman's propagator for different types of fields.

B. Interacting fields: Covariant perturbation theory, scattering matrix, Wick's theorem, cross-section and decay rates, Mandelstam variables and crossing symmetry, spin sum and averaging; Feynman rules and graphs for some basic QED processes. Electron-muon scattering, Moller scattering, Bhabha scattering, Compton scattering, electron-nucleus scattering and form factor. Basic ideas of regularization and renormalization.

Reference Books

A first book on quantum field theory – A. Lahiri and P. B. Pal

Quantum field theory – David Tong

An introduction to quantum field theory – M. E. Peskin and D. Y. Schroeder

Quantum field theory – F. Mandl and G. Shaw

DSE3-C : Digital Systems and Communication

Course Outcome

Knowledge gained : The course helps students to understand the fundamentals of system level design and analysis of digital communication systems.

Skill gained : Will be skilled to analyze the performance of digital communication systems, and will be skilled for employment in the rapidly growing communication industries.

Competency developed : The students will be competent in advanced studies of digital communications and in computing the power and bandwidth requirements of modern communicating systems.

Course Content

A. Digital communication Systems: Pulse coded communication, sampling theorem, PAM, PWM, PPM, PCM, Delta modulation, ASK, FSK, PSK, DPSK, QPSK, MSK. Computer communication- Different networks like LAN, ISDN, PBX, Medium access sublayer-TDMA, FDMA, ALOHA Mobile communication.

B. Advanced Digital Circuits: Shift registers, Controlled shift registers and application of shift registers. Asynchronous and synchronous counters, Mod counters, Up-down counters, Presettable counters. Three state buffer register, Bus-organization. Counter method of analog to digital converters.

C. Semiconductor Memories: Classification and characteristics of Memories, Read Only Memory (ROM), Read and Write Memory, Flash Memory, content of addressable Memories, Charge Couple Device Memory, Memory Organization and Operation.

D. Programmable Logic Devices: ROM as a Programmable Logic Device (PLD), Programmable Logic Array (PLA), Programmable Array Logic (PAL), Complex Programmable Logic Device (CPLD), Field-Programmable Gate Array (FPGA).

E. Microprocessors: Introduction to Microprocessors, Organization of Microprocessors, Signal Description of Microprocessors, Instruction Sets, Programming Techniques with Additional Instructions, Counters and Time Delays, Stack and Sub-routines, Physical Memory Organization, Bus Operation, I/O Addressing Capability, Application of Microprocessors.

Reference Books

Electronic communications systems: Wayne Tomasi

Communication systems (analog and digital): R P Singh and S D Sapre
Modern Digital Electronics: R.P. Jain
Digital Computer Electronics: Malvino and Brown
Fundamentals of digital circuit: Anand Kumar
Microprocessor Architecture, Programming and Application with the 8085: Ramesh Gaonkar

PHYS-ET-405 (DSE4)

DSE4-A : Soft Condensed Matter Physics

Course Outcome

Knowledge gained : Knowledge gained in intermolecular forces, phase transitions, polymers and liquid crystals.

Skill gained : Skill gained in explaining the significance of soft condensed matter physics and explain material properties using analytical methods.

Competency developed : The students will be competent to recognize everyday examples of soft matter systems and use material learned in this course to understand the behaviour such systems.

Course Content

A. Forces, energies, and time scales in condensed matter: Intermolecular forces in Gases, liquids, and solids. Viscous, elastic and viscoelastic behaviour. Liquids and Glasses.

B. Phase transitions: Phase transition in soft matter. Equilibrium phase diagrams. Kinetics of phase separation. Liquid-Solid transition-freezing and melting.

C. Polymers: Synthesis. Polymer chain conformation. Chain statistics in polymer melts-the Flory theorem. Characterization. Polymer solutions. Bio-polymers.

D. Colloids: Types of colloids. Forces between the colloidal particles. Characterization of colloids. Charge and Steric stabilization. Kinetic properties. Forms of colloids.

E. Amphiphiles: Types of Amphiphile. Surface activity. Surfactant monolayers and Langmuir Blodgett films. Detergency. Solubilization in micelles. Interfacial curvature and its relationship to molecular structure.

F. Molecular order in soft condensed matter—liquid crystallinity: Introduction, Liquid crystal phases and transitions. Response to electric and magnetic fields.

Reference Books

Principles of Condensed Matter Physics, P. M. Chaikin and T. C. Lubensky

Introduction to Soft Matter, Ian W. Hamley.

Soft Condensed Matter, R. A. L. Jones.

Soft Matter Physics, M. Kleman and O. D. Lavrentovich.

DSE4-B : Symmetries and Gauge fields

Prerequisite - Quantum Electrodynamics

Course Outcome

Knowledge gained : Students will gain knowledge in advance theories like the gauge theory, electro-weak theory which will help them to understand the basis interactions among elementary particles.

Skill gained : Skill gained in tensor and group theories and in solving problems in advanced particle physics.

Competency developed : The students will be competent to apply the techniques and concepts in his/her research in theoretical particle physics.

Course Content

A. Discrete symmetries: Parity transformation, charge conjugation, and time reversal of quantum fields, CPT theorem.

B. Gauge theories: $U(1)$ gauge symmetry of QED, $SU(2)$ symmetry and Yang-Mill's theory, non-abelian gauge theories, $SU(3)$ colour symmetry, gluon self-interaction, quark-quark, quark-gluon and gluon-gluon scattering in lowest order perturbation theory. Spontaneous symmetry breaking and Higg's mechanism.

C. Electro-weak theory: $SU(2)_L \times U(1)_Y$ gauge symmetry of weak interaction. Gauge boson and fermion masses, neutral current, experimental tests.

Reference Books

Quarks and Leptons – F. Halzen & A.D. Martin

Quantum field theory – David Tong

An introduction to quantum field theory – M. E. Peskin and D. Y. Schroeder

Quantum field theory – F. Mandl and G. Shaw

An Introductory Course of Particle Physics – P. B. Pal

Gauge Theories in Particle Physics – T. -P. Cheng and L.-F. Li

An Introduction to Gauge Theories and Modern Particle Physics – E. Leader and E. Predazzi

DSE4-C : Physics of Liquid Crystals

Course Outcome

Knowledge gained : Knowledge gained in theoretical and experimental aspects of liquid crystals

Skill gained : Skill gained in understanding experimental data on x-ray diffractions, relaxation time measurements and various electrical and magnetic properties and magneto-optical behaviour of liquid crystal.

Competency developed : The students will be competent to apply the techniques learned therein in the research areas of liquid crystal physics.

Course Content

A. Liquid crystals: Thermotropic, lyotropic and amphotropic phases; smectic order and smectic polymorphism; the role of chirality; ferroelectricity, antiferroelectricity and ferrielectricity; phases associated with complex molecular architectures.

B. Theoretical models: Maier-Saupe, McMillan and Landau-de-Gennes models

C. Elastic Continuum Theory: Fundamental Equation; Applications of Continuum theory: Twisted Nematic Cell, Magnetic Coherence Length, Freedericksz transition.

D. Structural investigation by X-ray diffraction: Experimental details; Diffraction patterns of liquid crystal phases; High resolution X-ray diffraction; positional order; Correlation at the nematic to smectic-A phase transition.

E. Relaxation phenomena: Structure and rotational possibilities; Dielectric relaxation and orientational effects in nematic and smectic phases.

F. Display and memory devices: Electro-optic and magneto-optic effect of liquid crystals. Applications of liquid crystals.

Reference Books

Liquid Crystals: S. Charandrasekhar

Liquid Crystals – Fundamentals: S. Singh

The Physics of Liquid Crystals: P.G. de Gennes and J. Prost

Thermotropic liquid crystals: fundamentals: G. Vertogen and W.H. de Jeu.

Introduction to Liquid Crystals: phase type, structures and applications: P.J. Collings and M. Hird

DSE4-D : Project and Dissertation

Course Outcome

Knowledge gained : Student will gain knowledge in a specific topic of his/her interest so that it becomes useful in his/her area of research.

Skill gained : Depending upon the type of project work undertaken the students will be skilled to solve/understand the research methodologies and learned to write report of research/project outcome.

Competency developed : The students will be competent to apply the techniques/methods learned in his/her research works.

Course Content

Depends upon the project undertaken.

PHYS-GE-406 : General Theory of Relativity, Astrophysics and Cosmology

Prerequisite – Tensors and Special Theory of Relativity

Course Outcome

Knowledge gained : Knowledge gained in general relativity and its applications in astrophysics and cosmology.

Skill gained : The students learned to solve problems in general relativity, astrophysics and cosmology. Also skill gained in tensor analysis and in some special techniques to describe real world astrophysical observations.

Competency developed : The students will be competent to apply the techniques learned through the course in research on theoretical physics and mathematics. Also competence developed in analyzing data of various astrophysical observatories, and their theoretical interpretations.

Course Content

A. General Relativity : Riemannian geometry; covariant differentiation, geodesics; Riemann curvature tensor; Bianchi identity; Ricci tensor; Ricci scalar; condition of flatness; Einstein tensor and field equations. Energy momentum tensor for dust and perfect fluid; conservation laws; gravitational red-shift; Einstein's equations for weak fields; gravitational waves. Schwarzschild exterior solution; conditions for circular orbits; Tests for GTR.

B. Astrophysics: Magnitudes of a star, distance modulus relation, comparison of radii of stars with surface temperature and luminosity. H-R diagram, general features of the sun; transient phenomena in the sun; origin of energy in the sun, pp chain reactions, solar- neutrino problem, CNO cycle. Hydrostatic equilibrium of a Newtonian star; Lane-Emden equation; stellar evolution, white dwarf, neutron star, pulsars, black holes.

C. Cosmology: Cosmological principle; Robertson-Walker line element. Einstein's static universe, standard model of the universe, relics of big-bang model, microwave background radiation, Hubble constant, Hubble's law, cosmological parameters and their significance.

Reference Books

Introduction to Cosmology – J. V. Narlikar

Modern Cosmology – S. Dodelson

Gravitation & Cosmology – S. Weinberg

Gravity – J. B. Hartle

An Introduction to Astrophysics – B. Basu

Astrophysics – K. D. Abhayankar

Introduction to relativity – J. B. Kogut