Ph.D.(Physics) Entrance Syllabus (2023-24)

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I. Mathematical Physics

Vector spaces and matrices: linear independence, bases, dimensionality, inner product, linear transformations, matrices, inverse, orthogonal and unitary matrices. Independent elements of a matrix, eigenvalues and eigenvectors, diagonalization, complete orthonormal sets of functions.

Function of a complex variable: Analytic functions, Cauchy-Reimann conditions, Elementary functions of Z, Cauchy's integral theorem, Cauchy's integral formula, Taylor and Laurent series, Residues, Residue theorem, Jordon 's lemma, Evaluation of real definite integrals.

Second order linear ODE's: series solution (Frobenius's method). Solution of Legendre, Bessel, Hermite and Lagaurre equations. Generating functions and recurrence relations.

Integral transforms, Laplace transform (LT), first and second shifting theorems, Inverse LT by partial fractions, L T of derivatives and integral of a function. Fourier series (FS) FS of arbitrary period, Half-wave expansions, partial sums; Fourier integral and transforms.

II. Classical Mechanics

Lagrangian equation, and its applications, Hamilton's principle and derivation of Lagrange's equations from Hamilton's principle, symmetries and conservation laws.

Reduction to equivalent one body problem, the equation of motion and first integrals, the equivalent one – dimensional problem and the classification of orbits, the differential equation for orbits, the Kepler's problem (inverse square law), scattering in central force field.

The Euler's angles, rate of change of a vector, the Coriolis force and its applications, Legendre transformation and Hamilton's equation of motion, cyclic coordinates, the equations of canonical transformation, examples of canonical transformation, Poisson's brackets, Poisson's theorem.

Hamilton-Jacobi equation for Hamilton's principal function, Harmonic Oscillator problem, stable and unstable equilibria, elementary idea of small oscillations, normal modes and coordinates, free vibrations of a linear triatomic molecule.

III. Quantum Mechanics

The Schrodinger equation: Time dependent and time independent forms, Probability current density, expectation values, Ehrenfest's theorem, Gaussian wave packet and its spreading. Exact statement and proof of the uncertainty principle, Time independent equation, eigenvalues and eigenfunctions, Degeneracy and orthogonality. Applications of Schrodinger equation for 1 d Box, Tunneling problem & Linear Harmonic Oscillator.

Operator formalism in quantum mechanics, Hermitian operators and their properties, Vector representation of States-Bra and Ket algebra, relationship between kets and wave functions, Linear harmonic oscillator problem, coherent states, annihilation and creation operators, Matrix representation of an operator, Unitary transformation.

The angular momentum operators and their representation in spherical polar coordinates, solution of Schrodinger equation for spherically symmetric potentials, spherical harmonics, Hydrogen atom. Angular momentum matrices and Pauli spin matrices.

Time independent perturbation theory: Nondegenerate case, first and second order perturbations, Degenerate case, removal of degeneracy in second order. First order Stark effect in hydrogen, The Variational Method: expectation value of the energy, application to excited states, ground state of helium.

WKB Approximation: The WKB method for one-dimensional problems, Application to barrier penetration, The WKB method for three dimensional problems.

Time-dependent perturbation theory: harmonic perturbation; Fermi's golden rule, adiabatic and sudden approximations.

Basic concept of scattering, scattering amplitude, differential and total scattering cross sections, scattering by spherically symmetric potentials, partial waves and phase shifts, scattering by a perfectly right sphere and by square well potential. Born approximation and its application to scattering of electrons by atom.

IV. Electronics

The junction field Effect Transistor: Basic structure & Operation, pinch off voltage, single ended geometry of JFET, volt – ampere characteristic, Transfer Characteristics.

MOSFET: Enhancement MOSFET, Threshold Voltage, Depletion MOSFET, comparison of p & n channel FET,s. JFET low frequency common source amplifiers.

Differential Amplifier: Circuit configuration, dual input balanced output different amplifier, D.C. & A.C. analysis, Inverting and Non-inverting inputs, CMRR – constant current bias level translator.

Operational Amlifier: Block diagram, open loop configuration, inverting & non-inverting amplifier, OP-AMP with negative feedback – Voltage series feedback, Effect of feedback on closed loop voltage gain, Input resistance, output resistance, band width, output offset voltage.

OP-AMP Application : DC and AC amplifer, summing, scaling and Averaging amplifier, Integrator, Differentiator, Electronic analog computation comparator

Oscillators: principles, Types, frequency stability, Phase shift oscillator, Wein bridge oscillator, LC tunable oscillator, Square wave, Triangular wave and pulse generator (Monostable & Astable, multivibrators)

Digital operation of system: Introduction to OR, AND & NOT gates Ex-OR gate, De Morgan's Laws, NOR & NAND DTL Logic, Binary adder, Digital Comparator, Decoder/Demultiplixer, Data selector/Multiplixer-Encoder, ROM and its applications.

Flip-Flops : R-S, J-K, Master slave, T & D type flip flop, shift Register, Synchronous & Asynchronous Counter.

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V. Solid State Physics

Crystalline solids, unit cells and direct lattice, two and three-dimensional Bravais lattices, closed packed structures.

Interaction of X-rays with matter, absorption of X-rays. Elastic scattering from a perfect lattice. The reciprocal lattice and its applications to diffraction techniques. The Laue, powder and rotating crystal methods, crystal structure factor and intensity of diffraction maxima.

Dispersion relation for one dimensional lattice vibration in monatomic and diatomic basis: acoustical and optical modes. Quantization of elastic waves, phonon momentum, in elastic scattering by phonons. Free electron fermi gas: energy levels and density of orbitals, the Fermi-Dirac distribution, free electron gas in 3-dimensions, electronic

Electrons in a periodic lattice: Bloch theorm, band theory, and classification of solids, effective mass. Tight bonding, pseudopotential methods. Fermi surface, de Hass von Alfen effect, cyclotron resonance, magneto resistance, quantum Hall effect.

Basic Properties of Superconductors, Critical Temperature, Meissner Effect, Transport Behavior, Types of Superconductors and Concept of λ and , Ginzburg Landau Theory, Hard Type-II Superconductors and Critical Current Density, Some introduction to High Temperature Superconductors

Diamagnetism, Para-Magnetism: Vanveleck Theory and Pauli theory of Paramagnetism. Theory of Ferromagnetism: Weiss, Heisenberg Model and Molecular Field Theory, Curie Weiss law of Susceptibility, and concept of Spin Waves. Ferri and Antiferro–magnetic order. Domains andBloch-wall energy.

VI. Atomic & Molecular Physics

Two electron systems : - Interaction energy in L S and J J coupling, Atomic states arising due to different electronic configuration (L S coupling only). Spectrum of Helium and Heisenberg's resonance. Hyperfine structure of spectral lines: Isotope effect, nuclear spin and hyperfine multiplet.

The diatomic molecule as a Rigid Rotator & Harmonic Oscillator, Energy levels and Infrared spectra. Raman Effect: Quantum theory, The Raman Spectrum of the Rigid Rotator and of the Harmonic Oscillator. The diatomic molecule as Non-rigid Rotator and Anharmonic Oscillator: Energy levels and I R spectrum. Raman Spectra for the Non-rigid Rotator and Anharmonic Oscillator.

The diatomic molecule as a Vibrating Rotator: Energy levels, Infrared spectrum and Raman Spectrum. Thermal distribution of Quantum states: Intensities in rotation- vibration spectra, symmetry properties of the rotational levels: Influence of nuclear spin, Isotope effect on vibration and rotation spectra.

Electronic band spectra: Electronic energy & total energy, resolution of the eigenfunction (Born-Oppenheimer approximation) & total energy, Vibrational structure of Electronic transitions. Rotational structure of Electronic bands: The branches (P,Q,R) of a band, Band-head formation. Intensities in Electronic bands: Intensity distribution in the vibrational structure, The Franck-Condon principle (absorption & emission)

VII. Statistical Mechanics

Foundations of statistical mechanics, specification of states of a system, concept of phase space and ensemble contact between statistics and thermodynamics, equipartition theorem, classical ideal gas, entropy of mixing and Gibb's paradox.

Microcanonical ensemble, phase space, trajectories and density of states, Liouville's theorem, Boltzmann H Theorm. Canonical and grand canonical ensembles, partition function. Calculation of statistical quantities, Energy and density fluctuations.

Density matrix, statistics of ensembles, statistics of undistinguishable particles, Maxwell – Boltzmann, Fermi-Dirac and Bose – Einstein statistics, properties of ideal Bose – Einstein and Fermi-Dirac gases, Bose Einstein condensation, Laser cooling of atom as an example of Bose Condensate. Planck's radiation formula (Black body Radiation)

Virial equation of state, Ising model, mean – field theories of the Ising model in one dimension and Exact solution in one dimension. Landau theory of phase transition,

VIII. Electrodynamics

Energy stored in an electric and magnetic fields. Maxwell's equations, power flow in an electromagnetic field and pointing theorem. Electromagnetic waves in a homogeneous medium- solution for free space conditions. Uniform plane waves, the wave equations for a conducting medium, Sinusoidal time variations, Maxwell's equations using phasor notation. Wave propagation in a loss less medium, wave propagation in a conducting medium, wave propagation in a good dielectric.

Polarization : Linear, elliptical and circular Polarization, Direction cosines.

Reflection and refraction of plane waves: Reflection by a perfect conductor – normal and oblique incidence. Reflection by a perfect dielectric – normal and oblique incidence. Power loss in a plane conductor.

Dispersion and Scattering; Coherent and Incoherent Scattered Light, Polarization of Scattered Light, Dispersion in Solids, Liquids and gases.

Wave Equation for Vector and Scalar Potential and Solution Retarded Potential and Lienard – Wicehert Potential, Electric and Magnetic fields due to a Uniformly Moving Charge and An Accelerated Charge, Linear and Circular Accelerating and angular Distribution of Power Radiated, Bremsstrahlung, Synchrotron Radiation and Cerenkov Radiation.

Chairperson
Department of Physics
Guru Jambheshwar University
of Sc. & Tech., Hisar-125001

IX. Nuclear & Particle Physics

Two Nucleon Problem, Exchange forces, Meson theory of nuclear forces, nucleon- nucleon scattering, Effective range theory, Spin dependence of nuclear forces, Charge independence and charge symmetry of nuclear forces. Direct and compound nuclear reaction mechanism, Cross-section in terms of partial wave amplitude.

Liquid drop model, Bohr-Wheeler theory of fission, Experiment evidence for shell effect, Magic numbers, Shell model, Spin-orbit coupling, Angular momenta and parities of nuclear ground states, Qualitative discussion and estimates of transitions rates, Magnetic moments and Schmidt lines.

Beta decay, Fermi theory of beta decay, Shape of the beta spectrum, Total decay rate, Angular momentum and parity selection rules, Detection and properties of neutrino, Gamma decay, Multipole transitions in nuclei, Angular momentum and parity selection rules, Internal conversion, Nuclear isomerism, Interaction of charged particle with matter, (qualitative idea).

Type of interaction between elementary particle – Hadrons and leptons, Symmetry and conservation laws, Elementary ideas of CP and CPT invariance, Classification of hadrons, SU (2)-SU (3) multiples (qualitative only), Quark model, Gell-Mann-Okubo formula for octet and decuplet hadrons-Charm, bottom and top quarks.

X. Computational Methods & Programming

Elementary information about Digital Computer Principles, Compilers, Interpreters and Operating system. Fortran programming, Flow charts, Integer and Floating Point Arithmetic, Expressions, built in functions, executable and non-executable statements, assignment, control and input-output elements, Subroutines and functions.

Solution of simultaneous linear equations, Gaussian elimination, pivoting, iterative Method, matrix inversion, Stability analysis of above techniques.

Eigenvalues and eigenvectors of matrices, Power Method.

Finite differences, interpolation with equally spaced and unevenly spaced points. Curve fitting, Polynomial least squares and cubic Spline fitting. Stability and error analysis.

Numerical differentiation and integration, Newton-Cotes formulae, error estimates, Gauss method. Gaussian Quadrature method.

Random variation, Monte Carlo evaluation of Integrals, Methods of importance sampling, Numerical solution of ordinary differential equations (introduction to second and higher order, Euler and Runge Kutta method, Predictor and corrector method

Chairperson
Department of Physics
Guru Jambheshwar University
of Sc. & Tech., Hisar-125001