PG DEPARTMENT OF PHYSICS
UNIVERSITY OF KSHMIR

Syllabus for PhD Entrance Test 2025

Part II and Part III

Subject: PHYSICS

Unit-I. Mathematical Methods of Physics

Complex variable theory, Laurent series, singularities, calculus of residues for definite integrals. Schwarz Reflection Principle; conformal mapping. Special functions via Rodrigue's formula and generating functions. Gamma function properties, factorial relations, Digamma function; Beta function and Legendre duplication formula. Infinite series convergence; Riemann Zeta function. Dirac Delta function properties. Reduction of PDEs to ODEs; series solutions for ODEs. Bessel functions: recurrence relations, integral representations, orthonormality, spherical Bessel functions. Legendre functions: properties, recurrence relations, Associated Legendre functions, spherical harmonics. Hermite and Laguerre polynomials: orthonormality, connections to quantum oscillator and radial equations.

Unit-II. Classical Mechanics

Degrees of freedom, generalized coordinates, D'Alembert's principle, and the Euler-Lagrange equations; Hamiltonian via Legendre transform, cyclic coordinates, and canonical momenta. Applications: double pendulum, spherical pendulum. Variational calculus and principle of least action; Hamiltonian dynamics: Hamilton's equations, conservation laws, phase space, and Liouville's theorem. Theoretical mechanics: canonical transformations, Poisson brackets, action-angle variables, and the Hamilton-Jacobi equation for central force motion. Oscillations: simple, damped, and coupled harmonic oscillators; general solution methods. Lagrangian and Hamiltonian formulations for continuous systems: transition from discrete to continuous description.

Unit-III. Quantum Mechanics

Experiments (Double-Slit, Stern-Gerlach) and fundamentals: kets, bras, operators, matrix representations, measurement, uncertainty, and basis changes via unitary operators. Wave functions in position/momentum space. Time evolution, Schrödinger vs. Heisenberg pictures. Schrödinger equation properties: current density, 1D motion, classical limit. Examples: infinite well, harmonic oscillator. Scattering: transmission, reflection, delta potentials, tunneling. Angular momentum: rotations, O(3)/SU(2), eigenvalues/eigenfunctions, symmetries (parity, time reversal). Addition of angular momentum: Clebsch-Gordan coefficients, symmetry relations, evaluation. Central potentials: spherical waves, infinite well, plane wave expansion, hydrogen atom (Coulomb field).

Unit-IV. Classical Electrodynamics

Condensed Electrodynamics: Core principles of electrostatics: Gauss's law, scalar potential, Poisson's and Laplace's equations with boundary conditions. Introduction to Green's functions and the method of images (e.g., point charge and sphere). Multipole expansion, energy of charge distributions, and Gauss's law in dielectrics. Boundary value problems with linear dielectrics. Maxwell's equations in free space and matter, including boundary conditions at interfaces. Conservation laws: Poynting's theorem for energy and momentum. Electromagnetic waves in vacuum and matter; introduction to waveguides. Potentials and radiation: scalar and vector potentials, gauge transformations (Coulomb, Lorentz). Retarded potentials, fields of a moving point charge, and electric dipole radiation. Relativistic electrodynamics: four-vectors, field tensor, covariant Maxwell's equations, and Lorentz transformation of fields. Lagrangian for a relativistic charged particle. Particle motion in uniform static electric and magnetic fields.

Unit-V. Statistical Physics

Statistical independence, Liouville's theorem, and the Statistical Matrix. Ensembles: Microcanonical, Canonical, Grand Canonical; Partition Functions and calculation of statistical quantities. Fluctuations in energy and density. Gibbs distribution, leading to Maxwellian distribution and thermodynamic relations. Quantum statistics: Fermi and Bose distributions; applications to degenerate electron gas and blackbody radiation. Non-ideal gases: virial expansion. Phase equilibria: Clapeyron-Clausius formula, critical point, and law of corresponding states. Phase transitions of the second kind: discontinuities in specific heat, effect of external fields, fluctuations of the order parameter, and critical indices.

Unit-VI. Nuclear and Particle Physics

Deuteron's properties and the tensor force, Yukawa and meson theories of nucleon-nucleon forces. Weak interaction, Fermi's theory of beta decay, Gamow's theory of alpha decay. Nuclear models, liquid drop model, semi-empirical mass formula, closed shell and Fermi gas models, collective motion, and deformations. Rutherford, Mott, and electron scattering form factor. Elementary particles and quantum numbers, Eightfold Way, Gellmann- Nishijima formula. baryons and mesons, Quark model, Standard model. Parity violation, CP violation, and CPT invariance. Application of symmetry arguments to particle reactions.

Unit-VII. Condensed Matter Physics

Crystal lattices, planes, symmetry, point and space groups. Diffraction theory, reciprocal lattice, Brillouin zones, and structure factors. Free electron model, Bloch's theorem, band structure of semiconductors and metals, Fermi surfaces, and effective mass. reduced dimensionality, one and two dimensional systems, van Hove singularities, Landau levels, the quantum Hall effect, conductance quantization, and resonant tunneling. Ferromagnetism, Heisenberg and Ising models, spin waves, magnons, and domain theory. Classification of ferroelectric crystals, Landau's theory of the ferroelectric phase transition. Phonon softening and ferroelectricity, Soft-mode theory.

Unit-VIII. Atomic & Molecular Physics

One-electron atoms, Fine structure of hydrogenic atoms, the Lamb shift, hyperfine structure, Zeeman and Stark effects, and selection rules. Two-electron atoms, Schrödinger equation for two-electron atoms, spin wavefunctions, Pauli principle, electron correlation, and atomic term structures via L-S and j-j coupling schemes, Hund's rules and the Landé interval rule. Rotation and vibration of diatomic molecules, Born-Oppenheimer approximation, the Franck-Condon principle for electronic transitions, and vibrational progressions. Raman spectroscopy, polarization of Raman lines, resonance Raman effect and spectroscopic applications in structural analysis.

Unit-IX. Electronics

Semiconductor device physics, including diodes, junctions, transistors, field effect devices, homo and heterojunction devices, device structure, device characteristics, frequency dependence and applications; Optoelectronic devices, including solar cells, photodetectors, and LEDs; High-frequency devices, including generators and detectors; Operational amplifiers and their applications; Digital techniques and applications (registers, counters, comparators and similar circuits); A/D and D/A converters; Microprocessor and microcontroller basics.

Unit-X. Experimental Techniques and data analysis

Data interpretation and analysis; Precision and accuracy, error analysis, propagation of errors, least squares fitting, linear and nonlinear curve fitting, chi-square test; Transducers (temperature, pressure/vacuum, magnetic field, vibration, optical, and particle detectors), measurement and control; Signal conditioning and recovery, impedance matching, amplification (Op-amp based, instrumentation amp, feedback), filtering and noise reduction, shielding and grounding; Fourier transforms; lock-in detector, box-car integrator, modulation techniques. Applications of the above experimental and analytical techniques to typical undergraduate and graduate level laboratory experiments.