Syllabus for Ph.D. Entrance test in Physics

I. **Mathematical Methods of Physics:** Dimensional analysis; Vector algebra and vector calculus; Linear algebra, matrices; Cayley-Hamilton Theorem; Eigenvalues and eigenvectors; Linear ordinary differential equations of first & second order; Special functions (Hermite, Bessel, Laguerre and Legendre functions); Fourier series; Fourier and Laplace transforms; Elements of complex analysis: Cauchy Riemann conditions, Cauchy's theorems, singularities, residue theorem and applications, analytic functions, Taylor & Laurent series, poles, residues and evaluation of integrals; Elementary probability theory: random variables, binomial, Poisson and normal distributions, Central limit theorem; Green's function; Partial differential equations (Laplace, wave and heat equations in two and three dimensions); Elements of computational techniques: root of functions, interpolation, extrapolation, integration by trapezoid and Simpson's rule, Solution of first order differential equation using Runge Kutta method, Finite difference methods; Tensors. Introductory group theory: SU(2), O(3).

II. **Classical Mechanics:** Newton's laws; Dynamical systems; Phase space dynamics; stability analysis; Central force motions; Two body Collisions - scattering in laboratory and Centre of mass frames; Rigid body dynamics moment of inertia tensor; Non-inertial frames and pseudoforces; Variational principle; Generalized coordinates; D'Alembert's principle; Lagrangian and Hamiltonian formalism and equations of motion; Central force and scattering problems; Conservation laws and cyclic coordinates; Periodic motion: Small oscillations, Normal modes; Special theory of relativity; Lorentz transformations; Relativistic kinematics and mass–energy equivalence; Dynamical systems; Phase space dynamics; Stability analysis; Poisson brackets and canonical transformations; Symmetry, Invariance and Noether's theorem; Hamilton-Jacobi theory; Special theory of relativity: Lorentz transformations, Relativistic kinematics, Mass-energy equivalence.

III. **Electromagnetic Theory:** Electrostatics: Gauss's law and its applications; Laplace and Poisson equations; Boundary value problems; Magnetostatics: Biot-Savart law; Ampere's theorem; Electromagnetic induction; Maxwell's equations in free space and linear isotropic media; Boundary conditions on the fields at interfaces; Scalar and vector potentials; Gauge invariance; Electromagnetic waves in free space, Dielectrics and conductors; Reflection and refraction; Polarization; Fresnel's law; Interference; Coherence; Diffraction; Dynamics of charged particles in static and uniform electromagnetic fields; Electromagnetic Theory Dispersion relations in plasma; Lorentz invariance of Maxwell's equation; Poynting vector; Poynting theorem; Energy and momentum of electromagnetic waves; Transmission lines and wave guides; Radiation- from moving charges and dipoles and retarded potentials.

IV. **Quantum Mechanics:** Wave-particle duality; Schrödinger equation (time-dependent and time-independent); Eigenvalue problems (particle in a box, harmonic oscillator, etc.); Tunneling through a barrier; Wave-function in coordinate and momentum representations; Commutators and Heisenberg uncertainty principle; Dirac notation for state vectors; Motion in a central potential: Orbital angular momentum, Angular momentum algebra; Spin; Addition of angular momenta; Harmonic oscillator; Hydrogen atom; Stern-Gerlach experiment; Time independent perturbation theory and applications; Variational method; Time dependent perturbation theory and Fermi's golden rule; Selection rules; Identical particles; Pauli exclusion principle; Spin-statistics connection; Linear vectors and operators in Hilbert space; Spin-orbit coupling; fine structure; WKB approximation; Elementary theory of scattering: Phase shifts, Partial waves, Born approximation; Relativistic quantum mechanics: Klein-Gordon and Dirac equations; Semi-classical theory of radiation.

V. **Thermodynamic and Statistical Physics:** Laws of thermodynamics and their consequences; Thermodynamic potentials; Maxwell relations; Chemical potential; Phase equilibria; Phase space; Micro- and macro-states; Micro-canonical; Canonical and grand-canonical ensembles and partition functions; Free energy and its connection with thermodynamic quantities; Classical and quantum statistics; Ideal Bose and Fermi gases; Principle of detailed balance; Blackbody radiation and Planck's distribution law; First- and second-order phase transitions; Phase equilibria; Critical point; Diamagnetism, Paramagnetism, and ferromagnetism; Ising model; Bose-Einstein condensation; Diffusion equation; Random walk and Brownian motion; Introduction to non-equilibrium processes.

VI. **Electronics and Experimental Methods:** Semiconductor devices (diodes, junctions, transistors, field effect devices, homo- and hetero-junction devices); Device structure; Device characteristics; Frequency dependence and applications; Opto-electronic devices (solar cells, photo-detectors, LEDs); 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; 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 fields, 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; High frequency devices (including generators and detectors).

VII. **Atomic & Molecular Physics:** Quantum states of an electron in an atom; Electron spin; Spectrum of helium and alkali atom; Relativistic corrections for energy levels of hydrogen atom; Hyperfine structure and isotopic shift; Width of spectrum lines; LS &

JJ couplings; Zeeman; Paschen-Bach & Stark effects; Electron spin resonance; Nuclear magnetic resonance; Chemical shift; Frank-Condon principle; Born-Oppenheimer approximation; Electronic; Rotational; Vibrational and Raman spectra of diatomic molecules; Selection rules; Lasers: Spontaneous and stimulated emission; Einstein A & B coefficients; Optical pumping; Population inversion; Rate equation. Modes of resonators and coherence length.

VIII. **Condensed Matter Physics:** Bravais lattices; Reciprocal lattice; Diffraction and the structure factor; Bonding of solids; Elastic properties; Phonons; Lattice specific heat; Free electron theory and electronic specific heat; Response and relaxation phenomena; Drude model of electrical and thermal conductivity; Hall effect and thermoelectric power; Electron motion in a periodic potential; Band theory of solids: Nearly free electron and tight binding models; Metals, Semiconductors and Insulators; Conductivity; Mobility and effective mass; Optical; Dielectric and Magnetic properties of solids; Superconductivity: Type-I and type-II superconductors; Josephson junctions; Superfluidity; Defects and dislocations; Ordered phases of matter: Translational and orientational order; Kinds of liquid crystalline order; Quasi crystals.

IX. **Nuclear and Particle Physics:** Basic nuclear properties: Size, Shape and charge distribution; Spin and parity; Binding energy; Semi empirical mass formula; Electric and magnetic moments; Liquid drop model; Nature of the nuclear force; Form of nucleon-nucleon potential; Charge-independence and charge-symmetry of nuclear forces; Deuteron problem; Evidence of shell structure; Single-particle shell model: Its validity and limitations; Rotational spectra; Elementary ideas of alpha, beta and gamma decays and their selection rules; Fission and fusion; Nuclear reactions: Reaction mechanism, Compound nuclei and direct reactions; Classification of fundamental forces; Elementary particles and their quantum numbers (charge, spin, parity, isospin, strangeness, etc.); Gellmann-Nishijima formula; Quark model; Baryons and mesons; C, P, and T invariance; Application of symmetry arguments to particle reactions; Parity non-conservation in weak interaction; Relativistic kinematics; Nuclear radii and charge distributions; Nuclear binding energy; Electric and magnetic moments; Nuclear models, Liquid drop model: Semi-empirical mass formula; Fermi gas model of nucleus, nuclear shell model; Nuclear force and two nucleon problem; Alpha decay; Beta-decay; Electromagnetic transitions in nuclei; Rutherford scattering; Nuclear reactions; Conservation laws; Fission and fusion; Particle accelerators and detectors; Elementary particles; Photons; Baryons; Mesons and Leptons; Quark model.