SYLLABUS OF
Ph.D. Entrance Exam (PHYSICS)

Approved by Board of Studies in Physics

EFFECTIVE FROM JULY 2023

(Valid for 1 Year 2023-2024)

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Syllabus for Ph.D Entrance Exam

MATHEMATICAL PHYSICS

Vector space and Matrices, Linear independence, Bases, dimensionality, Inner product, Linear transformation, matrices, Inverse, Orthogonal and Unitary matrices, Independent element of a matrix, Eigen values and eigen Vectors, Diagonalization, Complete orthonormal sets of functions.

Complex Variables: Cauchy- Riemann condition, analytic functions,Cauchy's theorem, Cauchy integral formula, Laurent series, singularities, residue theorem, contour integration, evaluation of definite integrals, problems.

Differential equations, first order differential equation, second order differential equation with constant coefficients, second order linear ODEs with variable coefficients, Solution by series expansion, nonhomogenous differential equations and solution by the method of Green's functions.

Special functions, Legendre, Bessel, Hermite and Laguerre functions with their physical applications, generating functions, orthogonality conditions, recursion relations,

Integral transforms, Fourier integral   and   transforms, inversion theorem, Fourier transform of derivatives, convolution theorem, Laplace Transform(LT), LT of Derivatives, Inverse LT, Fourier series; properties and applications, discrete Fourier transform.

CLASSICAL MECHANICS

Preliminaries, Newtonian mechanics of one and many particle systems, Conservation laws,Constraints & their classification, Principle of virtual work, Generalized coordinates, D'Alembert's principle and Lagrange's equations, Velocity-dependent potentials and dissipation function, Simple applications of the Lagrangian formulation, Hamilton's principle, Lagrange's equations from Hamilton's principle, Conservation theorems and Symmetry properties, Energy function and the conservation of energy.

The Hamiltonian formulation of mechanics, Legendre transformations and the Hamilton's equations of motion, Cyclic coordinates and Conservation Theorems, Hamilton's equations from Hamilton's principle, The principle of least action, Simple applications of the Hamiltonian formulation.

Canonical transformations with examples, The harmonic oscillator, Poisson's brackets, Equations of motion and conservation theorems in the Poisson Bracket formulation. Hamilton-Jacobi (HJ) theory: The HJ equation for Hamilton's principal function, Harmonic oscillator as an example of the HJ method, The HJ equation for Hamilton's characteristic function, The action-angle variables

The Central force: Two-body central force problem and its reduction to the equivalent one-body problem, The equations of motion and first integrals, The equivalent one-dimensional problem and classification of orbits, The differential equation of the orbit, Closure and stability of orbits, The Kepler problem, Scattering in a central force field: Rutherford scattering.

Rigid body dynamics, The Euler angles, Euler's theorem on the motion of a rigid body, Rate of change of a vector, The Coriolis force, Angular momentum and Kinetic energy of motion about a point, The Euler equations of motion of rigid bodies. Formulation of the problem of small oscillations, The eigen-value equation and the principal axis transformation, Frequencies of free vibration and normal coordinates, Free vibration of linear triatomic molecule.

ELECTRODYNAMICS & PLASMA PHYSICS

Maxwell's equations, vector and scalar potentials and the wave equation, Gauge transformations, Lorenz gauge, Coulomb gauge, Green function for the wave equation, four-vectors, mathematical properties of the space-time in special relativity, matrix representation of Lorentz transformation, covariance of electrodynamics, transformation of electromagnetic fields.

Radiation by moving charges, Lienard-Wiechert potential and fields for a point charge, total power radiated by an accelerated charge- Larmor's formula and its relativistic generalization, angular distribution of radiation emitted by an accelerated charge, radiation emitted by a charge in arbitrary extremely relativistic motion, distribution in frequency and angle of energy radiated by accelerated charge.

Plasma: definition, Debye shielding phenomenon and criteria for plasma, motion of charged particles in electromagnetic field; Uniform E & B fields, Electric field drift, Non-uniform magnetostatic field, Gradient B drift, Parallel acceleration and magnetic mirror effect, Curvature drift, adiabatic invariants.

ELECTRONICS
Operational Amplifier- Basic Op.Amp. Differential amplifier, the emitter coupled Difference Ampl, Transfer characteristics of a Diff. Ampl., an example of an IC Op.-Amp., offset error voltage and currents, measurement of Op.-Amp. Parameters, frequency response of Op-amp. Linear analog systems: Basic Op.-Amp. Applications, Analog integration and differentiation, Electronic analog computation, Non-linear analog systems: Comparators, Waveform generators. Combinational Logic – Basic logic gates: OR, AND and NOT gates, NOR and NAND gates, Boolean algebra, DeMorgan's theorems, exclusive OR gate, characteristics of logic families, saturated logic families: RTL, DCTL, non-saturated logic families: TTL and ECL, Unipolar logic families.

Sequential Logic, Flip-flops: RS Flip-flop, level clocking, Edge triggered Flip Flops, D Flip flops. JK Flip-flops, JK master slave Flip-flops, Registers: buffer, shift and control shift registers, counters: ripple synchronous & ring counters, tri-state registers, Buffer: controlled buffer Register, Bus organized structure, Latch, multiplexer, Demultiplexer, decoder, ALU Memories: RAM, ROM, PROM, EPROM, A/D and D/A converters.

Microprocessors – Building concept of microprocessors, developing inside of microprocessor , Instruction codes ,Instruction Register ,Introducing RESET Pin, Introducing on chip oscillator, Interfacing I/O devices, Introducing Interrupt lines :Stack, Push, Pop operation ,delay in servicing interrupts, multiply interrupts, location for interrupts .Introducing slow and fast data transfer, Status of microprocessor, interrupt pins, General purpose Register, flag Register, Increment/decrement register. Features of 8085 microprocessor. Pin diagram of 8085, block diagram of 8085. CPU of a microprocessor, timing and control, system timings and interrupt timings of 8085, registers in 8085, interfacing memory and I/O devices- a preliminary ideas. Number system, Floating Point notation.

Instructions set of 8085, types of instructions- Data transfer group, Arithmetic logic, branch group, stack I/O machine control group, addressing mode of Intel 8085, examples of Assembly language programs of 8085, summing of two 8-bit numbers to result a 16-bit number, summing two 16-bit number, multiplying two 8-bit number to result a 16-bit product, block transfer of data from one memory block to other, BCD to hexadecimal data, finding the largest number in a series.

QUANTUM MECHANICS
Inadequacy of classical mechanics, Plank quantum hypothesis and radiation law, Photoelectric effect, de-broglie's theory. Schrödinger equation, continuity equation, Ehrenfest theorem, admissible wave functions, general formalism of wave mechanics, representation of states and dynamical variables, stationary states, Schrödinger equation for harmonic oscillator and its solution.

Superposition principle, uncertainty relations, commutation relationship, completeness and normalization of eigen functions, Dirac-delta function, Bra & Ket notation, matrix representation of an operator, harmonic oscillator and its solution by matrix method, Heisenberg equation of motion.

Angular momentum in quantum mechanics, commutation relationships, eigen values, Spin angular momentum, Pauli`s matrices, addition of angular momentum, Clebsch-Gordon coefficients.

Central force problem, spherically symmetric potentials in three dimensions, separation of wave equation, parity, three-dimensional square-well potential and energy levels, the hydrogen atom; solution of the radial equation, energy levels and stationery state wave functions, discussion of bound states, degeneracy.

Time- independent perturbation theory, non-degenerate case, first order and second perturbations with the example of an oscillator, degenerate cases, removal of degeneracy in second order, Zeeman effect without electron spin, first-order Stark effect in hydrogen, perturbed energy levels, correct eigen function, occurrence of permanent electric dipole moments.

Variational method, expectation value of energy, application to excited states, ground state of He-atom, Zero point energy of one dimensional harmonic oscillator, Vander-waals interaction, the W.K.B. approximation, approximate solutions, asymptotic nature of the solution, solution near turning point, connection formulae, energy levels of a potential well and quantization rule.

Theory of scattering: differential and total scattering cross section, wave mechanical picture of scattering & the scattering amplitude, Green's functions and formal expression for scattering amplitude, The Born approximation and its validity, Partial wave analysis, asymptomatic behavior of partial waves and phase shifts.

Time-dependent perturbation theory, first order perturbation, Harmonic perturbation, Fermi`s Golden rule, Ionization of a H-atom, absorption and induced emission, Selection rules. Identical particles. Relativistic quantum mechanics, formulation of relativistic quantum theory, the Klein-Gordon equation; plane wave solutions, charge and current densities, The Dirac equation for a free particle, matrices alpha and beta, Lorentz covariance of the Dirac equation, free particle solutions and the energy spectrum.

The spin of the Dirac particle, Dirac particle in electromagnetic fields and the significance of the negative energy state, Dirac equation for a central field : Spin angular momentum, approximate reduction, spin –orbit energy, separation of equation, the hydrogen atom.

STATISTICAL MECHANICS

Foundation of statistical mechanics : macroscopic and microscopic states, contact between statistics and thermodynamics, physical significance of $\Omega(N, V, E)$, the classical gas, entropy of mixing and Gibb's paradox, phase space of classical system, Liouville`s theorem and its consequences, quantum states and phase space.

Elements of ensemble theory – A system in microcanonical, canonical, and grand canonical ensembles, partition functions, physical significance of statistical quantities, example of classical system, energy and energy-density fluctuations and mutual correspondence of various ensembles.

Formulation of quantum statistics – Quantum mechanical ensemble theory, density matrix, statistics of various quantum mechanical ensembles, system composed of indistinguishable particles.

Theory of simple gases –Ideal gas in various quantum mechanical ensemble, Maxwell-Boltzmann, Bose-Einstein, Fermi-Dirac distributions, statistics of occupation number.

Ideal Bose and Fermi gases -Thermodynamic behavior of an ideal Bose gas, Bose-Einstein condensation and, elementary excitations in liquid helium II, Thermodynamic behavior of an ideal Fermi gas, the electron gas, nonrelativistic and relativistic degenerate electron gas, theory of white dwarf stars.

Statistical Mechanics of interacting systems – the method of cluster expansion for a classical gas, Virial expansion of the equation of state. Theory of phase transition – general remark on the problem of condensation, Fluctuations: thermodynamic fluctuations, Spatial correlation in a fluid Brownian motion: Einstein Smoluchowski theory of Brownian motion.

ELECTRONIC & PHOTONIC DEVICES AND OPTICAL MODULATORS

Special Bipolar devices: Thyristors- the four-layer diodes and their basic characteristics, Shockley diode, three terminal thyristor, Diac & Triac, SCR, UJT, Field controlled Thyristors.

Unipotar Devices : JFET, MESFET and MOSFET, basic structure, working and device I-V characteristics, small signal equivalent circuit for Microwave performance Introduction to MIS and MOS diodes, charge coupled devices (CCDs), basic structure and working principle , MOSFET-basic device characteristics, types of MOSFET.

Special Microwave Devices: Tunnel diode and backward diode- basic device characteristics, IMPATT diodes and their static and dynamic characteristics, Transfer electron devices- transferred electron effect, Gunn diodes.

Photonic Devices : Radiative transitions, LEDs, Visible and infrared SC lasers; Photo detectors; Photo conductor, & Photodiode, Solar cells, Solar radiation and ideal conversion efficiency, p-n junction solar cells, Hetero junction. Interface thin film solar cells.

Optical Modulators and Display Devices :Modulation of light- Birefringence, Optical activity, Electro-optic, Magneto-optic and Acoustic- optic effects, Materials exhibiting these properties, Non-linear optics.Display devices: Luminescence, Photo-luminescence, Electro-luminescence, Liquid crystal displays, Numeric displays.

ATOMIC AND MOLECULAR PHYSICS

Quantum states of one electron atoms-atomic orbitals, Hydrogen spectrum, spin- orbit(l-s) interaction energy, fine structure of hydrogen spectrum including l-s interaction and relativistic correction, spectra of alkali elements, fine structure in alkali spectra, penetrating and non-penetrating orbits, intensity rules.

Pauli's principle, equivalent and non-equivalent electrons, ground state (basic level of different elements), two electron systems, interaction energy in L-S. and J-J. Coupling, Hyperfine structure, line broadening mechanisms (general ideas).

Normal and anomalous Zeeman effect, early discoveries and developments, vector models of one electron system in a weak magnetic field, magnetic moment of a bound electron, magnetic interaction energy, selection rules, intensity rules, Paschen-Back(PB) effect – principal series effect, Zeeman and PB effects in hydrogen, Stark effect- discovery, Stark effect in Hydrogen, orbital model, weak and strong effect in Hydrogen.

Types of molecules: linear and diatomic molecules, symmetric top, asymmetric top and spherical top molecules. Rotational spectra of diatomic molecules: rigid rotator model, energy levels, spectrum, comparison with observed spectrum and non-rigid rotator model, Intensities of spectral lines, microwave spectrometer, Raman spectrum; classical and quantum theory of Raman Effect, pure rotational Raman spectrum.

Vibrational spectra of diatomic molecules: simple harmonic model, energy levels and spectrum, comparison with observed spectrum and an harmonic model, Vibrating rotators, Interaction of rotations and vibrations, fine structures and P-Q-R branches, IR spectrometer, Vibrational Raman spectrum, Vibrational rotational Raman spectrum.

SOLID STATE PHYSICS

Electrons in Solids and Electronic Properties, Energy bands: nearly free electron model, origin of energy gap and its magnitude, Bloch function, Kronig-Penny model, Wave equation of electron in periodic potential, restatement of Bloch theorem, crystal moment of an electron, solution of Central equation, Kronig-Penny model in reciprocal space, empty lattice Approximation, approximate solution near zone boundary, Number of orbitals in a band, metals and insulators.

Fermi surfaces and metals

Effect of temperature on F-D distribution, free electron gas in three dimension. Different zone schemes, reduced and periodic zones, construction of Fermi surfaces, nearly free electrons, electron, hole, open orbits, Calculation of energy bands, Tight binding, Wigner-Seitz, cohesive energy, pseudo potential methods. Experimental methods in Fermi surface studies, quantization of orbits in a magnetic field, de Haas van Alphen Effect, External orbits, Fermi surface of copper.

Crystal vibration and thermal properties

Lattice dynamics in monoatomic and diatomic lattice: two atoms per primitive basis, optical and acoustic modes, quantization of elastic waves, phonon momentum, inelastic neutron scattering by phonons, Anharmonic crystal interactions-thermal expansion, thermal conductivity, thermal resistivity of phonon gas, umklapp processes, imperfections.

Electron-Phonon interaction- superconductivity

Meissner effect, heat capacity, energy gap, MW, and IR properties, isotope effect. Theoretical survey : thermodynamics of superconducting transition, London equation, Coherence length, Cooper pairing due to phonons, BCS theory of superconductivity, BCS ground state, flux quantization of superconducting ring, duration of persistent currents, Type II superconductors, Vortex states, estimation of Hc1 and Hc2, single particle and Josephson superconductor tunneling, DC/AC Josephson effect.

Plasmons, Polaritons- Dielectric function of the electron gas, Plasma optics, Dispersion relation for EM wave, Transverse optical modes in Plasma, Transparency of Alkali metals in the ultraviolet, Longitudinal Plasma oscillations, Plasmon, electrostatic screening and screened Coulomb potential, Mott metal-insulator transition, screening and phonons in metals, Polaritons, LST relation .

Dielectric and ferroelectrics

Maxwell's equations, polarization, macroscopic electric field, depolarization filed, E1;local electric field at an atom, Lorentz filed E2, fields of dipoles inside cavity E3; dielectric constant and polarizability, electronic polarizability; structural phase transition; ferro-electric crystals, classification; displacive transition, soft optical phonons, Landau theory of phase transitions, first and second order transition, antiferro-electricity, ferro-electric domain, piezoelectricity, ferro-elasticity, optical ceramics.

Magnetism- General ideas of dia- and para- magnetisms, quantum theory of paramagnetism, rare earth ions, Hund rule, iron group ions, crystal field splitting, quenching of orbital angular momentum, spectroscopic splitting factor, van vleck temperature dependent paramagnetism, Cooling by isentropic demagnetization, nuclear demagnetization, paramagnetic Susceptibility of conduction electrons.

Optical Processes & Excitons and defects- Optical reflectance, excitons, Frenkel and Mott-Wannier excitons, Alkali Halides and Molecular crystals Defects: lattice vacancies, Schottkey and Frenkel point effects, colour centers, F and other centres, Line defect. Shear strength of single crystals, dislocations-edge and screw dislocations, Burger vectors, Stress fields of dislocations, low angle grain boundaries, dislocation densities, dislocation multiplication and slip, strength of alloys, dislocations and crystal growth, hardness of materials**.**

NUCLEAR AND PARTICLE PHYSICS

Nuclear Interactions : Nucleon-nucleon interaction, Two-nucleon system, The ground state of the deuteron, Tensor forces, Nucleon-nucleon scattering at low energy, Scattering length, Effective range theory, Spin dependence of nuclear forces, Charge independence and charge symmetry of nuclear forces, Iso-spin formalism, Exchange forces, Meson theory of nuclear forces and the Yukawa interaction.

Nuclear Reactions: Reaction energetics: Q-equation and threshold energies, Reactions cross sections, Resonance: Breit-Wigner single-level formula, Direct and compound nuclear reactions, Formal reaction theory: Partial wave approach and phase shifts, Scattering matrix, Reciprocity theorem.

Nuclear Decay : Beta decay, Femi's theory of beta decay, Shape of the beta spectrum, Total decay rate, Angular momentum and parity selection rules, Comparative half-lives, Allowed and forbidden transitions, Selection rules, Parity violation, Two component theory of neutrino decay, Detection and properties of neutrino
Gamma decay, Multiple transitions in nuclei, Angular momentum and Parity selection rules, Internal conversion, Nuclear isomerism.

Nuclear models : Liquid drop model, Bohr-Wheeler theory of fission, Shell Model, Experimental evidence for shell effects, Single particle shell model, Spin-orbit interaction and magic numbers, Analysis of shell model predictions, Magnetic moments and Schmidt lines, Collective model of Bohr and Mottelson.

Elementary particle Physics: The fundamental interactions, Classification of elementary particles, Leptons and Hadrons, Symmetries, groups and conservation laws, SU(2) and SU(3) multiplets and their properties, Quark model, Properties of Quarks, the standard model.

LASER PHYSICS AND APPLICATIONS

Laser Characteristics – Spontaneous and stimulated emission, Einstein's quantum theory of radiation, theory of some optical processes, coherence and monochromacity, kinetics of optical absorption, line broadening mechanism, Basic principle of lasers, population inversion, laser pumping, two & three level laser systems, resonator, Q-factor, losses in cavity, threshold condition, quantum yield.

Laser Systems- Solid state lasers- the ruby laser, Nd:YAG laser, ND: Glass laser, semiconductor lasers – features of semiconductor lasers, intrinsic semiconductor lasers, Gas laser -neutral atom gas laser, He-Ne laser, molecular gas lasers, CO_2 laser, Liquid lasers, dye lasers and chemical laser. Laser applications.