Ph.D. Syllabus

Physical Sciences

<u>Ph.D. PHYSICAL SCIENCE</u>

PHY 601: Advanced Mathematical Methods for Physics (4)

***Learning Objectives*:**

The main objective of the course is to equip the students with the tools of mathematics which are required for graduate courses and physics research.

***Course Contents*:**

Vector space and matrices, linear independence, bases dimensionality, Inner product, tensors, parallel transport, linear transformation matrices, inverse, orthogonal and unitary matrices, independent element of a matrix, Eigen values and Eigen vectors, diagonalization.

Theory of complex variables, Cauchy- Riemann condition, analytic functions, Cauchy’s theorem, Cauchy integral formula, Laurent series, singularities, branch points and cuts, residue theorem, contour integration, evaluation of definite integrals, method of steepest descent.

Ordinary differential equations, second order linear ODEs with variable coefficients, Solution by series expansion, non-homogeneous differential equations and solution by the method of Green’s functions with applications. Eigenvalue methods, up to Strum-Liouville systems. Special functions, Legendre, Bessel, Hermite and Laguerre functions with their physical applications, generating functions, orthogonality conditions, recursion relations, Legendre, Bessel, Hermite, Laguire equations and their solutions. Fourier integral and transforms, inversion theorem, Fourier transform of derivatives, convolution theorem.

Partial differential equations, Solution of Laplace and Poisson's equations, Wave equation

Introduction to Groups, Representations, Finite Groups, Permutation Groups, Continuous Groups, Lie algebras.

***Suggested Books*:**

- B. Arfken and H. J. Weber, Mathematical Methods for Physicists, 6th Ed.
- P. K. Chattopadhyay, Mathematical Physics.
- M. L. Boas, Mathematical Methods in Physical Sciences.
- S. D. Joglekar, Mathematical Physics: The Basics.
- A. K. Ghatak, Mathematical Method of Physics.
- F. B. Hildebrand, Methods of Applied Mathematics.
- A. W. Joshi, Elements of Group Theory for Physicist.
- S. Hassani, Mathematical Physics.
- P. Dennery and A. Krzywicki, Mathematics for Physicists.
- J. Mathews and R. L. Walker, Mathematical Methods of Physics.

PHY 603: Advanced Quantum Mechanics (4)

***Learning Objectives*:**

The course will be a review of foundations of quantum mechanics along with some advanced topics like approximation methods in quantum mechanics, atomic and molecular theory, time-dependent perturbation theory and scattering theory.

***Course Contents*:**

Review of Quantum Mechanics Postulates of quantum mechanics, operator methods, matrix representations, time-dependence, symmetry : Unitary operators: translations in space, translation in time (evolution). Rotations, reflections and parity. Conservation laws.

Solutions to the Schrodinger equation in one dimension. Angular momentum and spin.

Charged particles in electromagnetic fields Hamiltonian for a charged spinless particle in an electromagnetic field. Gauge transformations and gauge nvariance. Aharonov-Bohm effect; Free electron in a uniform magnetic field: Landau levels.

Approximate Methods: Time-independent perturbation theory, first and second order expansion; Degenerate perturbation theory; Stark effect; nearly free electron model. Variational method: ground state energy and eigenfunctions; excited states. The WKB method: bound states and barrier penetration.

Atomic and molecular structure: Revision of the Hydrogen atom. Fine structure: relativistic corrections; spin-orbit coupling; hyperfine structure. Zeeman effects; diamagnetic hydrogen. Multi-electron atoms: central field approximation; LS coupling; Hund's rules. Born-Oppenheimer approximation; H_2+ ion; molecular orbitals; H_2 molecule; ionic and covalent bonding.

Time-dependent perturbation theory: Two-level system, Rabi oscillations, Magnetic resonance. Perturbation series, Fermi's Golden rule, scattering and Born approximation. Radiative transitions, dipole approximation, stimulated emission and absorption, spontaneous emission, Einstein's A and B coefficients, selection rules; Cavity rate equations and lasers.

Scattering by a Potential: Formalism; Born approximations; Partial wave analysis Relativistic Quantum Mechanics Klein-Gordan and Dirac equations and their solutions. Chirality and helicity.

***Suggested Books*:**

- Quantum Physics, S. Gasiorowicz
- Quantum Mechanics: Non-Relativistic Theory, Volume 3, L. D. Landau and L. M. Lifshitz
- The Physics of Atoms and Quanta, H. Haken and H. C. Wolf Quantum Mechanics, F. Schwabl
- Principles of Quantum Mechanics, R. Shankar
- Problems in Quantum Mechanics, G. L. Squires
- Quantum Mechanics: A New Introduction, K. Konishi and G. Paffuti
- Quantum Mechanics, F. SchwablQuantum Mechanics, C. Cohen-Tannoudji, B.D. Franck Laloe

PHY 6: DEPARTMENTAL ELECTIVE I**

PHY 6/800: DEPARTMENTAL ELECTIVE II / Ph.D. THESIS**

PHY 602: Advanced Classical Mechanics (4)

Review of Classical Mechanics

Variational principles- Lagrange's equation and its application,

Hamilton's equation of motion

Perturbation theory

Hamilton Jacobi theory

Poisson's bracket in Classical Mechanics and its transition to quantum mechanics

Classical field theory

***Suggested Books*:**

- Classical Mechanics, John R. Taylor, University science books, 2004
- Mechanics (Volume 1), Landau and Lifshtz, Butterworth-Heinemann (1976), Ed. 3
- Analytical Mechanics, Fowels and Cassiday, Thompson Books (2004) Ed. 7
- Classical Mechanics, Herbert Golstein, Pearson (2011), Ed .3

PHY 604: Statistical Mechanics (4)

***Prerequisite**: PHY 303: Quantum Mechanics I, PHY 301: Mathematical Methods I, PHY 309: Thermal Physics*

Motivation : Why do we need statistical mechanics ? Thermodynamic description of a system. Microscopic origin of of thermodynamic results - introduction of statistical description. Introduction and definition of ensemble. Examples of ensembles.

Phase spac: Introduction and definition of phase space. Examples. Phase space density Time average and ensemble average. Equivalence between time average and ensemble average - Postulate of statistical mechanics (Ergodic hypothesis). Liouville's equation.

Equilibrium Statistical mechanics

A. Definition.
B. Micro-canonical ensemble: Definition ,Volume of phase space, Definition of entropy, Definition of temperature, Physical interpretation of temperature. Validity of statistical description. Definition of pressure,1st law of thermodynamics. Statistical interpretation of entropy. Classical ideal gas in microcanonical ensemble. Gibbs paradox.
C. Canonical ensemble: Definition, Average in canonical ensemble, Partition function Equivalence between canonical and microcanonical ensemble average. Definition of free energy. Ideal gas in canonical ensemble.
D. Grand-canonical ensemble: Definition, Grand-canonical partition function, Definition of chemical potential, Equivalence between canonical and grand-canonical average. Ideal gas in grand canonical ensemble

Quantum statistical mechanics: Pure and mixed ensemble. Examples of pure and mixed ensemble. Quantum ensemble average. Introduction of density matrix. Properties of density matrix. Examples of density matrix. Micro-canonical ensemble, Canonical ensemble and Partition function, Grand-canonical ensemble and partition function.

Three different statistics Boltzmann statistics: Partition function for ideal Boltzmann gas. Equation of state. Bose and Fermi statics/distribution

Ideal Fermi gas: Partition function. Equation of state. High temperature fermi gas. Low temperature fermi gas. Fermi energy, fermi temperature and fermi surface. Pressure of low temperature fermi gas. Zero point pressure.

Magnetization: Dia-magnetization, Paramagnetization.

Ideal Bose gas: Partition function. Equation of state. Gas of photon - Black body radiation Lattice vibration : Specific heal, Einstein and Debye's model of specific heat.

***Suggested Books*:**

- F. Reif, *Fundamentals of Statistical and Thermal Physics*.
- R.K. Pathria, *Statistical Mechanics, 2nd Ed.*
- M. Plischke and B. Bergersen, *Equilibrium Statistical Physics*.

- J. K. Bhattacharjee, *Statistical Physics: Equilibrium and Non-Equilibrium Aspects*.
- Kerson Huang, *Statistical Mechanics*.
- S-K. Ma, *Statistical Mechanics*.
- L. D. Landau and E. M. Lifshitz, *Statistical Physics*.
- R. Kubo, M. Toda and N. Hashitsume, *Statistical Physics I and II*.
- S-K. Ma, *Modern Theory of Critical Phenomena*.

PHY 6: DEPARTMENTAL ELECTIVE III**

PHY 6/800: DEPARTMENTAL ELECTIVE IV / Ph.D. THESIS**