Faculty of Science

PHYSICS

Ph.D **SYLLABUS OF COURSE CONTENT**

❖ **Theoretical Physics**

Quantum Mechanics: Schrödinger Picture, **Time independent perturbation theory**: Theory and an example; **Scattering theory**: Quantum theory, Partial wave analysis (one example), Born Approximation and its validity (One example); **Path integral formulation**: propagator, Schrödinger wave equation from path integral, eg: free particles; Introduction to second quantization; **Quantum field theory**: quantization of scalar field and Dirac field

Condensed Matter Physics: **Electronic Structure Calculation:** Hartree-Fock Theory, Introduction to Density Functional Theory; **Correlated Electron States:** Mott Transition, Hubbard Model, Magnetic impurities and Kondo Model; **Quantum Hall effect:** Integer and fractional Hall Effect, Laughlin wave function;
Magnetism: Mean-field approximation for Heisenberg Hamiltonian model for Ferromagnetism.

Statistical Mechanics: Landau theory for phase transitions. Ising model: transfer matrix method; Onsager solution of 2-dimensional Ising model. **Non-equilibrium Statistical Mechanics**: Response function and susceptibility; fluctuation-dissipation theorem; irreversibility and the master equation; Fokker-Planck and diffusion equations.

General Theory of Relativity: Equivalence principle and its applications: gravity as a curvature of space-time; geodesics as trajectories under the influence of gravitational field; generalization to massless particles.

High Energy Physics: Introduction to relativistic kinematics, Review of Experimental methods: fixed target and collider experiments, Introduction of four forces and interactions, Feynman diagrams Basics of quantum electrodynamics: Glashow-Salam- Weinberg model, Standard Model Physics.

Nonlinear Optics: Nonlinear wave propagation in Anisotropic media; Second Harmonic Generation (SHG); Phase Matching Techniques; Three-Wave Interactions; Third Harmonic Generation (THG); Density Matrix and Perturbation approach to Nonlinear susceptibility

Books:

1. Introduction of Quantum Mechanics; David J. Griffiths; Pearson Education; 2010.
2. Introduction to Condensed Matter Physics; F. Duan, J. Guojun; World Scientific; 2007.
3. Statistical Mechanics: R. K. Pathria; Elsevier; 2002.
4. Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity, Steven Weinberg; Wiley; 2013.
5. Introduction to Elementary Particles; David J. Griffiths; Wiley; 2008.
6. Introduction to High Energy Physics, Donald Perkins; Cambridge University Press; 2000.
7. Nonlinear Optics, 3rd Ed; R. W. Boyd, Academic Press; 2008.

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R. P. Vaidya
03/11/'20

❖ EXPERIMENTAL PHYSICS

Vacuum Generation and Measurement Techniques:
Introduction to vacuum, gas law; Rotary vane pump, Turbomolecular pump, Cryo pump; Pirani gauge, Penning gauge.

Fundamentals of Synthesis and Fabrication of Materials:
Classification of powders; Synthesis of powders: Sol-gel, Hydrothermal, Combustion techniques; Synthesis of thin films: Spin- coating, Dip coating, Thermal and electron beam evaporation, Pulsed laser deposition; General concept of lithography, Photolithography, Electron beam lithography; Clean room.

Introduction to Basic Measurements and Characterization Techniques: Study of Crystal Structure: X-ray diffraction (XRD), Transmission
Electron diffraction (TED)

Microscopic Techniques: Optical Microscopes (Bright field, Confocal, Super-resolution), Scanning Electron Microscope, Transmission Electron Microscope, Scanning Probe Microscopes.

Spectroscopic Techniques: UV-Vis, Fluorescence, IR and FTIR, Photo-Acoustic, Laser Induced Breakdown, Raman, Twyman-Green interferometer as a special case of Michelson Interferometer for testing of optical components, Lateral shearing interferometers and its applications such as testing. Collimation of a lens, laser speckle techniques and its applications.

Surface and Compositional Analysis Methods: EDAX, XPS.

Dielectric Characterization: Complex impedance spectroscopy, Analysis of Nyquist plot, Various RC network schemes, Analysis of CV curves, ac conductivity, Charging-discharging cycle of capacitors.

Electrochemical Measurements: Different potentiometric / galvanometric techniques.

Methods for studying electrical, magnetic, thermal properties.

Accelerator and Fusion Techniques: Pelletron, Linear accelerator, Cyclotron, Synchrotron, Tokamac;

Applications in High energy physics, Materials science and Particle therapy.

Books:

1. Materials Science of Thin Films; Milton Ohring; Academic Press; 2001.
2. Microstructural Characterization of Materials; Brandon & Kaplan; Wiley; 2008
3. Encyclopaedia of Materials Characterization - Surfaces, Interfaces, Thin Films; Brundle, Richard, Evans & Shaun; Elsevier; 1992

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❖ ADVANCED MATHEMATICAL METHODS IN PHYSICS

Applications of mathematical techniques in Physics problems based on the following topics: Vector spaces - Discrete and continuous: orthogonality, operator algebra, Hermitian and unitary operators, projection operators, Matrices , eigenvalue problems and applications in Physics. Differential equations. Boundary value problems. Orthogonal polynomials, Spherical harmonics, addition theorem and multipole expansions, Integral transforms (e.g. Fourier, Laplace, etc.), Green's functions and applications to physics. Method of residues, poles and cuts in complex variables.

Group theory: Introduction, Generators of the continuous groups and discreet groups, Group representation: reducibility, equivalence, Schur's lemma. Lie groups and Lie algebras, SU(2) and SU(3). Representations of simple Lie algebras, SO(n), Lorentz group, applications to spectroscopy, condensed matter and particle physics etc.

Tensor analysis: Introduction, tensor algebra (linear combinations, direct products, contraction, Raising and lowering indices) Tensor densities, Covariant differentiation, Invariant equations and applications to physics.

Text Books:

1. Mathematical Methods for Physicists; Arfken, Weber (Academic Press)
2. Complex Variables; A. K. Kapoor (World Scientific)
3. Matrices and Tensors in Physics; A. W. Joshi (New age international)

❖ ADVANCED QUANTUM MECHANICS

Scattering Theory: Scattering amplitude and cross-section, Partial wave analysis and application to simple cases; Integral form of scattering equation, Born approximation validity. The optical theorem.

Relativistic Quantum Mechanics: The Klein-Gordon equation. The Dirac equation. Dirac matrices, spinors. Magnetic Moment and Spin of electron; Positive and negative energy solutions, physical interpretation. Nonrelativistic limit of the Dirac equation.

Identical Particles: Symmetric and antisymmetric wave functions: Bosons and Fermians. symmetrization postulates, Pauli's exclusion Principle. Spin-statistics connection, self consistent field approximation:Slater determinant, HartreeFock method.

Quantum Field Theory: Preliminaries: why QFT? Classical Field Theory; Lagrangian formulation; Action for a scalar field; Symmetries and conservation laws, Noether's theorem; Quantum equation for field, Canonical quantization of scalar field; Dirac Field; Fock space and particle number representation.

Reference Books:

1. Relativistic Quantum Mechanics: Bjorken and Drell; McGraw-Hill; 1998.
2. Quantum Field Theory, Rev.Ed.; Mandland Shaw; Wiley; 1993.
3. Principles of Quantum Mechanics; Shankar; Springer; 2006.

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❖ NUMERICAL METHODS AND SIMULATION

Programming Fundamental: Representation of numbers on a computer; Errors in numerical solutions, round-off errors and truncation errors; Estimation of errors in numerical solution; Introduction to Computer programming.

System of Linear equations: Basics of Matrix algebra; Gauss elimination method; LU decomposition method; Inverse of a matrix method, Iterative methods;

System of Nonlinear equations: Bisection method; Newton's method; Fixed-point iteration method;

Least Squares Regression and Curve fitting: Numerical Curve fitting of linear equation and nonlinear equation. Curve fitting using quadratic and higher order polynomials; Interpolation; Lagrange polynomials; Newton's polynomial.

Fourier Methods: Square wave; General Fourier Series; Triangular wave; Discrete Fourier Transform

Numerical Calculus: Numerical differentiation; Finite difference approximation; Finite difference using Taylor series; Differentiation using Curve fitting;

Differential equations: Ordinary Differential Equations (ODE) – Initial value problems (Euler's method, and Runge-Kutta); Boundary-value problems of ODE; Partial Differential Equations:

Stochastic Systems: Probability Distributions; Generating Random numbers; Monte Carlo Simulation.

Modeling Using MATLAB/ Any Programming Language: Introduction to Modeling; Modeling Concepts and Definitions; Review of computational science examples; Accuracy and precision in modeling; Modeling terminology; Introduction to MATLAB; MATLAB Scripts; MATLAB Arrays; Linear models; Graphing data in MATLAB; MATLAB Array Math; Advanced graphing in MATLAB; Nonlinear Functions; Nonlinear modeling examples; MATLAB I/O; MATLAB conditional statements; MATLAB loops; MATLAB functions; Curve fitting;

Books:

1. Numerical Analysis, R. L. Burden and J. D. Faires, 1993.
2. Numerical Methods for Engineers and Scientists: An Introduction with Applications Using MATLAB; Amos Gilat and Vish Subramiam

❖ LASER AND NONLINEAR OPTICS

Basic principle of Laser: Spontaneous and stimulated Emission and Absorption; Laser and its characteristics; Population inversion, Properties of Laser Beams: Monochromaticity, Coherence: first order & higher order, Directionality, Brightness, Laser speckles.

Pumping processes: Pumping schemes for population inversion, Optical pumping, Electrical pumping.

Beams & Resonators: Plane Parallel resonator, Spherical resonator, Stable and unstable resonators, Gaussian beams & propagation, Directionality.

Types of Lasers: Solid State Lasers: Ruby Laser and Nd-YAG Laser, Titanium sapphire laser, Semiconductor Lasers, Gas Lasers: Neutral atom gas Lasers, Ion Lasers, Molecular Gas Lasers, Excimer Lasers, Dye Lasers, Chemical Lasers, Free-electron laser.

Applications of Lasers: Fibre-optics, Holography, Optical data Processing, Laser surgery, Microscopy.

Nonlinear Optics: Introduction, Nonlinear optical processes: Second harmonic generation (SHG), Phase matching techniques, Parametric fluorescence, Parametric amplification, Three wave mixing, Sum and Difference frequency generation, Parametric oscillation, Third harmonic generation (THG), Self-phase modulation, Cross-phase modulation, Four wave mixing, Optical phase conjugation, Kerr effect, Self-focusing and Self-defocusing, Spontaneous and Stimulated Raman Scattering, Hyper-Raman effect, Higher-order Raman processes, Multiphoton processes.

Text Books:

1. Laser Fundamentals, by William T. Silfvast, Cambridge University Press, 2008.
2. Principles of Lasers, by Orazio Svelto; Springer, 2009.

❖ ADVANCED CONDENSED MATTER PHYSICS

Many electron theory: Introduction to many-electron wave function, Hartree-Fock theory, Second quantization formalism; Interactions of Electrons and Phonons with Photons, Excitons and Polaritons.

Localization in Disordered Systems: Electron Localization, Anderson localization, Mott's Localization, Hopping Conductivity.

Correlated Systems: Hubbard Model, Mott insulator, Kondo effect.

Theory of Superconductivity: Flux quantization, Macroscopic Quantum interference, Cooper Pairing, Energy gap, BCS theory; Ginzburg-Landau theory; Introduction to high temperature superconductors.

Quantum Hall Effect: Integer quantum Hall effect, Introduction to fractional QHE.

Introduction to Soft Matter: What is Soft Condensed Matter: Qualitative discussion of Colloids,

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Polymers, Gels, Liquid crystals.

Reference Books:

1. Advanced Condensed Matter Physics, L. M. Sander, Cambridge.
2. Basic notions of Condensed Matter Physics, P.W. Anderson, Perseus Books

❖ PHYSICS OF SEMICONDUCTING MATERIALS AND DEVICES

Physical Mechanisms Concept of band gap, electrical and optical band gaps; Direct and indirect bands in semiconductor, degenerate and non-degenerate semiconductors.

Doping and degeneracy: Carrier concentration in intrinsic and doped materials; Fermi level, carrier generation and recombination process

Semiconductor continuity equation: recombination process, excitons, allowed, forbidden and phonon assisted optical transitions, concept of photo conductivity

Band bending, effect on bulk properties effective masses and their measurement, carrier transport and carrier lifetime.

Effect of traps and defects: diffusion and drift currents, variation of mobility with temperature and impurities.

Impurity profiling through capacitance measurement, junction capacitance, depletion layer formation.

Metal semiconductor contact: semiconductor superlattices and heterostructures.

P-N junction Diodes: Zener diodes, Avalanche diodes, Junction field effect transistors (JFETs), FETs, Schottky barrier diodes, MOSFET.

Microwave Devices: Tunnel Diode, MIS Tunnel Diode, MIS Switch Diode, Transferred Electron Devices (TEDs).

Photonic Devices: LED, LASER diodes, Photo detectors, Solar-

Power Devices: Thyristors, Heterojunction bipolar transistor (HBT), high electron mobility transistors (HEMTs).

High speed and high frequency devices: Hot electron injection transistors, Resonant Tunnelling Diodes, Single electron devices.
cell

Text Books:

1. Introduction to Semiconductors, Smith, John Wiley, 1962
2. Physics of Semiconductor Devices; Sze; Wiley; 1969

❖ ADVANCED MATERIALS AND ENERGY DEVICES

Introduction to advanced materials: theories and physical mechanisms, concept of *Fermi*-energy, work function and electron affinity, equilibrium and non-equilibrium condition, linear and non-linear characteristics.

Interaction between materials of different chemical origin; organic and inorganic species; motifs and functions, bio-functional structure.

Carbon based materials: ACs, Graphenes, CNTs, MWNTs.

Conjugates and nano-conjugates of conductive polymers, co- polymers, and their hybrid electrode materials.

Organic and inorganic hole and electron transport materials, their efficiency and properties.

Energy Devices Concept of energy production and storage;
Emerging trends in LEDs and optoelectronic devices;
Electrochemical capacitors and supercapacitors: principle, design and development, efficiency and properties, performance and applications;
Piezoelectric and pyroelectric devices;
Photochromic and electrochromic devices;
Magneto-hydrodynamics and magnetic fluids
Rechargeable batteries; Solar batteries and solar charger;
Solar cells: organic, inorganic and dye sensitized;
Hydrogen production and storage using hybrid materials;
Fuel cells: SOFC, PEFC, PAFC, MCFC design, development and properties.

Text Books:

1. Advanced Materials: Physics, Mechanics and Application; Shun-Hsyung Chang; Springer, 2014.
2. Energy Storage Devices for Electronic Systems; Nihal Kularatna; Academic Press, 2014
3. Graphene-based Energy Devices; Rashid bin Mohd Yusoff; Wiley, 2015

❖ MATERIALS CHARACTERIZATION

Microscopic techniques: Scanning Electron Microscope (SEM), Transmission electron microscope (TEM), Atomic force microscopy (AFM), Scanning tunnelling microscopy (STM).

spectroscopy, Photoluminescence, Nuclear Magnetic Resonance (NMR), Electron Paramagnetic Resonance, Ellipsometry.

Compositional characterization techniques: X-ray and Ultra- violet Photoelectron Spectroscopy (XPS & UPS), Energy Dispersive
X-ray analysis (EDAX), Rutherford Backscattering Spectroscopy (RBS), Inductively Coupled Plasma Mass Spectrometry (ICPMS).

Crystalline Structure characterization techniques: Rietveld refinement of XRD patterns using FullProf software. Transmission electron diffraction (TED), Reflection high energy electron diffraction (RHEED)

Electrical characterization techniques: Measurement of resistivity by four-probe method, Impedance and ferroelectric measurements.

Characterization of Mechanical Properties: Micro/Nanoindenter, Nanoindentation and scratch tests by AFM, Frictional Force Microscopy.

Magnetic characterization techniques: Vibrating Sample Magnetometer (VSM), Superconducting Quantum Interference Device (SQUID) based magnetic properties measurement system (MPMS), Magnetic Force Microscopy (MFM).

Thermal characterization techniques: Differential Scanning Calorimeter (DSC), Thermo-Gravimetric and Differential Thermal Analyzer (TG-DTA).

Text Books:

1. ASM Handbook: Volume 10: Materials Characterization; Crankovic; ASM International; 1986
2. Encyclopedia of Materials Characterization - Surfaces, Interfaces, Thin Films; Brundle, Richard, Evans & Shaun; Elsevier; 1992