# Ph.D. COURSES

## Group A

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A quick review of the following topics with emphasis on problem solving.

Vector calculus in $\mathbb{R}^3$ – gradient divergence curl, line surface and volume integrals, Green’s, Stoke’s and Guass’s theorem. Extension of these ideas to $\mathbb{R}^n$.

Finite dimensional vector spaces over infinite and finite fields – linear independence, basis, algebra of subspaces, linear functionals, dual and quotienting, linear operators, scalar product, self adjoint, unitary, positive, projection operators and their properties. Orthonormal sets and special theorem. Tensor products. Extension of these ideas to infinite dimensional vector spaces, over complete bases.

Elementary ideas about probability theory and stochastic differential equations with white noise.


Molecular structure, electronic structure of diatomic molecules. Rotation and vibration spectra. General introduction to polyatomic molecules.

1. H.A. Bethe and E.E. Solapeter. Quantum Mechanics of one and two electron atoms
PY902

Advanced Statistical Mechanics

Review of Thermostatics: equilibrium, different processes, thermodynamic potentials and postulates. Statistical entropy; irreversibility and growth of entropy.


Non-equilibrium statistical mechanics: linear response theory, fluctuation-dissipation theorem, Langevin equation and Fokker-Planck equation, Brownian motion; introduction to projection techniques.


Recommended Books:

2. D. Chandler, *Introduction to modern statistical mechanics*, Oxford University
Review of electrostatics, magnetostatics and elementary electromagnetic theory with special emphasis on solving problems.

A Review of free electron gas problem and band theory, Models for band structure calculations interacting electron gas, quasi electron and Plasmons, excitons


Defects: point defects, stacking faults & dislocations, effects on electronic & lattice properties, Alloys.

Characterization methods: XRD & HRXRD, RBS/Channeling, TEM, AFM, PL & Raman spectroscopy
Boltzmann transport equation, Linear response theory for the solution of Boltzmann transport equation for different scattering mechanisms under relaxation time approximation. Quantum transport theory, Kubo formalism, Kubo-Greenwood formula.


Optical properties of solids.

Magnetism:
Diamagnetism and paramagnetism: Review of elementary and quantum theories of diamagnetism and paramagnetism. Effect of crystalline field, Quenching of orbital angular momentum. Relaxation and resonance phenomena, NMR,

Ferromagnetism: Molecular field theory, Heisenberg model, Mean field solution, The series expansion method, The Bethe-Peierls-Weiss method, Holstein-Primakoff transformation, Magnons; Itinerant ferromagnetism, Stoner model, Wohlfarth’s modification; Crystalline anisotropy magnetoelastic effects, Magnetisation of ferromagnetic materials.
Ferrimagnetism: Molecular field theory, Spinels,Garnets, Quantum mechanical theories. Ferromagnetic, antiferromagnetic and ferrimagnetic resonance, Mossbauer effect. The s-d Zener model, Kondo effect, RKKY interaction, Spin glass.

Strongly correlated electron systems, Hubbard model, Different solutions of the Hubbard model, Mott transition.
Localized states in disordered lattice, Anderson model, Metal-insulator transition.
Review of Canonical quantization
Path Integral quantisation (Scalar and Spinor fields):


Path integral quantisation: Gauge field:

Spontaneous symmetry breaking: Goldstone theorem, Spontaneous symmetry breaking of gauge symmetries. Weinberg -Salam model.

Renormalisation:
Dimensional regularisation and renormalisation of Phi-4 theory.
Renormalization group
1-loop renormalisation of QED. Asymptotic freedom of YM theories. Chiral anomalies

Books: Quantum field theory - Ryder
Quantum field theory-Peshkin an Schroder
Review of tensor, general relativity:


Quantum field theory in curved space-time: space-time structures, scalar field quantization. Meaning of particle concept. Cosmological particle creation.


**Suggested books**

1. Quantum fields in curved space: N.D. Birrel and P.C.W. Davis
2. General relativity: R.M. Wald
Review of Finite groups

Continuous groups: examples, Rotation group, Lorentz group, su(2), SU(3).

Lie algebras, Casimir operator, Cartan Theorem (statement), Cartan classification.

Root diagram and Dynkin diagram.

Representation theory, SU(2), SU(3). Weight diagram. Rotation group, Lorentz group and Poincare group-induced representation.


Books:
Classical group for Physicists, Wyborne
Lie algebras, Lie groups and applications – Glimore
PY910

Differential Geometry in Physics


Fiber bundles: Concept of fiber bundle, Tangent spaces and cotangent bundles. Vector and principle bundle.

Applications to Classical mechanics, electromagnetism and general relativity.

Books:

Introduction to topology and differential geometry and group theory for Physicists: Mukhi and Mukunda

Geometric methods in Physics: Schutz
This is a Lab/Theory course with an aim to meet the day to day requirements of research scholars for scientific computation, data visualization and data fitting. The goal is to acquaint the students with the routines/functions/toolboxes in softwares like MATLAB, Mathematica, Octave (linux clone of matlab), Maxima, etc. At the end of the course students should have enough skills to tackle most of the following.

- Data input/output
- Curve/surface plots
- Simultaneous equations and matrix inversion

Root finding for both algebraic and transcendental equations
Eigenvalues and eigenvectors
Interpolation and integration
Special functions
Stiff and nonstiff differential equations
Fourier and other transforms
Initial and boundary value problems

The above are to be covered preferably via physics problems (from any branch of physics depending on the expertise of the instructor). The same problem may, in principle, cover many of the above modules.

Advanced students will be exposed to pseudo-spectral and FDTD methods for solving partial differential equations using recently acquired programs like BEAMPROP and FULLWAVE.
Advanced Particle Physics

The Standard Electroweak Guage Model: Quantum electrodynamics, Yang-Mills Fields: (SU(2) symmetry, The Unbroken SU(2)\textsubscript{L} x U(1)\textsubscript{Y}Model, The Higgs Mechanism, The effective four-fermion Interaction Lagrangian, Parameters of the guage sector, Lepton masses, Quark masses and mixing, Mixing matrix parametrization, Weak currents, Chiral anomalies, CP violation in heavy meson.


Neutrinos: Neutrino oscillations, Terrestrial searches for neutrino mixing, Solar neutrinos, Dirac mass and Majorana mass.

References:

Systems of identical particles, Symmetric and anti-symmetric wave functions.

Interacting electron gas. Hartree and Hartree-Fock approximations.

Second quantization for bosons and fermions.

Time-dependent operators- Schrodinger, Heisenberg and Interaction pictures.
Perturbative treatment of interacting electron gas.
Plasma oscillations in metals, Bohm-Pines theory - Random phase approximation.

Green’s function, Self energy, Dyson equation, Equation of motion method, Diagrammatic perturbation theory, Wick’s theorem, Feynman’s diagrams, Linked-Cluster theorem. Thomas-Fermi, Lindhard, Hubbard and Singwi-Sjolander Dielectric functions.
Green’s function at finite temperature, Double time-temperature Green’s Function technique of Zubarev.
Exactly soluble models: 1. Localized impurity in the continuum (Fano-Anderson model),
2. Independent Boson model,
3. Tomonaga-Luttinger model,
4. Polaritons(Photon-phonon complex)

Applications of many-body techniques to:
i) electron gas problem.
ii) superconductivity
iii) liquid helium


Elements of atom optics and cavity QED.
Phase Transitions, Critical Phenomena and Non-equilibrium Statistical Mechanics

**Phase Transitions:** Thermodynamic relations; Phase transitions and experimental Observations; Continuous phase transitions and critical points; Order parameter; Divergence of generalized susceptibilities and Specific heat at critical point; Critical-point exponents; Rigorous thermodynamic exponent inequalities; Fluctuations and Correlation functions; Spontaneous symmetry breaking; Mean-field theory; Ginzburg-Landau theory; Gaussian approximation; Universality and Scaling hypothesis; Renormalization Group; Fixed points; Scaling fields; Crossover phenomena

**Non-equilibrium Statistical Mechanics:** Density matrices and their properties; Liouville equation and its perturbation solution; Linear Response Theory; Response functions (conductivity, dielectric constant, structure factor, generalized susceptibility); Fluctuation-dissipation theorem; Boltzmann transport equation; Relaxation time approximation and electrical conductivity.

**Books Recommended:**


Arc-melting and Radio Frequency (RF) induction-melting techniques;
Ultra High Vacuum systems; Thin film deposition by thermal evaporation;
RF / DC sputtering; Pulsed Laser deposition; Nanocluster deposition system;
Atomic Force Microscopy; X-ray Diffractometer; Femto-second Laser system; Laser
Raman Spectrometer; Field-cycle Nuclear Magnetic Resonance Spectrometer; Electron
Spin Resonance Spectrometer; Infra-red Spectrometer; Production of low temperatures;
Low-temperature techniques; Closed-cycle refrigerators and their use; Liquid nitrogen
and Helium Cryostats; Low-temperature and High-magnetic Field facility
Experimental Techniques (Theory)

Energy and time scales for physical phenomena occurring in Condensed Matter and appropriate experimental probes:

Nuclear magnetic and quadrupole resonance; Moessbauer Spectroscopy; Neutron scattering; Muon Spin Resonance; Electron Spin Resonance; Raman scattering; Fluorescence spectroscopy; Electron energy loss spectroscopy; ac susceptibility; ac conductivity, Rutherford Backscattering Spectroscopy/Channeling, ERDA/Channeling and Blocking

Books Recommended:
PY919

Atomic and Molecular Physics


Molecular structure, electronic structure of diatomic molecules. Rotation and vibration spectra. General introduction to polyatomic molecules.


PY920 : Research Methodology
Each of the following modules may be taught and evaluated by a different expert. Teaching may not necessarily be confined to classroom. Visits to laboratories, workshop, library etc. should be components of the course. Hands on exposure to instruments can also be included. Each module may be evaluated independently by the concerned instructor.

**Module I: Definition of problem and presentation of results**

1. Overview of research methods involved – literature survey: journals, books, making hypothesis and model building, testing a hypothesis for acceptance or rejection
2. Introduction to presentation – poster, journals article, seminar

**Module II: Data acquisition/analysis**

1. Automation and computer interface – introduction to basic concepts of computer interface
   (a) DAQ cards (b) RS232, GPIB, TCP/IP protocols for instruments control. Introduction to Lab View
2. Data Analysis – Plotting, systematic errors, plotting of error bars, curve fitting etc.
3. Design Elements – Basics of machine drawing, visit to workshop, practice etc.

**Module III: Computational tools**

1. Introduction and scope of various programming techniques like FORTRAN, C, Mathematica, Matlab – packages like LaTeX, Word, Power Point, Excel
2. Application of above for real physics problems. (for extra assignments)

**Module IV: Exposure to advanced research techniques**

1. Laboratory experience on systems like Vacuum techniques, XRD, Thin film deposition system, SEM, AFM, Raman, NMR, Fluorescence spectrometer etc.
2. Computer simulation of Physics problems – molecular dynamics, Monte Carlo Techniques, Density functional theory etc.