Ph.D. COURSES

Group A

Course No.	Name of the Course
PY900	Advanced Quantum Mechanics
PY901	Advanced Mathematical Physics
PY902	Advanced Statistical Mechanics
PY903	Advanced Electromagnetic Theory
PY904	Advanced Condensed Matter Physics – I
PY905	Advanced Condensed Matter Physics – II
PY906	Advanced Condensed Matter Physics – III
PY907	Advanced Field Theory
PY908	Advanced General Relativity & QFT in Curved Space
PY909	Lie Groups, Lie Algebras and applications
PY910	Differential Geometry in Physics
PY911	Computational Techniques for Research
PY912	Advanced Particle Physics
PY913	Many Body Theory
PY914	Advanced Laser Physics, Quantum and Nonlinear Optics – I
PY915	Advanced Laser Physics, Quantum and Nonlinear Optics – II
PY916	Phase Transitions, Critical Phenomena and Non-equilibrium Statistical Mechanics
PY917	Advanced Condensed Matter Physics Laboratory
PY918	Experimental Techniques Theory
PY919	Atomic & Molecular Physics
PY920	Research Methodology

PY901

Advanced Mathematical Physics

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

Vector calculus in IR^3 – gradient divergence curl, line surface and volume integrals, Green's, Stoke's and Guass's theorem. Extension of these ideas to IR^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.

Quantum mechanics of one and two electron atoms. Interaction of one electron atoms with electromagnetic radition. Fine structure and hyperfine structure. Stark and Zeeman effect. Lamb shift. Many electron atoms – various approximation schemes.

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
2. H. Haken and H.C. Wolf. Molecular Physics and Elements of Quantum Chemistry.
3. B.H. Bransden and C.J. Joachain. Physics of Atoms and Molecules.

PY902

Advanced Statistical Mechanics

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

Equilibrium statistical mechanics: mean values and fluctuations; partition function and thermodynamics. classical statistical mechanics, chemical potential: examples. Quantum statistics, Bose-Einstein and Fermi-Dirac distributions: ideal Fermi gas, black-body radiation, Debye model.

Irreversible processes: conservation laws, transport coefficients, dissipation and entropy production, Navier-Stokes equation. Kinetic theory: distribution function, Boltzmann equation: H-theorem, linearization.

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

Numerical simulations in statistical mechanics: Markov chains, detailed balance, and stochastic matrices. Classical Monte Carlo methods. Critical slowing down, quasi-ergodicity and cluster algorithms.

Recommended Books:

1. H. Callen, *Thermodynamics and introduction to thermostatics*, John Wiley
2. D. Chandler, *Introduction to modern statistical mechanics*, Oxford University
3. M.L. Bellac, F. Mortessagne and G.G. Batrouni, *Equilibrium and non-equilibirum statistical thermodynamics*, Cambridge University
4. N. van Kampen, *Stochastic processes in Physics and Chemistry*, North-Holland
5. K. Binder and D. Heermann, *Monte Carlo simulations in statistical physics*, Springer-Verlag

PY903

Advanced Electromagnetic Theory

Review of electrostatics, magnetostatics and elementary electromagnetic theory with special emphasis on solving problems.

Radiating systems and scattering. Magnetohydrodynamics and plasma physics.
Covariant formulation of electrodynamics.
Dynamics of relativistic particles and electromagnetic fields.
Radiation by moving charges, Bremmsstrahlung, (including coherent Bremmsstrahlung), Cerenkov radition, sychrotron radiation, transition radiation.
Multipole fields.
Radiation dampings, scattering and absorption of radiation by a bound system.

PY904

ADVANCED CONDENSED MATTER PHYSICS -1

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

Lattice dynamics in three dimensions. Quantization of the lattice vibrations. Electron-phonon interactions. Physics of semiconductors – Elemental and Compound. Semiconductors, direct and indirect brand gap semiconductors. Intrinsic and Extrinsic (n-type and p-type) semiconductors, carrier transport in semiconductors – Injection and recombination of carriers, Basic equation for semiconductor Devices operation, p-n junction and applications in Devices. Heterostructures and Super lattices.

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

Characterization methods: XRD & HRXRD, RBS/Channeling, TEM, AFM, PL & Raman spectroscopy

PY905

ADVANCED CONDENSED MATTER PHYSICS -- II

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.

Superconductivity: Review of thermodynamic and electrodynamic properties of a superconductor, London's theory, GL theory, Cooper problem, Frohlich Hamiltonian, BCS theory, Spontaneous symmetry breaking, Meissner effect as Higgs mechanism, GLAG theory, Josephson tunneling, Strong coupling theory of Eliashberg.

Liquid helium-4: Pairing theory, Bogoliubov theory of He-4, Ground state properties-Theory of superfluidity of liquid He-4, ODLRO, Theory of Penrose and Onsager, Excitation spectrum of He-4, Bijl-Feynman theory, Landau's explanation of superfluidity of He-4.
Liquid He-3: Normal liquid, Fermi liquid theory, Experiments and microscopic theories, Superfluid He-3, Triplet pairing theory of Balian and Werthamer.

PY906

ADVANCED CONDENSED MATTER PHYSICS -- III

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,

Ferromagnetiam: 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.
Antiferromagnetism: Molecular field theory, Superexchange. Double-exchange. Series-expansion method, Bethe-Peierls-weiss method, Spin waves, Crystalline anisotropy, Domains in antiferromagnetic 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.

PY907

Advanced Field Theory

Review of Canonical quantization
Path Integral quantisation (Scalar and Spinor fields):

Path Integrals in Quantum mechanics., Functional integration for Scalar fields, Free particle Greens function. Phi -4 theory: Generating functional - 2, 4 Point function, connected diagram . Fermions and functional method

Path integral quantisation: Gauge field:
Photon propagator in functional method. Non-abelian gauge fields. Fadeev-Popov method. Feynmann rules for YM theories. Ward -Takashashi identities in QED. BRS transformation. Slanov-Taylor identities.

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 anomolies

Books: Quantum field theory - Ryder
Quantum field theory-Peshkin an Schroder

PY908

ADVANCED GENERAL RELATIVITY & QFT IN CURVED SPACE

Review of tensor, general relativity:

Black holes: Schwarz child solution Kruskal coordinate Penrose diagram Kerr solution Kerr-Newman solution Basic idea of black hole thermodynamics

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

Cosmology: Phenomenology of universe: Friedman-Robertson-Walker metric. Einstein's field equations Friedman's solution. Early universe inflationary universe

<u>Suggested books</u>

1.Quantum fields in curved space: N.D.Birrel and P.C.W.Davis
2.General relativity: R.M.Wald
3.Classical theory of fields: L.D. Landau and E.M. Lifshitz

PY909

Lie Groups, Lie Algebras and Applications

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.

Applications: Hydrogen atom, particle classification.

Books:

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

PY910

Differential Geometry in Physics

Differential manifolds: definition, differentiation of function, calculus on manifolds, differential forms and their properties. Riemannian geometry, frames, connections, curvature and torsion. Isometry, integration of differential forms, stokes theorem, Laplacian of differential forms.

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

PY911

Computational Techniques for Research

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.

PY912

Advanced Particle Physics

The Standard Electroweak Guage Model: Quantum electrodynamics, Yang-Mills Fields: (SU(2) symmetry, The Unbroken $SU(2)_L$ x $U(1)_Y$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.

Quantum Chromodynamics: The QCD lagrangian, The Renormalization Group Equation, Asymptotic freedom.

Neutrinos: Newtrino oscillations, Terrestial searches for neutrino mixing, Solar neutrinos, Dirac mass and Majorana mass.

References:

1. Collider Physics: V.D. barger and R.J.N. Phillips
2. Dynamics of the Standard Model: J.F. Donoghue, E. Golowich and B.R. Holstein
3. Quarks and Leptons: F. Halzen and A.D. Martin.

PY913

MANY BODY THEORY

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

PY914

Advanced Laser Physics, Quantum and Nonlinear Optics - I

Density matrices and semiclassical theory of atom-field interaction. Overview of resonator physics and semiclassical laser theory. Single and multimode operation of lasers. Homogeneous and inhomogeneous broadening. Q-switching and mode locking.

Overview of waveguide and fiber optics. Dispersion management: Slow and fast light. Fiber Bragg gratings. Erbium doped fibers. Solitons in nonlinear fibers.

Semiclassical theory of linear and nonlinear susceptibilities. Overview of elementary nonlinear optical processes and phase matching. Quasi phase matching. Elements of ultrafast and intense field nonlinear optics. Supercontinuum generation.
Local field effects in linear and nonlinear optics.

PY915

Advanced Laser Physics, Quantum and Nonlinear Optics – II

Overview of quantum theory of radiation, coherent and squeezed states. Elements of quantum distribution theory. P, Q and W- distributions.

Quantum theory of atom-field interaction. Theory of spontaneous emission. Atomic coherence and interference. Coherent population trapping. Lasers without inversion. Electromagnetically induced transparency.

Elements of atom optics and cavity QED.

PY916

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:

H. E. Stanley: Introduction to Phase Transitions and Critical Phenomena (Clarendon, 1971).

S. K. Ma: Modern Theory of Critical Phenomena (Benjamin, 1976).

L. D. Landau and I. M. Lifshitz: Statistical Physics (Pergamon, 1980).

N. Goldenfeld: Lectures on Phase Transitions and the Renormalization Group (Addison-Wesley, 1992).

PY917

Advanced Condensed Matter Physics Laboratory

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

PY918

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; Florescence spectroscopy; Electron energy loss spectroscopy; ac susceptibility; ac conductivity, Rutherford Backscattering Spectroscopy/ Channeling, ERDA/Channeling and Blocking

Books Recommended:

C. N. Banwell: Fundamentals of Molecular Spectroscopy (McGraw-Hill, 1983).
S. W. Lovesey: Theory of Neutron Scattering from Condensed Matter (Oxford, 1984).
L. C. Feldman, J. W. Mayer, S. T. Picraux: Materials Analysis by Ion Channeling (Academic Press, 1982).

PY919

Atomic and Molecular Physics

Quantum mechanics of one and two electron atoms. Interaction of one electron atoms with electromagnetic radiation. Fine structure and hyperfine structure. Stark and Zeeman effect. Lamb shift. Many electron atoms – Various approximation schemes.

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

1. H.A. Bethe and E.E. Salpeter. Quantum Mechanics of one and two electron atoms.
2. H. Haken and H.C. Wolf. Molecular Physics and Elements of Quantum Chemistry.
3. B.H. Bransden and C.J. Joachain. Physics of Atoms and 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.