Course Outline

The predoctoral period is divided into three terms. The first two terms are about three months duration and the last is about four months duration. Following courses are given to the predoctoral scholars over one year period. It is mandatory for the scholars to attend all the courses. Passing percentage for all courses is 50%. The contact hours for all the courses is about 35 hours. All of them (expect laboratory experinments) carry 100 marks. In the last term the scholars do a project which is essentially self study under the guidance of one of the faculty members. At the end of the term the scholars write a short report on their project and give a short (about 20 minutes) talk. The subjects for the project are given at the begining of the last term. The topics taught and a rough outline of the subject material covered is given below.

1 Quantum Mechanics

1) Introduction

2) Vector Spaces, Operators, and Representations

   Finite dimensional vector spaces, Inner product, Representations, Eigen value equations, Spectral decomposition, Infinite dimensions and Hilbert spaces, $\{|q>\}$ and $\{|p>\}$ representations, Tensor product of vector spaces

3) Postulates of Quantum Mechanics

   Postulates, The expectation value and the uncertainty, Heisenberg uncertainty relations

4) Quantum Dynamics

   General properties of the Schrodinger Equation, Ehrenfest theorem, Evolution operator, Schrodinger, Heisenberg, and Interaction pictures, Conservative systems, Density Operator, Propagator, Quantum entanglement, The EPR argument, Bell's inequalities, Approximation methods: perturbation theory, variational method, WKB method

5) Symmetries in Quantum Mechanics

   General discussion, Translational symmetry, Rotational symmetry, Parity, Time-reversal symmetry, Gauge symmetry

6) Two-State Systems

   General discussion, Rabi's formula, Spin-$\frac{1}{2}$ particles, Larmor precession and magnetic resonance, System of two spin-$\frac{1}{2}$ particles

7) Systems in One Dimension

   Harmonic oscillator, Coherent and squeezed states, Delta potential, Square potential well and infinite potential well, Potential barrier and tunneling, Periodic potential, Bloch's Condition, Kronig-Penney model

8) Systems in Two or Three Dimensions

General properties of the angular momentum, Landau Levels, Aharonov-Bohm effect, Particle in a central potential, Rotational-vibrational levels of diatomic molecules, Hydrogen atom, Fine structure, Zeeman effect

Books:

1. R. Shankar, 'Principles of Quantum Mechanics', Plenum Press, 1994
2. J. J. Sakurai, ' Modern Quantum Mechanics', The Benjamin, 1985
3. C. Cohen-Tannoudji, ' Quantum Mechanics', John Wiley, 1977
4. R. L. Liboff, 'Introductory Quantum Mechanics', Addison-Wesley, 1980
5. E. Merzbacher, 'Quantum Mechanics', John Wiley & Sons, 1970

2 Mathematical Methods

1. Complex variables: Set theoretic foundation, concepts of curves, limits, derivatives, analyticity, sequences, series, inverse of a function, singularities and contour integration, conformal mapping
2. Differential equations: Ordinary differential equations, hypergeometric equation, partial differential equations, method of characteristics, boundary value problems
3. Matrices: Matrices, determinants, diagonalization, eigenvalues
4. Special functions: Hypergeometric functions, Bessel functions, Hermite polynomeals, Legendre polynomeals Coulomb functions
5. Integral equations: Fredholm equation, iterative solution, Green functions

Books:

1. "Mathematical Methods for Physicists", G. Arfken
2. "Methods of Theoretical Physics" vol. 1 and 2, Morse and Feshbach

3 Classical Electrodynamics

1. Electrostatics (introduction), Boundary value problems, Multipole expansion, macroscopic media
2. Magnetostatics
3. Maxwell equations, gauge invariance, Poynting vector, magnetic monopole
4. Electromagnetic waves, reflection, refraction, waves in conducting or dissipative medium, wave guides, Radiating systems
5. Covariant formulation, special relativity, Lagrangian and Hamiltonian formulations, Dynamics of relativistic particles and electromagnetic fields

6. Geometry of Gauge Fields (Special Topic)

Books:
Classical Electrodynamics by J.D. Jackson (Main textbook)
Landau and Lifshitz, Vol.2 and Vol. 8
Classical Electrodynamics by W. Greiner

4 Statistical Physics

1. Basic concepts in thermodynamics. Entropy. Thermodynamic potentials.
2. Basic assumption of (equilibrium) statistical physics. Calculation of partition function under various constraints (constant energy, temperature, chemical potential, $\cdots$)
3. Classical and quantum non-interacting particles and spins.
4. Fluctuation, stability, response and correlation.
5. Classical gases and liquids, radial distribution function, Ornstein-Zernike theory, van der Waal equation, liquid gas transition.
6. Models of interacting spins on a lattice. Transfer matrix.
7. Mean field theory.
8. Systematics of phase transitions, critical exponents, Ginsburg Landau theory, Scaling.

Books:

1. "Statistical Mechanics", R. K. Pathria
2. "Statistical Mechanics", K. Huang
3. " Introduction to Modern Statistical Mechanics", D. Chander

$\star$ Sections 1, 2 and 3 will be covered mainly through problems.

5 Advanced Quantum Mechanics

Books which have good discussions of the relevant topics are mentioned topic-wise.

(1) N-particle systems (Shankar, Wieder):
N-particle Hilbert space, direct product space, N-particle Schrodinger equation.

(2) Identical particles (Shankar, Greiner, Gasiorowicz):
Symmetric and antisymmetric states (bosons and fermions), Pauli exclusion principle, spin-statistics theorem, normalization of states, Slater determinant, permutation operator, exchange degeneracy.

(3) Second quantization (Galindo & Pascual, Merzbacher):

Fock space, boson case, fermions, transformation of basis, dynamical variables, continuous one-particle spectrum case.

(4) Relativistic Quantum Mechanics, early attempts (Bjorken & Drell, Sakurai):

Klein-Gordon equation, negative energy and probability density.

(5) Dirac equation (Bjorken & Drell, Sakurai, Itzykson & Zuber, Gross):

Representation independence, relativistic covariance, bilinear covariants, Clifford algebra, non-relativistic approximations, plane-wave solutions, constants of motion, positron spinors and projection operators, Zitterbewegung, Klein's paradox, importance of negative energy solutions, Weyl equation and chiral transformations, electromagnetic coupling, approximate Hamiltonian for electrostatic case, Thomas term, Darwin term, Foldy-Wouthuysen transformation, Hole theory and positron, charge conjugation, time reversal and PCT, Hydrogen atom in Dirac theory, fine structure.

(6) Path integral quantization (Shankar, Feynman & Hibbs):

Propagator in path integral approach, free particle propagator, equivalence of path integral method to the Schrodinger equation, propagator for particle in a potential, harmonic oscillator, evaluation of path integral by Fourier series.

(7) Aharanov-Bohm effect (Shankar).

(8) Scattering Theory (Schiff)

6 Field Theory

1. Single particle relativistic wave equation
   - (i) Relativistic mechanics
   - (ii) Klein-Gordon Equation
   - (iii) Dirac Equation
   - (iv) Prediction of antiparticle
   - (v) Construction of Dirac spinors
   - (vi) Non-relativistic limit and the electron magnetic moment
   - (vii) Maxwell and Proca equations
2. Lagrangian formulation, symmetries and gauge fields
   - (i) Lagrangian formulation of particle mechanics
   - (ii) The real scalar field: variational principle and Noether's theorem
   - (iii) Complex scalar and Electromagnetic fields
3. Canonical quantisation and particle interpretation
   - (i) The real Klein-Gordon equation
   - (ii) The complex scalar Klein-Gordon equation

(iii) The Dirac field

(iv) The electromagnetic field

4. Interacting field and Feynman diagrams

   (i) Perturbation theory - philosophy and examples

   (ii) Perturbative expansion of correlation functions

   (iii) Wicks theorem

   (iv) Feynman diagrams

   (v) Cross sections and S-matrix

   (vi) Computing S-matrix elements from Feynman diagrams

   (vii) Feynman rules for fermions

   (viii) Feynman rules for quantum electrodynamics

5. Elementary processes of quantum electrodynamics

   (i) $e^+e^- \to \mu^+\mu^-$: Introduction

   (ii) $e^+e^- \to \mu^+\mu^-$: Helicity structure

   (iii) $e^+e^- \to \mu^+\mu^-$: Non-relativistic limit

   (iv) Crossing symmetry

   (v) Compton scattering

6. Radiative corrections *If time permits*

Books:

1. Quantum Field Theory by L. Ryder, Academic Press (1989)
2. Quantum Field Theory by M. Peskin and D. Schroder Addison-Wesley (1995)
3. Gauge Theory of Elementary Particle Physics by T. Cheng and L. Li, Clarendon Press (1984)

7 Computational Physics

1. Basics (fortran, representation of numbers in computers, loss of accuracy and propagation of errors, simple test programs)

2. Interpolation (Lagrange), sorting, pitfalls of interpolation, differentiation

3. Integration, quadratures, Monte Carlo

4. Differential equations (1-d), initial value and boundary value (eigenvalue) problems

5. Matrices, products and sums, diagonalization, inversion

6. Random number generators, numerical simulations

7. Data fitting, chi-squares, K-S method, goodness of fit
8. Plotting packages
9. latex
10. MATHEMATICA, MAPLE, matlab, scilab etc

Reference: "Numerical Recipes — The Art of Scientific Computing", W. H. Press, S. A. Teukelsky, W. T. Vellerling and B. P. Flannery

8 Condensed Matter Physics

- Elementary constituents of solids:
  Ions and electrons. Adiabatic approximation.
- Dynamics of electrons in a solid:
  Free electron model (classical and quantum), Drude theory, Weidenann-Franz law and electrical properties of solids.
- Structure of crystalline solids:
  Lattice in real space, reciprocal lattice, X-ray and neutron scattering.
- Dynamics of electrons (continued):
  Periodic potential, Bloch's theorem, energy bands and classification of solids (metals, semiconductors and insulators), electron correlation, Mott insulator.
- Dynamics of ions:
  Lattice vibrations (phonons). Lattice specific heat (Debye model). Thermal expansion and thermal conductivity. Soft modes and structural phase transitions.
- Semiconductors:
  intrinsic and extrinsic semiconductors. Law of mass action. Impurity bands, holes, excitons. p-n junctions, MOSFET, quantum wells and super lattices.
- Superconductivity:
  The phenomenon (experimental observations). Thermodyanomics of superconductors. Superconductivity as a phase transition. Type-I, Type-II superconductors. Landon theory and Ginzburg-Landau theory (brief discussion). Cooper pairs and BCS theory of superconductivity (basic ideas)- brief account of recent developments
- Magnetism:
  Magnetic phase transitions. Para, Ferro and Antiferro-magnetism. Spin waves, itinerant magnetism in metals and Pauli paramagnetism.
- Surfaces:
  Surface states, behavior of physical properties on or near the surface.

Books: "Solid State Physics", N. W. Ashcroft and N. D. Mermin

9 Nuclear Physics

1. NN interaction: symmetries, basics, low energy scattering and shape independence, meson theory and properties of NN interaction.
2. Nuclear systematics: masses, radii, shapes, magnetic and quadrupole moments,shell structure, radioactivity, fission
3. Basics of shell model, Hartree-Fock, pairing, rotational and vibrational spectra, giant resonances, halo nuclei
4. Nuclear Reactions: resonances and compound nucleus, direct reactions (inelastic, stripping, pickup etc), extracting nuclear information from reactions
5. Nuclear matter, nuclear equation of state, neutron stars (intro.)
6. Quark models (bag), quark equation of state, relativistic heavy ion collisions, signatures of QGP

Books:

1. "Structure of Nucleus", Preston and Bhaduri
2. "Theoretical Nuclear Physics", Blatt and Weisskopf
3. "Nuclear Structure" Bohr and Mottelson
4. "Nuclear Models" Greiner and Eisenberg
5. "Physics of Quark Gluon Plasma" Muller

10 Particle Physics

1. Introduction
2. Lie Groups and Lie Algebras: Representation Theory, Young Tableau
3. Conservation Laws
4. Hadron Specroscopy: Eight-fold way, Quark Model
5. S-Matrix, Cross-section and Decay Rate: General discussion, Feynman rules, sample calculations
6. Broken and Unbroken Symmetries in Field Theory: Global and local symmetries, Goldstone and Higgs phenomena
7. Standard Model: Electroweak Model, Quantum Chromodynamics
8. Beyond Standard Model: Comments on Grand Unification, Supersymmetry, String theory

Books

1) F. Halzen and A. D. Martin, 'Quarks and Leptons', John Wiley & Sons, 1984
2) T. P. Cheng and L. F. Lee, 'Gauge Theory of Elementry Particle Physics', Oxford Univ., 1984
3) G. Kane, 'Modern elementary particle physics', Addison-Wesley, 1987
4) D. Perkins, 'Introduction to High Energy Physics', Addison Wesley, 1987

11 Experimental Physics

1. Interactions of Charged Particles, Photons and Neutrons with Matter:
   A) Rutherford Scattering and Its Applications.
   B) Scattering of Photons
   i) Elastic Scattering - Bragg Diffraction And Its Applications
   ii) Inelastic Scattering, Compton Scattering And Applications.

2. Vacuum Techniques
3. Introduction to Particle Accelerators
4. Nuclear Radiation Detectors (semiconductor, gas, scintillation and other advanced detectors)
5. Pulse Processing Techniques and Nuclear Instrumentation
6. Counting Statistics and Error Analysis

   Books:
   1. “Radiation Detection And Measurement”, G. F. Knoll
   2. “Techniques for Nuclear and Particle Physics Experiments”, W. R. Leo

12 Laboratory Experiments

- EXPERIMENTS
  1. Gamma-ray spectroscopy
     - Energy calibration, Identifying unknown source
     - Identification of spectral features
     - Attenuation experiment
  2. Compton scattering - angle dependence
  3. Temperature dependence of resistivity of metals and semiconductors
  4. Muon life time measurement
  5. Charged particle spectroscopy with semiconductor detectors
  6. Thin film deposition
  7. Experimental controle through computers
- INTRODUCTION TO ADVANCED EXPERIMENTS
  1. X-ray Reflectivity
  2. Molecular Beam Epitaxy
  3. Transmission Electrom Microscopy
  4. Photoluminiscence
  5. Raman Spectroscopy
  6. X-ray Photoelectron Spectroscopy
  7. Particle Induced X-ray Emission / XRF
  8. Ion Implantation