Pre-Ph.D Course (Physics) - Syllabus

1. ***Research Methodology & Computational Techniques***

A. ***Research Methodology*** – statistical analysis, data compilation, interpretation, etc. ***10 Hours*** — 6 credits

B. ***Computational Techniques*** section shall consists of theory and computer lab work, in which the student is taught programming in Fortran/C++, Monte-Carlo simulations etc. ***14 Hours***

Examination: Three hours (150 Marks)

2. ***Advanced Theoretical & Experimental courses in Physics***

A. ***Research subjects*** – The student will be asked to take one course out of 7-8 courses offered depending upon his/her requirement and the availability of an expert. ***10 Hours*** — 4 credits

Examination: Three hours (100 Marks)

B. ***Problem solving session*** – Assignments on core subjects – Classical mechanics, Quantum mechanics, Electrodynamics, Statistical physics, Mathematical physics, Nuclear Physics, Particle Physics, Condensed matter Physics, Electronics, Atomic & molecular Physics – shall be given to students, and they are expected to gain experience in solving them. Take home-test and Assignments / tutorials. — 4 credits

50 Hours

Examination: One hour (30 Marks) each for ten core subjects

3. ***Project work (Seminar & Presentation)***

The student should select a research topic and read the literature and present one talk in a seminar. This has to be done in consultancy with the Ph.D. supervisor — 2 credit

Examination: Viva based on presentation/seminar (100 Marks)

Pre-PhD Course Contents

1. Research Methodology and Computational Techniques

A. Research Methodology: 10 Hours

Descriptive Statistics – Measures of Central tendency, Dispersion, Skewness, Kurtosis, Correlation.
Sampling, sampling distribution, Statistical Inference, Testing of Hypothesis, Hypothesis testing for mean, proportion and Variance, Chi-Square Tests, Regression Analysis, Factor Analysis.

Research Methodology – Methods and Techniques (Third Edition) C.R. Kothari and G. Garg

B. Computational Techniques: 14 Hours

Resume of Practical approach of learning operating systems (DOS, UNIX, Windows), Graphical packages, Calculations using Spreadsheet programming and Latex, Internet use.

Programming using Fortran 90/ C^{++} to handle various numerical techniques.
Mathematica software: Numerical calculations, Mathematical operations, in-built functions, Equation solving, matrices, differentiation, integration, series, limits.
Graphics including 3D plots.

Matrix inversion using iterative methods and accuracy, Numerical Solution of systems of linear equations, error analysis.

Linear and non-linear least squares fitting methods, Interpolation methods including splines.

Numerical integration methods - Simpson's rule, quadrature formula and Monte Carlo methods.
Numerical methods for Ordinary and partial differential equations.

Fast Fourier Transform.

Simulations using Monte Carlo methods : Geometrical simulations, absorption of gamma rays in matter, Molecular dynamics.

Teachers shall choose relevant / useful topics from the above for students.

2. Physics

A. In order to keep the syllabus topical and relevant this section shall have 10 courses. ***<u>The students will have to make one choice</u>***. The courses will be offered depending on the availability of the experts. Each course will involve a minimum of ***<u>10 hrs.</u>*** of teaching with major emphasis on problem solving.

10 Hours

(i) Solitons and Chaos:
Discovery of solitary waves and soliton interactions, Importance of solitons, KdV equation and its elementary solutions. Solitons in field theories. Chaos and its examples, parameters, one dimensional maps.

(ii) Astrophysics:
The Big Bang origin and the early evolution of the universe, the origin and evolution of the Milky-way Galaxy, stellar evolution and nucleosynthesis, galactic chemical evolution, the origin and evolution of the solar system.

(iii) Theoretical Techniques in Particle Physics:
Covariant Perturbation theory, Feynman Rules for spin 0 and spin ½ particles and their applications / Like groups: SU(2), SU(3) and SU(5) and their applications : Higgs Mechanism and Goldstone theorem and its application in gauge theories.

(iv) Theoretical Techniques in Nuclear Physics:
Review of static properties, binding energy, density, nuclear forces, and potentials, shell model, collective models and energy levels, Hartree-Fock theory of nuclear shape and states with good J Quantum number and applications, correlations in nuclear matter and exclusive principle correlations, Bethe-Goldstone equation and G-matrix, heavy-ion physics at low and intermediate energies, simulations and QMD model, hot and dense matter and multi fragmentation.

(v) Theoretical Techniques in Condensed Matter Physics:
Theory of NMR & ESR techniques, Theory of Anharmonic solids, Theory of Liquid state. Ising model, ferromagnetism, Phase transition, BCS theory, superconductivity, superfludity. DFT: Many body Schrödinger equation, density functional theory, equilibrium structure of materials, elastic properties of materials, vibrations of molecules and solids, Band structure and dielectric function.

(vi) Particle physics, Collider Physics & Accelerator:
Relativistic kinematics, Four vectors & invariants, some practical examples for use of invariants. Accelerator Physics: Ion optics including solutions of

differential equations dealing with motion of ions through magnets, electrostatic fields, electrostatic analyzers, etc. Transformation of differential cross-section. Monte Carlo calculations and its applications, typical uses of Monte Carlo techniques to High Energy particle physics. Collisions in colliders: Reconstruction of events-examples, LHC collider, CMS detector, ALICE detector, Belle detector (brief), Extraction of signal – top Higgs, QGP, CP violation.

(vii) Experimental methods for probing nuclear structure:
Experimental methods for gamma-ray, conversion-electron and charged-particle spectroscopy associated with nuclear reactions and Coulomb excitation, Compton-suppressed Ge detectors, multiplicity filter, Neutron detectors, Sector field electron spectrometer, mini-range spectrometer, Recoil mass-separator, Advanced detector arrays-GAMMASPHERE and EUROBALL. Lifetime measurements – DSAM and RDM techniques, coincidence method, pulsed beam method. Hyperfine interactions – Static magnetic and quadrupole Interactions, Time differential orientation measurements. Photon – atom Interactions – interaction processes in X-ray energy region, inner-shell photoionisation and subsequent processes, Elastic and inelastic scattering.

(viii) Experimental Techniques in Solid State Physics: High Vacuum: Diffusion Pump, Turbo Molecular Pump, Gauges for measuring high vacuum. Preparation of Materials: Crystal Growth, Amorphous materials, Nano materials, Polymers by different techniques. Device Fabrication: Oxidation Diffusion, Ion Implantation, Metallization, Lithography and Etching, Bipolar and MOS device fabrication. Characterization Techniques: Impedance, TEP, AFM, TEM, SIMS, micro-Raman, Luminescence, Ellipsometry.

(ix) Medical Physics (ASO) Dose calculation algorithms of External Beam Treatment Planning System for both photon and particle beams: kernels, PBC, AAA, CCC, Acuros XB, eMC, GGPB, VMC++, XVMC. Inverse planning optimization algorithms of Intensity Modulated Radiotherapy and Volumetric Modulated Arc Therapy: Theory of Optimization, Simulated Annealing, Dose Volume optimizer and Progressive Resolution Algorithm. Brachy therapy Treatment Planning algorithms: TG-43 formulism, TG-186 formulism, Acuros. Image Reconstruction Algorithm: FBP, Fourier transformation based algorithm using FFT, Wavelet FT, DFT, FDK, MCIR, Iterative Algorithms: Gradient descent (GD), conjugate GD, Expectation Maximization, Ordered Subset Expectation Maximum, DRR reconstruction algorithms.Radiobiological Modeling:Concepts of EQD2, EUD, BED, TD_{50}, $g_{50,}$ Emami, Quantec and Timmerman recommendation of tissue Tolerances. NTCP and TCP, LKB, Nimerko Model, Clinical implementation of models with detailed demonstration.

(x) *X-ray emission based analytical techniques*: Photon-atom interaction processes, Resonant Raman Scattering, X-ray absorption fine structure, Interaction of electron with matter: Interaction of charged particle with matter: Stopping power, Plane wave Born approximation, ECPSSR theory, Inner-shell vacancy decay processes, X-ray production cross sections for photons and charged particles. Analytical techniques: EDXRF, WDXRF, Microfocus XRF, Synchrotron based XRF, PIXE and TXRF, XRD for chemical phase identification, Detection of X-ray, Spectral analysis

B. Problem solving in various core Physics subjects. The students are expected to gain experience in solving them. Take home-test and Assignments / tutorials

10 × 5 Hours = 50 Hours

(i) Classical Mechanics: Rigid body dynamics, moment of inertia tensor, Non-inertial frames and pseudoforces, Small oscillations, normal modes, Variational principle, Generalized coordinates, Lagrangian and Hamiltonian formalism and equations of motion, phase space dynamics.

(ii) Quantum Mechanics: Schrödinger equation (time-dependent and time-independent), Hydrogen atom, Eigenvalue problems (particle in a box, harmonic oscillator in 3D, etc.), Tunneling through a barrier, Time independent perturbation theory and applications, WKB approximation.

(iii) Electrodynamics: Electric fields, potentials, Maxwell's equations in free space and linear isotropic media, boundary conditions on the fields at interfaces, Dynamics of charged particles in static and uniform electromagnetic fields, Electromagnetic waves, Radiation- from moving charges and dipoles and retarded potentials.

***(iv) Thermodynamic and Statistical Physics**:* Phase space, micro- and macro-states, Micro-canonical, canonical and grand-canonical ensembles and partition functions, thermodynamical functions, Classical and quantum statistics, Ideal Bose and Fermi gases, Bose-Einstein condensation.

(v) Mathematical Physics: Vector calculus, Special functions and applications (Hermite, Bessel, Laguerre and Legendre functions). Fourier series, Fourier and Laplace transforms. Elements of complex analysis, analytic functions, Partial differential equations (Laplace, wave and heat equations in two and three dimensions).

(vi) Electronics and Experimental methods: Semiconductor devices, diodes, junctions, Field effect devices, Opto-electronic devices. Operational amplifiers and their applications. Digital techniques and applications, Microprocessors and Microcontrollers.

(vii) Atomic & Molecular Physics: Quantum states of an electron in an atom, Spectrum of Helium and alkali atoms, hyperfine structure and isotope shift, width of spectrum lines, LS and jj coupling, Zeeman, Electronic, rotational, vibrational and Raman spectra of diatomic molecules, selection rules, Lasers – Optical pumping,

(viii) Nuclear Physics: Basic nuclear properties, Binding energy, Alpha, Beta and Gamma decays, Liquid drop model, nucleon-nucleon potential, Deuteron problem, Shell model, Rotational spectra, Fission and Fusion, Nuclear reactions, compound nuclei and direct reactions.

(ix) Particle Physics*:* Application of symmetry arguments and conservation laws to particle decays and reactions, Application of symmetry arguments to particle reaction, Relativistic kinematics.

(x) Condensed Matter Physics: Bravais lattices. Reciprocal lattice. Diffraction and the structure factor. phonons, lattice specific heat. Free electron theory and electronic specific heat. Drude model of electrical and thermal conductivity. Electron motion in a periodic potential, band theory of solids: metals, insulators and semiconductors. Superconductivity.

Recommended Books:
(*Additional references can be provided by the concerned teachers*):

1. Solitons an Introduction by P.G. Drazin and R.S. Johan (Cambridge Univ. Press, 1989)
2. Chaos in Dynamical Systems by E. Ott (Cambridge Univ., Press, 1993)
3. Solitons and Instantons by R. Rajaraman (North Polland. 1989)
4. Gauge theory of Elementary Particles by T.P. Cheng and Li (Oxford)2000
5. Structure of the Nucleus by M.A. Preston and R.K. Bhadhuri.
6. Quantum Theory of Solids by C.Kittel
7. Liquid State Physics by N.H. March and M.P. Tosi
8. Liquid State Physics by Engelsta
9. Quantum field theory by Lahiri and Pal
10. The chemical evolution of the galaxy by F. Matteucci
11. Planetary Science by I. Pater and J.J. Lissauer
12. Solar system evolution: A new perspective by S.R. Taylor
13. Relativistic Kinematics by R. Hagedon.
14. Statistics for Nuclear and Particle Physicists by Louis Lyons. 500726
15. CMS – Technical Proposal
16. ALICE – Technical
17. In beam gamma-ray spectroscopy by II, Morinaga and T. Yamazaki.
18. Nuclear spectroscopy and reactions (part A & C) edited by Joseph Cerny.
19. Radiation detection and measurements by Glenn. F. Knoll.
20. Gamma-ray and electron spectroscopy in Nuclear Physics by H. Ejiri and M.J.A. de Voigt.

21. The electromagnetic interaction in Nuclear Spectroscopy, Edited by W.D. Hamliton.
22. Alpha, Beta-and Gamma-ray Spectroscopy, Vol 1 and 2, Edited by Kal Siegbahn.
23. X-rays in Atomic and Nuclear Physics by N.A. Dyson
24. Elastic scattering of gamma-rays and X-rays by atoms – Phys, Reports 140 (1986-75 by P.P. Kane, L. Kissel, R.H. Pratt and S.C. Roy.
25. Inelastic scattering of X-rays and gamma-rayus by Inner shell electrons-Phys. Reports 218 (1992) 67 by P.P. Kane,L. Kissel, R.H. Pratt and S.C. Roy.
26. Thin Films Phenomena by K.L. Chopra
27. Science of Engineering Materials by C.M. Srivastava and C. Srinivasan, Wiley East. Ltd.
28. Nanoparticles and Nanostructured Films-Preparation, Characterization and Applications: J.H. Fender (Wiley).
29. Microelectronic Processing by W. Scot Ruska, McGraw-Hill.
30. Characterization of Semiconductor Materials by Philips F. Kare and Greydon B. Lausbee, Mc Graw Hill.
31. Physical methods for Materials Characterization by P.E.J. Fiewitt & R.K. Wild.
32. Optical Properties of Solids by M. Fox, Oxford University Press. Fortran Programming – V. Rajaraman
33. Numerical Methods: A Computer Oriented Approach, BPB Publ. 1996 R.S. Salaria
34. Computer based Numerical Methods 3rd Ed. Prentice Hall India 1980, V. Rajaraman
35. The C++ Programming Language/Addison Wesely
36. Mathematica, S. Wolfram, Addison. Wesely
37. Application of the Monte Carlo Method, K. Binder, Springer Veriag
38. Numerical Recipes in Fortran: The Art of Scientific Computing, W.H. Press et al., Cambridge Press.
39. Numerical Recipes in Fortran: the Art of Scientific Computing, W.H. Press et. al, Cambridge Press
40. An Introduction to Computer Simulation Methods, H.Gould and J. Toobochnlik, Addison Wesley, 1996.
41. Computational Physics by S.E. Koonin
42. Materials modeling using density functional theory, by Feliciano Giustino, Oxford Press