Integrated M. Sc-Ph. D programme at the School of Physical Sciences, NISER

The programme is expected to start from the academic year 2016 at the School of Physical Sciences (SPS) in the NISER Campus at Jatni, Khordha.

1 Admission

The minimum qualification for admission to the programme is Bachelor's degree in Physical Sciences or an equivalent degree from a University recognised by UGC.

Prospective candidates will be shortlisted based on their performance in national level entrance exams like JEST and/or JAM. A shortlist will be drawn by putting a cut-off on JEST and JAM exam results. The shortlisted candidates will be interviewed at NISER.

2 The Academic Programme

- The Integrated M. Sc-Ph. D programme at NISER shall consist of : (i) Course work involving classroom courses as well as a research project leading to the award of the M.Sc. degree (3 years), and (ii) Research work leading to a PhD thesis and the award of Ph. D degree.
- The course work for the Integrated M. Sc-Ph. D programme will be based on courses that have been approved by the Academic Council of NISER. The details are given in section 4. The duration of the course work shall be equivalent to **three** academic years. Approximately one third of the course credits are to be earned through a Master's project leading to a Master's thesis.
- The evaluation of the students will be based on continuous assessment (quizzes/homeworks etc) and examinations. The Master's project will be evaluated in each semester by the School and the thesis will have to be defended in an open thesis defence. The students who have a CGPA 7.0 or more at the end of two years and successfully defend

their Master's thesis at the end of the third year of the programme shall be eligible for award of the Master's degree.

- Students who are unsuccessful in earning a CGPA of 7.0 after the first two years shall be considered ineligible for the M. Sc degree.

- For the continuation of studies towards a Ph. D degree the students will be required to take a General Comprehensive Examination based on the courses attended during the M. Sc course work. This exam can be taken by students after they have completed all the course requirements for the M. Sc degree other than the research project. On satisfactory performance in the comprehensive exam and the successful completion of the M. Sc course work the PGCS after informing the PGCI can recommend the student to register for a Ph D.

- A student will at most be allowed two attempts to pass the General Comprehensive Examination. A student failing to pass the General Comprehensive Examination twice will be deemed ineligible for a Ph. D degree.

- The programme will be conducted according to the rules and regulations of the Homi Bhaba National Institute (HBNI) of which NISER is a constituent institute. On admission to the Integrated M. Sc-Ph. D programme the students will be registered with HBNI. They will receive an M. Sc degree after three academic years and on passing the General Comprehensive Exam they can continue research towards a Ph. D degree. The rules of the Homi Bhabha National Institute (HBNI) regarding the award of the Ph. D degree apply during this period.

3 Fellowship

The students of the programme will receive a monthly stipend of Rs. 16,000 for the first year and Rs. 25,000 in the next two years and Rs. 28,000 thereafter. A contingency grant, housing and medical facilities will be provided as per DAE rules.

4 Course structure

The course work in the Integrated M. Sc-Ph. D program for the award of an M. Sc degree will span **three** academic years. The total number of course credits required for the award of the M. Sc degree at the end of three years is proposed to be 120. The workload is proposed to be distributed uniformly across the three years and hence each semester would correspond to 20 credits of course work. At SPS, NISER most theory courses are 4-credit courses (3 hours of lectures and 1 hour tutorial per week) and for a laboratory course 2 credits are usually equivalent to one laboratory session lasting 3 hrs.

NISER currently has two different sets of courses for its Integrated M. Sc programme and the Ph. D programme. It is proposed that the core courses to be taken by the incoming Integrated M. Sc-Ph. D students be a mix of courses for the Ph. D programme and those taken by advanced undergraduates of the Integrated M. Sc programme.

The semester-wise distribution of courses for meeting the course requirements are as follows. The syllabi can be found in the Appendices.

4.1 1st year

1st semester	Classical Mechanics - P601 Mathematical Methods - P602 Electromagnetism - P603 Laboratory - 4+4=8 credits (P741, P742)
2nd semester	Quantum Mechanics - P615 Statistical Mechanics - P614 Introduction to Condensed Matter Physics - P306 Laboratory - 4+4 = 8 credits (P743, P744)

4.2 2nd year

3rd semester	Special Theory of Relativity - P304 Nuclei and Particle Physics P307 Elective course Elective course Computational Lab. - P745 4 credits
4th semester	Atoms, Molecules and Radiation - P305 Elective course Elective course Master's Project - 8 credits

The details of the experiments to be carried out by the students in the 1st year can be found in the Appendix.

4.3 3rd year

The third year of course work will entirely consist of research work for the Master's project. The project as a whole consists of 48 credits and is started in the 4th semester as shown above. After completion of an initial 8 credits of work in the 4th semester the rest of the project is to be completed in the 3rd year (20 credits each in each of the 5th and 6th semesters.)

After the completion of the project the student can continue research work towards a Ph. D degree if the performance in the oral comprehensive examination is deemed satisfactory.

Appendix A First semester experiments

Duration and credits: 15 weeks (including exams), 4 lab classes (of three hours duration) per week, 4+4=8 credits

- **P741: Integrated M. Sc-Ph D first semester experiments - Part 1**

  1. Recapitulation of basic concepts: Includes lectures to recall material expected to be covered in the Bachelor's courses and a quick introduction to function generators, oscilloscopes, power supply etc in NISER teaching labs.
  2. Transistor characteristics, single and two-stage RC coupled amplifiers.
  3. Op Amp basics and applications: 741 Op-Amp and its characteristics, mathematical operations, Schmitt trigger, comparator using 741 Op-Amp.
  4. Passive and active filters.
  5. Study and design of RC coupled, Wien-bridge, Colpitt and Phase shift oscillators.

- **P742: Integrated M. Sc-Ph D first semester experiments - Part 2**

  1. Kater's pendulum.
  2. Determination of magnetic susceptibility of a paramagnetic solution using Quincke's tube method.
  3. Coefficient of linear expansion of a solid by Fizeau's method.
  4. Young's modulus of glass by Cornu's method.
  5. Measurement of specific charge (e/m ratio) of electrons.
  6. Study of B-H loop.
  7. Measurement of dielectric constant by parallel plate capacitor.
  8. Study of Rutherford scattering using Al and Au films.
  9. Study of absorption of beta and gamma rays using GM counter.
  10. Study of energy dependence of gamma rays absorption coefficient using sources Co-60, Cs-137 etc.
  11. Study of Compton scattering using X-rays and gamma rays.

Appendix B Second semester experiments

Duration and credits: 15 weeks (including exams), 4 lab classes (of three hours duration) per week, 4+4=8 credits

- **P743: Integrated M. Sc-Ph D second semester experiments - Part 1**
  1. Logic GATE circuits, Boolean operations, Multiplexer, Demultiplexer.
  2. Half and full adder/subtractor.
  3. Flip-Flop circuits.
  4. Counters.
  5. IC 555 timer circuits.
  6. Data Aquisition.
- **P744: Integrated M. Sc-Ph D second semester experiments - Part 2**
  1. Determination of Planck's constant by Photoelectric effect.
  2. Study of Hydrogen spectra (Balmer's series).
  3. Study of Michelson interferometer.
  4. Study of Fabry-Perot interferometer.
  5. Study of Hall effect in semiconductors.
  6. Determination of energy band gap in semiconductors four probe/two probe method.
  7. Measurement of magnetoresistance of a semiconductor.
  8. Study of electron spin resonance.
  9. Study of optical waveguides and fibers.
- Additional experiments: Students are expected to work on at least one of the following experiments on completion of the those listed above. These experiments take longer to perform and the students are expected to spend about 6 laboratory sessions on an experiment from this list.

1. Study of earth field Nuclear Magnetic Resonance (NMR)
2. Study of Mie scattering/Laser Doppler Anemometry (LDA)
3. Determination of Verdet's constant and study of Faraday's effect in homogeneous magnetic field.

Appendix C Core courses

P601: Classical Mechanics

1. Generalized coordinates, velocities and momenta, Lagranges formulation
2. Principle of least action, formulation by Maupertuis, Euler, Hamilton. Liouville's theorem
3. Two-body central force problem (reduced mass), planet orbits, Virial theorem
4. Collisions and scattering, CM and Lab frames, scattering cross section
5. Motion in non-inertial frames, Coriolis force
6. Hamilton's equations, Poisson brackets
7. Canonical transformations, Hamilton-Jacobi equation, Generating functions, Symmetries and conservation laws
8. Small oscillations, Normal modes.
9. Rigid body dynamics, Euler angles, Euler equations, rotation of a top
10. Special topics : nonlinear oscillators, non-linear dynamics, Lyapunov exponents, Introduction to chaos.

References:

1. Classical Mechanics, H. Goldstein
2. Mecanics - Landau and Lifshitz
3. Classical Mechanics - John R Taylor
4. Classical dynamics of particles and systems - Marion and Thornton
5. Introduction to dynamics - Percival and Richards

P614: Statistical Mechanics

1. Review of thermodynamics, thermodynamic potentials, thermodynamic equilibrium and stability
2. Probability theory: Probability densities, cumulants and correlations, central limit theorem, laws of large numbers
3. Gibbs distribution : Ensembles, classical and quantum free particles, systems with continuous and discrete spectrum, degenerate Fermi systems, Bose condensation
4. Interacting systems: Cluster and Virial expansions, radial distribution function
5. Introduction to response, fluctuation and noise, Einstein formula
6. Phase transition : phenomenology of first order and continuous phase transitions, order parameters, 1D Ising model, universality and scaling, Ginzburg- Landau- Wilson theory, spontaneous symmetry breaking
7. Fundamentals of statistical mechanics: phase space, Liouville theorem, statistical distribution theorem
8. Brownian motion, Langevin equation, Markov processes and Fokker Planck equation

References:

1. Introduction to Statistical Mechanics - Kerson Huang
2. Statistical Physics - Reif
3. Statistical Physics of particles - M. Kardar
4. Introduction to Phase transitions and critical phenomena - H. E. Stanley

P615: Quantum Mechanics

1. Hilbert space (states, operators, evolution)
2. Review of one dimensional problems, delta and periodic potentials, Bound states vs scattering states, Simple harmonic oscillator
3. The central force problem, review of the hydrogen atom, hard and soft sphere
4. Angular momentum, rotation operators and the rotation group, spin, spherical harmmonics, addition of angular momentum.
5. Symmetries in quantum mechanics
6. Introduction to path integrals
7. Time independent perturbation theory, WKB approximation, variational method, Zeeman and Stark effects
8. Identical particles and exchange statistics
9. Time dependent perturbation theory, Heisenberg and interaction representations, Rabi Oscillations
10. Basic aspects of scattering theory : Born approximation and partial waves and phase shifts

    Special topics: Dirac equation/semi classical theory of radiation/geometric phase (a subset of these topics depending on available time)

References:

1. Principles of Quantum Mechanics - R. Shankar
2. Quantum Mechanics I and II - Cohen-Tannoudji, Diu and Laloe
3. Modern Quantum Mechanics - J. J. Sakurai
4. Introduction to Quantum Mechanics - David Griffiths
5. Quantum Physics - S. Gasiorowicz
6. Quantum Mechanics - E. Merzbacher
7. Quantum Mechanics - Bransden and Joachain
8. Introductory Quantum Mechanics - R. Liboff

P602: Mathematical Methods

1. Vectors and Tensors (index notation, vector analysis in curvilinear coordinates, Cartersian tensors and four vectors, General tensors)
2. Review of Linear Algebra with emphasis on applications to physical problems (linear transformations + Matrix representations, Eigenvalues, Eigenvectors, Inner product spaces
3. Review of complex analysis with applications (Cauchy-Riemann equations, Complex integration, Cauchy theorems, Contour integration, Branch points and branch cuts, Applications to integrals, series etc)
4. Hilbert space methods, special functions (Hilbert space, Orthonormal series expansions in Hilbert space especially Fourier series, Special functions)
5. Ordinary and Partial differential equations (Analysis of second order OFEs Sturm-Liouville system, Boundary value problems for Laplace, Diffusion(Heat) and wave equations)
6. Integral Transforms, its applications and Generalized functions (Laplace and Fourier transform, Dirac delta and other generalized functions, Greens functions of ODE and PDE)
7. Group theory (introduction using various groups occurring in physics, its algebra, Representation of groups, Characters)

References:

1. Mathematical Methods in the Physical Sciences, M. L. Boas
2. Mathematical Methods for Physicists, Arfken and Weber
3. Mathematical methods, C. Harper
4. Mathematical method for physicists, T. L. Chow
5. Mathematical methods in science and engineering (2books) - Seluk Bayin
6. Mathematical Methods in Physics and Engineering :Riley, Hobson
7. Mathematical Physics I and II: S.D. Joglekar
8. Mathematical Methods for Engineers and Physicists (3 books) -K. T. Tang
9. Graduate Mathematical Physics - James J. Kelly
10. Mathematical Methods In Classical And Quantum Physics : Tulsi Dass

P603: Electromagnetism

1. Electrostatics in vacuum, force, field, potentials and energy
2. Electrostatic boundary conditions and conductors
3. Solution of Laplace's equation in one, two and three dimensions, uniqueness theorem, methods of images, separation of variables, multipole expansion
4. Dielectrics
5. Current distributions, magnetic fields and magnetostatic boundary conditions
6. Motion of charges in electric and magnetic fields, energy and momentum of electromagnetic fields
7. Maxwell's equations, EM waves and their propagation in free space and in media
8. Potential formulation, Coulomb and Lorentz gauge, radiation from an accelerated charge, dipole radiation Special topics : Diffraction theory, polarization.

References:

1. Introduction to electrodynamics - David Griffiths
2. Foundations of electromagnetic theory - Reitz, Milford, Christy
3. Classical electrodynamics - J. D. Jackson
4. Electricity and Magnetism - M. H. Nayfeh, M. K. Brussel

P306: Introduction to Condensed Matter Physics

1. General introduction, Drude and Sommerfeld model.
2. Crystal structure; x-ray diffraction.
3. Cohesive energy.
4. Blochs theorem; Band theory nearly free electrons; tight binding approximation; semi-classical dynamics of electrons in a band, definition of metals and insulators.
5. Basic properties of Semiconductors.
6. Thermal properties of insulators, phonons.
7. Landau levels - de Hass van Alphen effect and Integer quantum hall effect.
8. Introduction to Magnetism.
9. Introduction to Superconductivity.

References:

1. Introduction to Solid-state Physics, C. Kittel
2. Solid-state physics, N. Ashcroft and N.D. Mermin,
3. Solid-state physics, Rosenberg
4. Solid sate physics, Burn
5. Oxford Series in Condensed Matter [Oxford university press]

P304: Special Theory of Relativity

1. Physics before relativity: Galilean relativity, Newtonian mechanics, electrodynamics and inconsistency with Galilean relativity, ether and experiments for its detection, failure to detect ether. Measurement of velocity of light in moving frames. Lorentz, Poincare and developments towards relativity.
2. Einstein's special theory: Constancy of velocity of light as a postulate. Derivation of Lorentz transformation. Length contraction and time dilation. Mass-energy relation, Doppler shift. Minkowski space-time diagram, boosts as complex rotations in Minkowski space.
3. Four dimensional space-time continuum, Lorentz transformations as coordinate transformations, vectors, scalar product, scalars, tensors, contravariant and covariant objects, laws of physics as tensor equations. Mechanics, hydrodynamics and electrodynamics as tensor equations.
4. Beyond special relativity: Inertial and gravitational mass. Equivalence principle. Introducing gravitational field as general coordinate transformation. Principle of general covariance. Metric tensor and affine connection. Gravitational potential as metric tensor. Laws of physics in presence of gravitation. Gravitational time dilation and red shift. Experimental observation of gravitational red shift.
5. Lorentz and Poincare groups: Abelian and non-Abelian groups. Rotations in two and three dimensions. Generators of rotations. Representations (finite dimensional). Casimir operators. Lorentz transformations as a group. Generators for translations, rotations and boosts. Finite and infinite dimensional representations. Casimir operators.

References:

1. Introduction to Special Theory of Relativity, Resnick
2. Subtle is the Lord, A. Pais (Oxford U. Press, Oxford, 1982)
3. Relativity, A. Einstein
4. Classical Electrodynamics, J. D. Jackson
5. Electrodynamics, Panofsky and Phillips
6. Classical Mechanics, Goldstein
7. GTR and Cosmology, Weinberg
8. Lecture notes in NISERwiki (also at http://www.iopb.ser.in/ phatak)

P307: Nuclei and Particles

1. Nuclear systematics and stability (masses, sizes, spins, magnetic moments, quadrupole moments, energetics and stability against particle emission, beta decay).
2. Nucleon-Nucleon interaction, space-time symmetries, conservation laws, isospin symmetry, low energy (effective range, shape independence, meson exchange picture (qualitative).
3. Liquid drop model, compound nucleus and fission, nuclear vibrations and rotations.
4. Shell model, introduction to Hartree-Fock, spins and magnetic moments.
5. Direct nuclear reactions.
6. Mesons and baryons, resonances, SU(3) classification, isospin and strangeness, quark model, colour.
7. Weak interactions (nuclear and particle decays, neutrinos etc).

References:

1. Introduction to Nuclear Physics - Roy and Nigam
2. Nuclear Physics - Preston and Bhaduri
3. Introduction to particle physics - Griffith
4. Introduction to particle physics - Perkins

P305: Atoms, Molecules and Radiation

1. Hydrogen atom including l.s coupling and hyperfine interaction.
2. Helium atom introduction to exchange and correlation; variational calculation of ground and excited-states.
3. Introduction to the idea of effective potentials for electrons in many-electron atoms (Hartree theory and idea of self-consistency); use of Clementi-Roetti wave-functions.
4. One-electron atomic systems in an electromagnetic field; dipole approximation and associated selection rules; Stark and Zeeman effect (Note: Instructor will have to introduce the students to time-dependent perturbation theory here).
5. Einsteins A and B coefficients, population inversion, laser action, derivation of A and B coefficients from semi-classical treatment of light-atom interaction.
6. Molecular formation: Discussion of atom-atom interaction, van der Waals force, ionic interaction and covalent bond.
7. Molecular structure: Hydrogen molecule MO and VB pictures; Importance of correlations.
8. Molecular spectra (restricted to two atom molecules) electronic, rotational and vibrational.
9. Some lectures left for interesting current topics.

References:

1. Elementary Atomic Structure - G.K. Woodgate
2. Atomic Physics: C.J. Foot
3. Atoms, molecules and Photons: W. Demtroder
4. The Theory of Atomic Spectra: Condon and Shortley
5. Topics in Atomic Physics: C.E. Butkhardt and J.L. Leventhal
6. Physics of Atoms and Molecules - B.H. Bransden and C.J. Joachain

P745: Integrated M. Sc-Ph D Computational Lab

1. Representation of numbers on the computer, integers and floating point number, finite precision.
2. Probability and Statistics (probability distributions, connection to stochastic processes like Brownian motion)
3. Statistical description of data: Mean, Variance etc. Statistical inference, Error propagation
4. Solving system of linear equations using Matrix algebra: Gaussian elimination, LU decomposition, evaluation of the Inverse
5. Eigenvalue problem : Power method, inverse iteration, Jacobi/Householder transformations, brief discussion of QR/QL algorithm.
6. Curve fitting : Introduction to least squares, Straight line fitting, General linear and non-linear function fitting.
7. Finding roots of polynomials and transcendental equations.
8. Numerical Differentiation and Numerical Integration.
9. Differential equations - Stability of numerical integration methods, Euler and Runge Kutta Methods.
10. Introduction to solving Partial Differential Equations.
11. Introduction to interpolation and extrapolation methods.
12. Minimisation of functions - golden section search, multivariable minimisation, gradient descent, conjugate gradient methods for quadratic and general functions.
13. Fast Fourier Transforms.

References:

1. Introduction To Error Analysis: The Study of Uncertainties in Physical Measurements, John .R. Taylor
2. Numerical recipes in C : The Art of Scientific computing, Press, Teukolsky, Wetterling and Flannery
3. Matrix Computations, Golub and Van Loan
4. S. D. Cante and C. de. Boor Elementary Numerical Analysis, an algorithmic approach.

Appendix D Elective Courses

P451: Advanced Solid State Physics

1. Introduction to physics of metals and insulators. Electrical, thermal and optical properties of metals and insulators, and need to study excitation spectrum in detail.
2. Electrons, phonons and Magnons, Screening and Plasma Oscillations
3. Charge impurity in a metal: Friedel Oscillation, Magnetic impurity in a metal,
4. moment formation and suppression in metals.
5. Electron gas in Low dimension: impurity and interaction effects.
6. Quantum Hall Effect
7. Metal-Insulator transition
8. Electron - phonon interaction, Frohlich Hamiltonian and Superconductivity.

References:

1. Advanced Solid State Physics: Philip Phillips
2. Elementary Excitations in Solids: D. Pines
3. Solid State Physics: Marder
4. Concepts in Solids: P.W. Anderson
5. Basic Notions in Condensed Matter: P.W. Anderson

P452: Computational Physics

1. Monte Carlo: Markov chain, Metropolis algorithm, Ising Model, Quantum Monte Carlo
2. Molecular Dynamics: Integration methods, extended ensembles, molecular systems
3. Variational methods for SchrodingerdEquation: Hartree and Hartee-Fock methods, Post HF methods
4. Density Functional Theory: Fundamental theorem, XC-potentials
5. Quantum Molecular dynamics: Carr-Parinello approach, hybrid QM/MM method
6. Computational methods for lattice field theories

References:

1. Computational Physics, Joseph Marie Thijssen, Cambridge University Press
2. An Introduction to Computational Physics, Tao Pang, Cambridge University Press
3. M. P. Allen and D. J. Tildesley, Computer Simulation of Liquids, Clarendon Press
4. D. P. Landau and K. Binder, A Guide to Monte Carlo Simulations in Statistical Physics, Cambridge University Press
5. M. Suzuki, editor, Quantum Monte Carlo Methods, Springer-Verlag
6. I. Prigogine and Stuart A. Rice, New Methods in Computational Quantum Mechanics, Wiley.
7. D. Frankel and B. Smit, Understanding Molecular Simulation, second edition, Academic Press.
8. Computational Methods in Field Theory, H. Gausterer and C.B. Lang, Ed.s, Lecture Notes in Physics 409
9. R. G. Parr and W. Yang, Density Functional theory of atoms and molecules
10. F. Jensen, Introduction to Computational Chemistry
11. C. J. Crammer, Essentials of computational chemistry

P453: Quantum Field Theory I

1. Relativistic quantum mechanics - Klein-Gordon equation, Dirac equation, free-particle solutions
2. Lagrangian formulation of Klein-Gordon, Dirac and Maxwell eqns, Symmetries (Noethers theorem), Gauge field, Actions
3. Canonical quantization of scalar and Dirac fields
4. Interacting fields - Heisenberg picture, perturbation theory, Wicks theorem, Feynman diagram
5. Cross-section and S-matrix
6. Quantization of gauge field, gauge fixing
7. QED and QED processes
8. Radiative corrections - self-energy, vacuum polarization, vertex correction
9. LSZ and optical theorem
10. Introduction to renormalization

References:

1. An Introduction to Quantum Field Theory - Peskin and Schroeder
2. Quantum Field theory: K. Huang
3. Quantum Field Theory: Mandl and Shaw
4. Quantum Field Theory: Itzykson and Zuber

P454: Particle Physics

1. Elementary particles, discrete symmetries and conservation laws.
2. Symmetries and Quarks.
3. Klein-Gordon equation, concept of antiparticle.
4. Lorentz symmetry and scalar / vector / spinor fields.
5. Dirac equation
6. Scattering processes of spin-1/2 particles (Feynmans rules as thumb rule QFT course), propagators.
7. Current-current interactions, weak interaction, Fermi theory.
8. Gauge symmetries, spontaneous symmetry breaking, Higgs mechanism
9. Electroweak interaction, Glashow-Salam-Weinberg model.
10. Intoduction to QCD, structure of hadrons (form factors, structure functions), parton model, Deep inelastic sattering.

References:

1. Quarks and Leptons: An Introductory Course in Modern Particle Physics - Francis Halzen, Alan D. Martin
2. Introduction to Elementary Particles, David Griffiths
3. An Introduction to Quantum Field Theory - Peskin and Schroeder

P455: Introduction to Phase transitions and Critical phenomena

Experimental evidences of classical and quantum critical phenomena, thermodynamic potentials. heat capacity, magnetic susceptibility, phases, phenomenol-ogy of 1st order phase transitions, continuous transitions, order parameters and models: Ising, XY, Heisenberg, uni-versality and scaling, Ginzburg-Landau-Wilson theory, spontaneous symmetry breaking. Bose-Einstein condensation,expansion around upper critical dimension, domain walls and surface tension, 1D Ising model and instantons, critical behavior, critical exponents, relations between critical exponents, Kadanoff scaling, universality conjecture, calculation of critical exponents: real space RG methods, Phi- 4 theory, 4- epsilon expansion.?RG of Wilson and Fisher, contin-uous symmetry: Mermin-Wagner theorem. Goldstone modes, non-linear sigma-model, vortices, Kosterlitz-Thouless phase transition, topology and duality, surface roughening and Sine-Gordon models, quantum critical phenomena,dissipative quantum tunneling, quantum phase transitions, Bose-Hubbard model.

References:

1. Introduction to Phase Transitions and Critical Phenomena by H. Eugene Stanley
2. A Modern Approach to Critical Phenomena by Igor Herbut
3. Statistical Physics: Statics, Dynamics and Renormalization by Leo P. Kadanoff
4. The Theory of Critical Phenomena by J. J. Binney, A. J. Fisher, M. E. J. Newman
5. Modern Theory of Critical Phenomena by Shang-keng Ma
6. Statistical Mechanics of Phase Transitions by J. Yeomans
7. Field Theory, the Renormalisation Group and Critical Phenomena by Daniel J. Amit

P456: Nonlinear Optics and Laser

Introduction to general lasers and their types, emission, absorption processes and rate equations, Population inver- sion, gain, optical cavities, three- and four- level lasers, CW and pulsed lasers, Q-switching and mode-locking, Physics of gas discharge, Atomic, Ionic, molecular, liquid, and excimer lasers, optical pumping, Holography, overview of non- linear Optics, nonlinear polarization, Nonlinear optical susceptibility, Symmetry considerations, Wave Propagation in nonlinear media, electro optical and magneto optical effects, higher harmonic generations, Phase matching and quasi phase matching, Sum and difference frequency generation, Optical parametric amplification and oscillation, Kerr ef- fect, Cross-Phase Modulation, Self phase modulation, Multiphoton Processes , Self focusing, Four-Wave Mixing, Laser Spectroscopy, wavefront conjugation Stimulated Raman Scattering, Stimulated Brillouin Scattering, Optical solitons and Optical Pulse Compression

References:

1. Lasers by P.W. Milonni and J.H. Eberly, John Wiley and Sons
2. Lasers by A. E. Siegman, University Science Books
3. Principles of Lasers by Orazio Svelto, Springer Verlag
4. The principles of nonlinear optics by Y. R. Shen, John Wiley and Sons
5. Nonlinear Optics by Robert W. Boyd, Academic Press
6. Nonlinear Optics: Basic Concepts by D.L. Mills, Springer Verlag
7. Optical waves in crystals by Amnon Yariv and Pochi Yeh, Wiley-Interscience
8. Laser Spectroscopy by Wolfgang Demtrder, Springer Verlag

P457: General Relativity and Cosmology

1. Review of Newtonian Mechanics. Special theory of relativity. Prelude to General relativity, historical developments
2. 4-Vectors and 4-tensors, examples from physics
3. Principle of Equivalence, Equations of motion, Gravitational force
4. Tensor Analysis in Riemannian space, Effects of Gravitation, Riemann-Christoffel curvature tensor, Ricci Tensor, Curvature Scalar
5. Einstein Field Equations, Experimental tests of GT
6. Scwartzchild Solution, Gravitational lensing
7. Gravitational waves: generation and detection
8. Energy, momentum and angular momentum in Gravitation
9. Cosmological principle, Robertson-Walker metric, Redshifts
10. Big-Bang Hypothesis, CMB.
11. Issues in Quantum Gravity

References:

1. A first course in General Relativity- B. Schutz
2. Gravity: HJ. Hartle
3. The Classical Theory of Fields: Landau and Lifshitz
4. Gravitation and Cosmology: S. Weinberg
5. Introducing Einstein's Relativity: D'Inverno

P458: Soft Condensed Matter

1. Prerequisite: Introduction to condensed Matter Physics, Statistical Physics
2. What is Soft Condensed Matter: forces, energies and time scales.
3. Phase transition in soft matter, Radial distribution function and description of liquids.
4. Colloids Polymers Gels Liquid Crystals
5. Soft matter in nature

References:

1. Chaikin Lubensky Condensed Matter Physics
2. D. Goldstein: States of Matter
3. Chandler: Statistical Physics (OUP 1987)
4. R A L Jones: Soft Condensed Matter (O U P 2002)
5. Soft Matter Physics: Daoud and Williams (Springer 1999)

P459: Applied Nuclear Physics

1. Basis of Nuclear Structure and reactions
2. Radioactivity and radioactive decays
3. Passage of charged particle through matter
4. Detectors and Accelerators
5. Applications: Effects of radiation on biological systems and nuclear medicine, Industrial applications
6. Power from fission and fusion: Characteristics of fission, Nuclear reactors, Thermonuclear fusion

References:

1. Nuclear Physics : Principles and Applications, John Lilley
2. The Atomic Nucleus, R. D. Evans
3. Fundamentals of Nuclear Reactor Physics, Elmer Lewis, Academic Press
4. An introduction to the passage of energetic particles through matter, N. J. Caron
5. Accelerator Physics, Shyh-Yuan Lee, World Scientific

P460: Many Particle Physics

1. Prerequisite: Statistical Physics, Quantum Mechanics, Introduction to Condensed Matter Physics
2. Second Quantization, One and two body operators
3. Observables and their relationship to one and two body Greens functions
4. Thermodynamic potential, Spectral functions, Analytic properties of Green's functions
5. Linear Response, correlation function, sum rules
6. Canonical Transformation: Bogoliubov Valetin, Schrieffer Wolf, etc.
7. Equation of motion,
8. Diagrammatic Perturbation theory for Green function and thethermodynamic potential, Luttinger Ward Identities.
9. Mean field theory
10. Functional Integration Methods

References:

1. Lifshitz Pitaeviski (Landau Lifshitz Stat Phys Part II)
2. Rickeyzen Greens function for condensed Matter
3. Doniach and Sondhaimer Greens function for condensed Matter
4. Fetter Walecka: Quantum Theory of Man body Particle systems:
5. Ben Simon: Many Particle Physics
6. Basic Notions in Condensed Matter: P.W. Anderson
7. Techniques and application of Path-integration Plan: S. Schulman

P461: Physics of Mesoscopic Systems

1. Prerequisite: Quantum Mechanics1; Statistical Mechanics; Introduction to Condensed Matter Physics
2. Effects of magnetic fields: The AharonovBohm effect; 2D electron gas; Landau levels; Transverse modes in 2D quantum wire; Shubnikovde Haas oscillations; Magnetic edge states; Integer Quantum Hall effect, Fractional Quantum Hall effect
3. Electron transport: Boltzmann semiclassical transport; Onsager reciprocity relations; Conventional Hall effect; Drude conductivity; Einstein relation; Electronic states in quantum confined systems; Conductance from transmission; Ballistic transport; Quantum of conductance; Landauer formula; Quantum point contact; T .matrices; Smatrix and Green functions; Current operator; LandauerButtiker formalism; Linear response and Kubo formula; Nonequilibrium Green's function approach to transport; Scattering: BreitWigner resonance and Fano resonance; Delay time for resonances; Friedel sum rule; Levinson.s theorem; Singleelectron tunneling: Coulomb blockade and Kondo effect
4. Quantum Information: Josephson Junctions and Cubits; Metastable states and escape dynamics
5. Disordered conductors: Weak localization; Mesoscopic fluctuations; Random Matrices; Anderson localization; Quantum Chaos; Dephasing; Decoherence

References:

1. Electronic Transport in Mesoscopic Systems, S. Datta, Cambridge University press.
2. Introduction to Mesoscopic Physics, Y. Imry, Oxford University Press.
3. Mesoscopic Electronics in Solid State Nanostructures, T. Heinzel, WileyVCH.
4. Quantum Transport in Mesoscopic Systems: Complexity and Statistical Fluctuations, P. Mello and N. kumar, Oxford University Press.

P462: Introduction to Quantum Optics

1. Prerequisite: Quantum Mechanics I & 2; Electromagnetism I
2. Electro-magnetic field quantization: Quantum fluctuation and Quadrature operators of a single mode field, Thermal fields, Vacuum fluctuation and zero point energy, Quantum phase
3. Coherent and squeezed states of radiation field: Properties and phase space picture of coherent state, Generation of a coherent state, Squeezed state physics, Generation and Detection of squeezed light, Schrodinger cat states, Multi-mode squeezing, Broadband squeezed light, Squeezing via non-linear process
4. Atom-field interaction: Rabi model (Semi-classical model for atom-field interaction), Jaynes-Cummings model (fully quantum mechanical model for atom-field interaction), Dressed states, Density operator approach, Hanle effect, Coherent trapping, electromagnetically induced transparency, Four wave mixing
5. Quantum coherence function: Photon detection and quantum coherence functions, First order coherence and Young.s type double source experiment, Second order coherence, Physics of Hanbury-Brown-Twiss effect, Experiments with single photon, Quantum mechanics of beam splitter, Interferometry with single photon
6. Optical test of quantum mechanics: Photon sources: spontaneous parametric down-conversion, Hong-Ou-Mandel Interferometer, Superluminal tunneling of photons, EPR paradox and optical test of Bell.s theorem
7. Atom Optics: Mechanical effects of light, Laser cooling, Atom interferometry, Atoms in cavity, Experimental realization of Jaynes-Cummings model
8. Heisenberg-limited interferometry and quantum information: Entanglement and interferometric measurements, Quantum teleportation, Quantum cryptography, An optical realization of some quantum gates.

References:

1. Introductory Quantum Optics, C. C. Gerry and P. L. Knight, Cambridge University Press
2. Quantum Optics, M. O. Scully and M. S. Zubairy, Cambridge University Press
3. Quantum Optics, M. Fox, Oxford Master series in Atomic, Optical and Laser physics
4. Quantum Theory of Light, R. Loudon, Oxford science publication

P464: Plasma Physics and Magnetohydrodynamics

Introduction to plasmas, applications: in fusion, space and astrophysics, semiconductor etching, microwave generation: characterization of the plasma state, Debye shielding, plasma and cyclotron frequencies, collision rates and mean-free paths, atomic processes, adiabatic invariance, orbit theory, magnetic confinement of single-charged particles, two-fluid description, magneto hydrodynamic waves and instabilities, heat flow, diffusion, kinetic description, and Landau damping, ideal magnetohydrodynamic (MHD) equilibrium, MHD energy principle, ideal and resistive MHD stability, drift-kinetic equation, collisions, classical and neoclassical transport, drift waves and low-frequency instabilities, high-frequency micro instabilities, and quasilinear theory.

References:

1. Plasma Physics by Peter Andrew Sturrock
2. Principles of Magnetohydrodynamics by J. P. Hans Goedbloed , Stefaan Poedts
3. Hydrodynamic and Hydromagnetic Stability by S. Chandrasekhar
4. The Physics of Plasmas by T. J. M. Boyd, J. J. Sanderson
5. Fundamentals of Plasma Physics by Paul M. Bellan,
6. Introduction to Plasma Physics by R.J Goldston , P.H Rutherford
7. An Introduction to Magnetohydrodynamics by P. A. Davidson
8. An Introduction to Plasma Astrophysics and Magnetohydrodynamics by M. Goossens

P466: Quantum- and Nano- electronics

Introduction and Review of Electronic Technology, From Electronics to Nanoelectronics: particles, waves and Schrodinger Equation, Quantum Description of atoms and molecules Quantum Description of metals, semiconductors, junction devices, Some newer building blocks for nanoelectronic devices, Fabrication and Characterization Methods for nanoelectronics, The field effect transistor FET: size limits and alternative forms, Devices based on electron tunneling, resonant tunnel diodes, Single electron transistors, molecular electronics, hybrid electronics, Devices based on electron spin and ferromagnetism, Qubits vs. binary bits in a Quantum Computer, Applications of nanoelectronic technology to energy issues, Summary and brief comment on the future of nanoelectronic techniques

References:

1. Quantum Nanoelectronics: An Introduction to Electronic Nanotechnology and Quantum Computing by Edward L. Wolf
2. Quantum Electronics - by Amnon Yariv
3. Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience - by Edward L. Wolf
4. Fundamentals of Nanoelectronics - by George Hanson
5. Introduction to Nanoelectronics: Science, Nanotechnology, Engineering and Applications - by Vladimir Mitin, Viatcheslav A. Kochelap, Michael A. Stroscio

P468: Magnetism and Superconductivity

1. Prerequisite: Solid State Physics, Quantum Mechanics, Statistical Physics
2. Review of atomic/ionic magnetism.
3. Diamagnetism Paramagnetism Ferromagnetism characteristics, Occurrence.
4. Orbital magnetism, de Haas van Alfen effect.
5. Heisenberg Model: Ground state, Spin waves.
6. Hubbard Model and Itinerant exchange.
7. Magnetic domains and hysteresis.
8. The phenomenon of Superconductivity: historical perspective, characteristics, occurrence.
9. London Equations, Thermodynamics, Meissner Effect.
10. Ginzburg Landau Theory, Abrikosov Vortices.
11. Josephson Effect.
12. Cooper Instability, BCS wave function, Gap equation, thermodynamics and magnetic response.
13. Conventional and non-conventional superconductors.

References:

1. Solid State Physics, Neil W. Ashcroft and N. David Mermin
2. Interacting Electrons and Quantum Magnetism , A. Auerbach
3. Magnetism D.C. Mattis
4. Magnetism: R.M. White
5. Superconductivity - Schrieffer
6. Superconductivity - de Gennes
7. Superconductivity - Tinkham

P469: Density Functional Theory of Atoms, Molecules and Solids

Many-body problem: QM of electrons and nuclei, approximation methods for many electron systems, Born-Oppenheimer approximation, Hartree and HF theory, tight binding method, greens functions, electron correlation, CI & many-body and Moller-Plesset theory, complete active space methods, coupled cluster theory, density matrices, time-dependent approach to all the above formalism

Foundations of Density Functional Theory(DFT): Hohenberg-Kohn (HK) theorem, degenerate ground states, variational DFT, $N-$ and $v-$ representability problem, Levy-Lieb constrained search, fractional particle number & derivative discontinuity, spin polarized systems, Exited states part I: Effective Single Particle Picture: Kohn-Sham (KS) construction, non-interacting $v-$ representability, degenerate KS DFT, KS equations for spin polarized systems, interpretation of KS eigenvalues

Exchange-Correlation (XC) Energy Functional: exact exchange formalism within DFT, exact representations of the energy functional, LDA, GGA, meta-GGA, weighted density approximation, self interaction correction (SIC), virial theorems, exact exchange formalism (OPM, KLI, HS), where DFT goes wrong, strengths of DFT, strong correlation: DFT+U, RPA, GW, DFPT, DMFT, orbital free DFT, DFT-hybrid

Crossover to Excited-States: time-dependent DFT: Runge-Gross theorem, time-dependent KS equations, adiabatic LDA & TD XC potentials, linear response TDDFT, Excited states part II, spin polarized TDDFT, frequency dependent XC kernel, TDCDFT, TDOEP, relativistic DFT, molecular orbital theories

References:

1. Density Functional Theory of Atoms and Molecules by Robert G. Parr, Weitao Yang
2. Density functional Theory by R.M. Dreizler, E.K.U. Gross
3. Density Functional Theory by Eberhard Engel
4. Primer in Density Functional Theory by C. Fiolhais, F. Nogueira, Miguel A.L. Marques
5. Fundamentals of TDDFT by Miguel A.L. Marques et al.
6. Time-dependent Density Functional Theory by Miguel A.L. Marques et al.
7. Time-dependent Density Functional Theory by Carsten Ullrich
8. Quantal Density Functional Theory I & II by Viraht Shani

9. Recent Advances in Density Functional Methods (Part I, II & III) by Delano P Chong
10. Atomic and Electronic Structure of Solids - by Ethimios Kaxiras
11. Electronic Structure: basic theory and practical methods by Richard M. Martin
12. Many-Body Quantum Theory in Condensed Matter Physics by H. Bruus, K. Flensberg
13. Quantum Theory of the Electron Liquid by Gabriele Giuliani, Giovanni Vignale
14. Molecular Electronic Structure Theory by T.U. Helgaker, P. Jorgensen, and J. Olsen
15. Electronic Structure Calculations for Solids and Molecules by J. Kohanoff
16. Methods of Electronic Structure Calculations by M. Springborg
17. Self Consistent Fields in Atoms by Norman March
18. Computational Materials Science by J. G. Lee
19. Density Functional Theory in Quantum Chemistry by Takao Tsuneda
20. Material Modeling using DFT by Feliciano Giustino

P470: Quantum Field Theory II

1. Path-integral formulation of quantum mechanics
2. Path-integral for scalar fields, generating functional, connected Greens functions, Feynman rules, 1 loop diagrams
3. Grassmann variable, path-integral for Dirac field
4. Path-integral for Electromagnetic field, gauge fixing
5. QED, symmetries and Ward identity
6. Renormalization divergences and power counting, 4 theory, QED, spontaneous symmetry breaking, Renormalization Group basics (running of coupling).
7. Yang-Mills theory, gauge fixing and ghosts, BRST, asymptotic freedom

P471: Quantum Information and Quantum computation

1. Introduction to Classical information: Shannon entropy, Mutual Information
2. Quantum Information I: Hilbert space, density matrices, quantum entropy and Holevo bound
3. Quantum Information II: Entanglement, Teleportation, super dense coding and Bell inequalities
4. Quantum dynamics:Two level systems, decoherence and Rabi oscillations
5. Quantum computation: single qubit gates-phase, swap, Hadamard; two qubit gates-CNOT
6. Quantum algorithms: Deutsch, Grover, Introduction to Shor's algorithm
7. Quantum error correction
8. Applications: Quantum simulation and Adiabatic quantum computation
9. Solid state quantum information and computation: Introduction to entanglement in nanostructures, quantum computation with superconducting devices and topological quantum computation.

References:

1. V. Vedral, Introduction to Quantum Information Science (Oxford U. Press)
2. Nielsen and Chuang, Quantum Information and Computation (Cambridge U. Press)
3. Kaye, Laflamme, Mosca, An Introduction to quantum computing. (Oxford U. press)

P472a: Experimental High Energy Physics

The interaction of high-energy particles with matter: specific applications related to EHEP.

1. Relativistic kinematics: Detailed derivation of kinematic variables and their transformations whenever needed. Decay kinematics. Rapidity, pseudo-rapidity, spacelike and time-like. Some examples where relativistic kinematics play important role for understanding of data.
2. Detectors in High Energy Physics: General concept of building a HEP experiment, coverage and options, Gas detectors; Semiconductor detector; Scintillator and Cerenkov detectors Specific to EHEP, Calorimeter and Preshower detectors: principle of electromagnetic and hadronic shower generation.
3. Detector Simulation: Need of simulation, various techniques, MC, some general Concepts.
4. Data Analysis in HEP: General approach of data cleanup, calibration, track reconstruction, reconstruction of events
5. Error analysis in EHEP.
6. Computing in EHEP: Basics of OO programming using C++, few applications in EHEPdata analysis.

References:

1. Relativistic Kinematics; A guide to the kinematic problems of High Energy Physics: R. Hagedorn
2. The Experimental Foundations of Particle Physics: R. N. Cahn, G. Goldhaber
3. Techniques for Nuclear and Particle Physics experiments: A How to Approach: W.R. Leo (Springer)
4. Experimental Techniques in Hugh Energy Nuclear and Particle physics: T. Ferbel (World Scientific)
5. Introduction to Experimental Particle Physics : R.C. Fernow
6. Data Reduction and Error analysis for the physical sciences: P. Bevington and D. K.Robinson
7. Data Analysis Techniques for High Energy Physics: R. Frunwirth, M. Regler, R. K. Bock and H. Grote

P472b: Experimental Techniques

1. Mechanical drawing and designs: Basics tools: hand tools, machines for making holes, the lathe, milling machines, grinders, casting; Mechanical drawing, drawing tools, basic principles of mechanical drawing, dimensions, tolerances, from design to working drawings
2. Vacuum technology: gases, gas flow, pressure and flow measurement, vacuum pumps, pumping mechanisms, ultrahigh vacuum, leak detection
3. Optical systems: optical components, optical materials, optical sources Charge particle optics: electrostatic lenses, charged-particle sources, energy and mass analyzer
4. Detectors: optical detectors, photoemission detectors, particle and ionizing radiation detectors, signal to noise ration detection, surface barrier detector.
5. Particle detectors and radioactive Decay: Interactions of charged particles and photons with matter; gaseous ionization detectors, scintillation counter, solid state detectors
6. Electronics: electronic noise, survey of analog and digital I/Cs, signal processing, data acquisition and control systems, data analysis evaluation
7. Nano- and micro-fabrication: various lithography techniques such as photolithography, nanoimprint lithography, e-beam lithography, ion-ball milling
8. Some experiments: SEM, TEM, X-ray diffraction, SQUID Magnetometry, Magnetotransport, PL/CL time resolved spectroscopy, Rutherford Backscattering spectrometry (RBS), RBS-Channeling, UV-VIS-IR spectrometry.

References:

1. The art of Measurement, by Bernhard Kramer, VCH publication
2. Building Scientific apparatus by J. H. Moore et al.
3. Experiments in Modern Physics, Second Edition by Adrian C. Melissinos, Jim Napolitano
4. The art of experimental Physics by Daryl W. Preston,
5. Vacuum Technology, A. Roth North-Holland Publisher
6. Charge Particle Beams, by Stanley Humphries, John Wiley and Sons
7. Principles of charged Particles Acceleration, by Stanley Humphries, John Wiley and Sons
8. Radiation detection and Measurements, G. Knoll, 3rd Edition
9. Techniques for Nuclear and particles physics experiments, W. R. Leo, 2nd edition, Springer

P473: Introduction to Cosmology

1. The cosmic history and inventory.
2. A sketch of General Relativity.
3. The expanding Universe
4. Friedmann Equations and Cosmological Models
5. The Standard cosmological model.
6. The inflationary Universe.
7. Primordial nucleosynthesis and the thermal history of the Universe.
8. Perturbations in an expanding Universe.
9. Growth of perturbations
10. Dark Matter Halos.
11. Statistical description of gravitational clustering
12. Special Topics:
    Fluctuations in the CMB, Lensing, Cluster Cosmology, The Lyman-Alpha Forest, Reionization, Halo Model, Redshift Space Distortions.

References:

1. Introducing Einstein's General Relativity - Ray D'Inverno
2. The Early Universe - Kolb and Turner
3. Introduction to Cosmology - Barbara Ryden
4. Modern Cosmology - Scott Dodelson
5. Principles of Physical Cosmology - P.J.E. Peebles
6. Large Scale Structure of the Universe - P.J.E. Peebles
7. Structure Formation in the Universe - T. Padmanabhan