PHYSICAL SCIENCES

Programme Code: PHYS04

Programme Outcome:

- Manpower development with the ability to apply basic concepts and methods in physics to research problems.
- Training of manpower with the ability to work in interdisciplinary subjects, particularly those in the interface of different disciplines in physics.
- Developing an understanding of modern mathematical methods and using them in the research environment.
- Training of manpower which has the ability to work in diverse areas and adapt to change in professional and national requirements.

Modified one-year Pre-doc Course Structure at IOP

To be implemented from August 2024

- **Introduction**

  Institute of Physics is conducting the Pre-doc courses in the existing format for the last 8 years. According to the New Education Policy (NEP-2020) and guidelines of HBNI, some modifications are needed in the credit system of the courses.

  The proposed modifications are mentioned below

  - According to the New Education Policy (NEP-2020) and circular of HBNI, new guidelines of credit system are “15 Hrs of Class/30 Hrs of Laboratory work= 1 credit”. Accordingly, our current 60 credit IoP Predoctoral course work will be reduced to 30 credit, satisfying the minimum number of credit requirement of 18 credit for the PhD programme.

  - According to this new credit system, our each theory course will be of 45 hours Class room teaching including tutorial (3 credit) and 90 hours Laboratory work (3 credit). The Project work will be of 6 credit (equivalent to two 3 credit courses). Hence, the modified IoP Predoctoral course work will of total 30 credit.

  - The present IoP Predoctoral semester structure and syllabus have been remained unaltered.

DETAILED COURSE STRUCTURE

Semester I (Aug–Dec) (2 core + 3 elective = 15 credits)

Sr No	Course Code	Course Name	Type	Hours	Credits
1	07-PHYS04-101-C	Advanced Quantum Mechanics	Core	45	3
2	07-PHYS04-102-E	Quantum Field Theory I	Elective	45	3
3	07-PHYS04-103-E	Advanced Statistical Mechanics	Elective	45	3
4	07-PHYS04-104-E	Advanced Classical Field Theory	Elective	45	3
5	07-PHYS04-105-E	Many Body Physics	Elective	45	3
6	07-PHYS04-106-E	Soft Condensed Matter Physics	Elective	45	3
7	07-PHYS04-107-E	Advanced Experimental Techniques	Elective	45	3
8	07-PHYS04-108-L	Experimental Physics – Lab Course	Core	90	3

Semester II (Jan–June) (1 core + 2 elective + 1 project = 15 credits)

Sr No	Course Code	Course Name	Type	Hours	Credits
9	07-PHYS04-201-C	Mathematical Methods, Numerical Methods and Research Methodology	Core	45	3
10	07-PHYS04-202-E	Advanced Condensed Matter Physics	Elective	45	3
11	07-PHYS04-203-E	Advanced Nuclear Physics	Elective	45	3
12	07-PHYS04-204-E	Quantum Field Theory II	Elective	45	3

13	07-PHYS04-205-E	High Energy Physics	Elective	45	3
14	07-PHYS04-206-E	Quantum Information and Computation	Elective	45	3
15	07-PHYS04-207-E	Nonlinear Dynamics and Chaos	Elective	45	3
16	07-PHYS04-208-E	Special Topics in Condensed Matter Physics	Elective	45	3
17	07-PHYS04-209-E	Special Topics in High Energy Physics	Elective	45	3
18	07-PHYS04-210-E	Special Topics in Mathematical Methods	Elective	45	3
19	07-PHYS04-211-E	Special Topics in Quantum Mechanics	Elective	45	3
20	07-PHYS04-212-E	Special Topics in Nuclear Physics	Elective	45	3
21	07-PHYS04-213-E	Special Topics in Statistical Physics	Elective	45	3
22	07-PHYS04-214-PR	Project	Core	90	6

Project may be submitted and defended in July, A grand viva in July. Total: 30 credits.

CORE COURSE CO-ORDINATORS

Course	**Coordinators**	**Email**
Advanced Quantum Mechanics	**Prof. Tapobrata Som**	tsom@iopb.res.in
Experimental Physics – Lab Course		
Mathematical Methods, Numerical Methods and Research Methodology		

Project	**Prof. Tapobrata Som**	tsom@iopb.res.in

ELECTIVE COURSE CO-ORDINATORS

Course	Coordinators	Email
Quantum Field Theory I	**Prof. Tapobrata Som**	tsom@iopb.res.in
Advanced Statistical Mechanics		
Advanced Classical Field Theory		
Many Body Physics		
Soft Condensed Matter Physics		
Advanced Experimental Techniques		
Advanced Condensed Matter Physics		
Advanced Nuclear Physics		
Quantum Field Theory II		
High Energy Physics		
Quantum Information and Computation		

Nonlinear Dynamics and Chaos	**Prof. Tapobrata Som**	tsom@iopb.res.in
Special Topics in Condensed Matter Physics		
Special Topics in High Energy Physics		
Special Topics in Mathematical Methods		
Special Topics in Quantum Mechanics		
Special Topics in Nuclear Physics		
Special Topics in Statistical Physics		

SYLLABUS

07-PHYS04-101-C: Advanced Quantum Mechanics (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

- **Review of basics through problem solving**
  Schrödinger equation, Heisenberg Picture, Scattering problem in one dimension, Time independent perturbation theory, Hydrogen atom, Born Approximation. Ladder operators and coherent states.
- **Time-dependent perturbation theory**
  Interaction picture, Time ordered perturbation theory, Fermis Golden rule, Floquet.
- **Relativistic Quantum Mechanics**
  Dirac Equation, Gamma matrices and Lorentz transformation of Dirac wave function, Positive and negative energy solutions and hole theory, Coupling to electromagnetic field, magnetic moment, Klein Paradox. Dirac equation for massless particles, Helicity. Majorana representation, Dirac equation in various space-time dimensions.
- **Path-integral formulation**
  Derivation of Path-Integral representation, Time-ordered correlators in path-integral formulation, coupling to electromagnetic field, Aharonov-Bohm effect, Double well potential in path-integral formulation, Instantons, Tunneling in path-integral formulation. Path-Integral in non-simply connected configuration space.
- **Geometric phase**
  Abelian and non-Abelian Berry phase. Some examples (According to the taste of the instructor), Aharonov-Bohm effect.
- **Discrete Symmetries**
  Wigners theorem, Translation, Rotation, Lorentz Transformation (Group), Parity, charge conjugation and Time-reversal. Kramers degeneracy.
- **Second quantization**
  Indistinguishable particles, Bose and Fermi statistics, Many-body quantum mechanics in the second quantized form, Electromagnetic field in the second quantized formalism, Light Atom interaction.

Course Outcomes:

- Understanding of advanced topics in quantum mechanics like time-dependent perturbation theory, relativistic quantum mechanics, Dirac equation, path-integral formulation etc.

References :

1. Sakurai - Modern Quantum Mechanics
2. Landau-Lifschitz - Quantum Mechanics (Non-relativistic theory)
3. Gottfried-Yan - Quantum Mechanics : Fundamentals
4. Feynman-Hibbs - Quantum Mechanics and Path Integrals
5. Sidney Coleman - Aspects of Symmetry, (Chapter : Uses of Instantons)

07-PHYS04-102-E: Quantum Field Theory-I (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

- **Canonical quantization of free field theory**
  Canonical quantization of free (complex) scalar field. Retarded, Advanced and Feynman propagator. Causality. Normal-ordering of operators. Concept of (connected) multi-point correlation function. Wicks theorem. Canonical quantization of free Dirac field. Feynman Propagator. Wicks theorem for Dirac field. Canonical quantization of electromagnetic field. Feynman Propagator. Casimir effect.
- **Interacting scalar field**
  Interacting scalar field: Perturbative evaluation of correlation functions. Time-ordered perturbation theory. Feynman Diagrams. Calculation of some tree-level amplitudes in phi-4 theory.
- **Path-integral quantization of scalar field theory**
  Derivation of Feynman propagator and Wicks theorem. Path-integral quantization of Maxwell theory. Grassmann numbers and Path-integral quantization of Dirac field. Path integral quantization of interacting scalar field theory: Generating functional of connected correlators and derivation of time-ordered perturbation theory.
- **S-matrix**
  LSZ reduction. Sample calculations of tree-level S-matrix.
- **Symmetries**
  Noether's theorem and Ward identity.
- **Miscellaneous topics**
  Wick rotation. Relation between d-dimensional QFT and (d + 1)-dimensional statistical mechanical system. Introduction to Wilsonian-RG and the concept of effective low energy field theory description.

Course Outcomes:

- Understanding the canonical formalism of quantum field theory.
- Formulation of Dyson series and understanding of scattering processes via Feynman diagram construction for interacting theory.

References :

1. Peskin and Schroeder - An introduction quantum field theory
2. Ramond - Field theory : A modern primer .

07-PHYS04-103-E: Advanced Statistical Mechanics (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

- **Review of Thermodynamics and Statistical mechanics by problem solving**
  a) Quick review of Basic postulates, potentials, Legendre transformation
  b) Basics of Statistical Mechanics: random walk/Probability, Basics of ensembles , Quantum statistics

- **Dynamics**
  Boltzmann H theorem, its use for transport properties Master equation, Langevin Equation, Fokker Planck equation Simple discussions on Detailed balance, fluctuation-dissipation theorem, Onsager relations, Work theorem, Basics of Monte Carlo

- **Classical Interacting systems**
  Phase equilibrium, chemical equilibrium, Saha ionization; variational principle, Debye-Huckel theory; Van der Waals, Virial expansion; equilibrium curves, phase diagrams

- **Phase transitions and critical phenomena**
  First order,continuous transitions; Ising and O(n) models; mean field theory; symmetry breaking, Order parameter; Landau theory (scalar and vector order parameter), Tricritical point, Alexander-McTauge theory; Gaussian model, Ginzburg criterion. Scaling near critical point.

- **Quantum systems**
  Bosons: Details of Bose condensation of an ideal gas and in a harmonic trap Fermions: Chandrasekhar limit, Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect

Course Outcomes:

- Review of thermodynamics, ensemble theory.
- Understanding of density matrix, quantum statistical mechanics.
- Concept building of phase transition and critical phenomena.

References :

1. F. Reif - Fundamentals of Statistical and thermal physics
2. K. Huang - Statistical Mechanics 2nd ed
3. Chaikin-Lubenskly - Principles of condensed matter physics
4. Other books by (a) Pathria, (b) J K Bhattacharjee, (c) Riechl, (d) S.K.Ma, (e) NewmanBarkema

07-PHYS04-104-E: Advanced Classical Field Theory (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

Selected topics from the list

- **Review of Basics Classical Electrodynamics**
  Vector analysis, Electrostatics Boundary-value Problems, Magnetostatics, Electric and Magnetic Fields in matter, Maxwell's Equations, Electromagnetic waves, Retarded Potentials, Relativistic Formulation
- **Classical Electrodynamics**
  Covariant formulation, Dynamics of relativistic particles in electromagnetic fields, Field and radiation from oscillating sources, Scattering and Diffraction, Wave-guides, Radiation by moving charges, Bremsstrahlung, Cherenkov radiation, etc
- **General Relativity**
  Principles of equivalence and general covariance, curvilinear coordinates, affine connection, covariant derivatives, metric, curvature tensors, geodesic equations, Einstein equation, Schwarzschild solutions, black holes, tests of general relativity, big bang theory
- **Hydrodynamics**
  Conservation laws and hydrodynamic description; Navier-Stokes equation for simple fluids; hydrodynamic description of ferro and antiferro magnets.
- **Field theory, Symmetry and Symmetry breaking**
  Landau-Ginzburg theory, order parameter, mean field theory, fluctuations Goldstone theorem, topological defects, solitons in different theories, nonlinear equations, Abelian Higgs model
- **Continuum Mechanics**
  General stress tensor, strain tensor, continuum limit, Hooke's law, Elastic distortions, models for elastic solids, liquid crystals, phonons in continuum

Course Outcomes:

- Understanding of co-variant formulation of classical electrodynamics.
- Formulation and concept building of General Relativity.

References :

1. J. D. Jackson - Classical Electrodynamics
2. L. D. Landau and E. M. Lifshitz - The Classical Field Theory
3. S. Carroll - Space-time and Geometry
4. R. Rajaraman - Solitons and Instantons
5. P. M. Chaikin and T. C. Lubensky, ”Principles of condensed matter physics”

07-PHYS04-105-E: Many Body Physics (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

- **Preliminaries**
  a) First and Second Quantization: Quantum Mechanics with many particles;
  b) First quantization, many particle systems; Operators in first quantization;
  c) Second quantization, basic concepts the occupation number representation;
  d) The general form for second quantization operators; Basis change in second quantization; Examples - Operators for kinetic energy, spin, density, and current; The Coulomb interaction in second quantization.

- **Mean Field Theories**
  a) Non-interacting many particles system vs interacting many particles system. Examples;
  b) Concepts of mean field approximation. Idea of broken symmetry;
  c) Hartree-Fock approximation, Thomas Fermi approximation.;
  d) Hohenberg-Kohn Theorem: Self-consistent Kohn-Sham Hartree-like theory for exact ground state energy and density of electrons; potential for alternative path to include many-electron effects;
  e) Application:
  i) model of ferromagnets, Stoner model of metallic ferromagnets,
  ii) application to BCS theory of superconductivity,
  iii) application to nuclear physics. f) short discussion on the limitations of mean field theories.

- **Method of Green functions**
  a) Single-particle Greens functions of many-body systems: meaning and significance; Greens function of free electrons; The Lehmann representation; The spectral function; Broadening of the spectral function due to interactions; Measuring the single-particle spectral function – spectroscopy; Two-particle correlation functions of many-body systems.
  b) Linear response theory and Kubo formalism for response function.
  c) Imaginary time Greens functions: Matsubara Greens functions; Connection between Matsubara and retarded and advanced Green's functions; Examples: Single-particle Matsubara Greens function; Evaluation of Matsubara sums. Equation of motion for Matsubara Greens functions; Wicks theorem and example of polarizability of free electrons.
  d)Feynman diagrams and Dyson series
  e) Application:
  i) Random impurities in disordered metals.
  ii)Anderson model for magnetic impurities
  iii)Random phase approximation for interacting electron system.
  iv)Application to interacting phonons (i.e beyond the Einstein model of lattice vibrations)

- **Renormalization Group method**
  a) Basic concepts;
  b) Wilsonian Renormalization Group
  c) Perturbative Renormalization Group
  d) Functional (or Exact) Renormalization Group method
  e) Applications.

Course Outcomes:

- Formulation of second quantization for non-interacting and interacting systems.
- Construction of zero temperature and finite temperature Green's function.
- Understanding of approximate methods like mean field theory, perturbation theory to solve many body systems.

References :

1. Many-body quantum theory in Condensed Matter Physics - Karsten Flensberg and Henrik Bruus
2. Condensed Matter Field Theory - Alexander Altland and Ben Simons
3. Introduction to Many Body Physics - Piers Coleman
4. Green functions for solid state physicist - S. Doniach and E. H. Sondheimer
5. Quantum Theory of Many-Particle system - Alexander L fetter and J d Walecka
6. Renormalization methods - W. D. McComb
7. Electronic Structure Calculations for Solids and Molecules-Theory and Computational
8. Methods by Jorge Kohanoff

07-PHYS04-106-E: Soft Condensed matter Physics (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

Selection of topics from the list

- **Basic introduction**
  Structure, scattering and correlation functions various structures and scattering: ordered systems, liquids (classical and quantum), polymers, fractals, glasses. Effective forces: van der Waals to various time-temperature dependent forces Liquid crystals, Polymers, and glass
- **Liquid crystals, Polymers, and glass**
  1) Liquid crystals and colloids: models, phases, and phase diagrams
  2) Polymers: Gaussian (ideal), self-avoiding, semiflexible polymer; scaling and its use; theta point; solutions and melts; topological effects; Response functions (elastic, viscoelastic behavior); Dynamics: single and many chain;
  3) Gels, rubber, percolation.
  4) Introduction to glass transition
- **Generalized elasticity**
  XY model, Liquid crystals, crystals;
- **Hydrodynamic description**
  Conserved quantities, broken symmetry variables, dynamics near phase transitions (critical dynamics, nucleation, spinodal decomposition, phase ordering)
- **Topological and geometrical problems**
  topological defects in ordered systems like liquid crystals Elementary analysis of BKT transition; Fluctuating surfaces, topological invariants

Course Outcomes:

- Understanding of soft matter systems like liquid crystals, polymers, glass etc.
- Concept building in this direction to carry out research.

References :

1. Chaikin-Lubensky: Principles of condensed matter physics
2. Doi-Edwards, Polymer dynamics
3. M Doi, Soft matter physics
4. Richard A. L. Jones, Soft Condensed Matter
5. Review Articles:
6. Gary L Hunter and Eric R Weeks: The physics of the colloidal glass transition Rep. Prog. Phys. 75 (2012) 066501
7. Daan Frenkel, Soft condensed matter, Physica A, Volume 313, Issues 12, 1 October 2002
8. A. Bray, Theory of Phase ordering kinetics, Adv.Phys. 43,357 (1994)
9. 4.R. D. Kamien, Rev Mod Phys. 84, 497 (2012)

07-PHYS04-107-E: Advanced experimental Techniques (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

Introduction to material science from bulk to nano to thin films. A multidisciplinary approach to structure-property relation and overview of few advanced experimental techniques to explore them. This course involves theory and visits to various experimental facilities to provide first-hand experience.

- **Crystallography**
  X-ray Diffraction and scattering, X-ray reflection from interfaces and multilayers, Neutron scattering
- **Optical spectroscopy**
  Raman spectroscopy, Photoluminescence spectroscopy, Infrared spectroscopy
- **Electron spectroscopy**
  Reveling the electronic structure via. Synchrotron radiation, Angle integrated and angle resolved Photoemission spectroscopy, X-ray absorption spectroscopy (XAS)
- **Ion spectroscopy**
  Introduction to particle accelerator, Ion Implantation, Rutherford back scattering (RBS), particle induced x-ray emission (PIXE)
- **Nuclear spectroscopy**
  Basic principles of Resonance spectroscopy and its application: Nuclear magnetic resonance spectroscopy (NMR), electron spin resonance (ESR), muon spin spectroscopy (μSR)
- **Surface Science**
  Growth of thin films and characterization by Scanning tunneling spectroscopy (STM), Atomic force microscopy (AFM), Low energy electron diffraction (LEED), transmission electron microscopy (TEM) scanning electron microscopy (SEM)
- **Transport measurements**
  Understanding magnetic and electronic transport measurements through SQUID-VSM magnetometer, 4 probe resistivity.

Course Outcomes:

- Introduction to the mechanism of modern experimental equipment's and understanding of their basic principle.

07-PHYS04-108-L: Experimental Physics: Lab course (90 Lab Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

5 experiments to be done.

- **Nuclear Radiation Detectors: Semiconductor/gas/scintillation/particle detectors. Their calibrations, identifying unknown source, Identification of spectral features, Attenuation and other experiments, Charged particle spectroscopy,**
- **Vacuum Techniques: Working with vacuum pumps, Pressure and flow measurements, leak detection**
- **Workshop training: using lathe machine for making holes, cutting, casting, drawings.**
- **Transport measurements: Temperature dependence of resistivity, Hall effect, Band gap determination**
- **Surface science experiments: Thin film deposition, investigating surface atomic structure, Scanning tunneling spectroscopy, Scanning electron microscopy.**
- **Electronic experiments, Solving differential equations using Op Amps, Digital electronics using OP Amps, timer etc., Analog to digital conversion &vice versa**
- **Experimental control through computers**
- **X-ray investigation of crystal structure/Laue method**
- **Muon life time measurements.**
- **Possible innovative experiment**

Course Outcomes:

- Acquiring hand to hand training of some modern day experiments in Lab.

07-PHYS04-201-C: Mathematical Methods, Numerical Methods and Research Methodology (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

Topics to be chosen as per interest:

- **Part-I: Mathematical Methods**
  - **Review (Problem solving)**
    Contour integration, analytic continuation, asymptotic expansion, branch cuts and Riemann surfaces, ODE/Special functions/integral representation, distributions (generalized functions)
  - **Integral equations, Partial differential equations**
    Classification of Integral equations: Fredholm (1st, 2nd kind), Volterra; Method of solution in special cases, including Wiener-Hopf method, Numerical methods; Ill-posed problems and regularization. Partial differential equations (beyond what is done in other physics courses): First and second order equations: Classification (hyperbolic, elliptic and parabolic), method of solutions, special equations like KdV, KPZ, Navier-Stokes and others.

References :

1. M. Stone and P. Goldbart, Mathematics for Physics; Arfken;

- **Group theory**
  Introduction to Groups, representations, Lie groups; Applications in quantum mechanics, crystal symmetry, solid state physics.

References :

1. Books By A. W. Joshi, M. Tinkham

- **Probability theory, measure theory and Lebesgue integration**
  Introduction to probability and statistics; Introduction to measure theory and probability as a measure; Integration - Lebesgue- Stieltjes, Lebsgue integrals; Discrete and continuous random variables; Various standard distributions; transformations of probability distributions; Characteristic functions; Law of large number, Tchebyshebv's inequality, central limit theorem, stable laws, large deviation theory; Bayesian inference;

References :

1. P. Halmos: Measure theory; Feller: Probability theory and applications; For Bayesian inference: Udo von Toussaint, Bayesian inference in physics, Rev. Mod. Phys. 83, 943 (2011).

- **Introduction to topology**
  Basic notions of topological space, fundamental and homotopic groups, homology and cohomology; Application in physics, like configuration and phase spaces, path integrals in QM, defects, textures, instantons, etc.

References :

1. Nash and Sen, Topology for physicists; Nakahara: Geometry, topology and physics.

- **Part-II: Numerical Methods**
  - **Introduction to computer languages: (Fortran/C/C++/python etc..) Representation of numbers, Numerical precision and estimation of errors.**
  - **Numerical Interpolation and extrapolations**
  - **Sorting and searching**
  - **Linear Algebra, eigenvalue and eigenvectors**
  - **Root finding algorithms: Bisection method, Newton-Raphsons method, The Secant Method**
  - **Numerical Integration, Quadratures**
  - **Numerical solution to Ordinary and Partial differential equations**
  - **Random number generation, Monte Carlo Simulation**
  - **Data fitting, chi-square fitting, goodness of fit test, Kolmogorov-Smirnov test**

- **Part-III : Research Methodology**
  - **Article writing, communication skills, seminar presentation, review of research papers.**

Course Outcomes:

- Basic review of complex variable theory.
- Understanding of integral equations, group theory.
- Training development in numerical methods and solving physics problems via programme language.

07-PHYS04-202-E: Advanced Condensed Matter Physics (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

Selection of topics

- **The Electron Gas and Liquid**
  a) The electron gas, Hartree-Fock, The fermi liquid and Landau Parameters, The Random phase approximations, strong interaction (Wigner crystals)
  b) Non fermi liquid
  c) interactions in the presence of lattice (Mott insulators)
  d) Electron-Phonon interaction.

- **Reduced Dimensionality**
  a) Quantum Dots,
  b) The special case of 1D, the Landauer formalism for transport,
  c) interactions in 1D: Luttinger liquids
  d) The 2D electron gas, the quantum Hall effect (integer and fractional)
  e) introduction to topological insulators.

- **Physics of Disordered System**
  a) Anderson localization,
  b) Weak localization,
  c) Hopping transport,
  d) The metal insulator transition
  e) interactions in the presence of disorder,
  f) many body localization.

- **Superconductivity**
  a) Preliminaries, conventional vs unconventional superconductivity.
  b) Microscopics of BCS
  theories, gauge symmetry breaking, Josephson effect.
  c) High temperature superconductivity, Cuprate and Pnictides superconductivity, introduction to simple models of High Tc superconductivity.
  d) distinction between s-wave, p-wave, d-wave superconductivity.
  e) heavy fermionic superconductivity.

- **Magnetism**
  a) Basics,
  b) Ferromagnetism and Anti ferromagnetism, spin waves.
  c) Stoner model, t-J Model
  d) Introduction to frustrated magnetism,
  e) Local moments, the Kondo effects and RKKY interactions.
  f) Introduction to heavy Fermionic system, the Kondo lattice.

Course Outcomes:

- Understanding of advanced topics like Mott insulators, Anderson localization, Kondo physics, BCS theory of superconductivity etc.
- Concept building towards theoretical research in quantum condensed matter physics.

References :

1. Karsten Flensberg and Henrik Bruus, Many-body quantum theory in Condensed Matter Physics
2. Philip Philips, Advanced Solid State Physics
3. Majlis, The quantum theory of Magnetism
4. Michael P Murder, Condensed Matter Physics
5. G Mahan, Many Particle Physics
6. P de Gennes, Superconductivity in metal and Alloys
7. D Pines, Elementary Excitations in Solids
8. A. C Hewson, The Kondo Problem to heavy fermions

07-PHYS04-203-E: Nuclear Physics (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

- **Nuclear Physics General**
  NN interaction: symmetries, basics, low energy scattering and shape independence, meson theory and properties of NN interaction, nuclear systematics: masses, radii, shapes, magnetic and quadrupole moments, shell structure, radioactivity, fission, halo nuclei.
- **Nuclear models**
  Liquid drop model, semi empirical mass formula, Fermi gas model, Basics of shell model, Hartree- Fock, pairing, Relativistic mean field formalism for finite and infinite nuclear many body problem (intro.) rotational and vibrational spectra, giant resonances.
- **Nuclear reactions**
  Resonances and compound nucleus, direct reactions (inelastic, stripping, pickup etc.), extracting nuclear information from reactions.
- **Nuclear matter**
  Nuclear equation of state (Relativistic and Non-relativistic Formalisms), neutron stars, Quark models, quark equation of state, relativistic heavy ion collisions, signature of QGP,
- **Big bang and QCD phase transition, hadron and quark, phase transition in neutron stars.**

Course Outcomes:

- Knowledge gathering and understanding of advanced topics in nuclear physics to do research.

References :

1. W. Greiner and J. Eisenberg - Nuclear Models, Vol. I, II and III
2. A. Bohr and B. R. Mottelson - Nuclear Structure, Vol I and II
3. Blatt and Weisskopf - Theoretical Nuclear Physics
4. M. A. Preston and R.K. Bhaduri - Structure of Nucleus
5. B. Muller - Physics of Quark Gluon Plasma
6. Cheuk-Yin Wong - Introduction to High-Energy Heavy-Ion Collision

07-PHYS04-204-E: Quantum Field Theory – II (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

A selection of topics from the following list.

- **Loop calculations in scalar field theory**
  One-loop calculation of 2 and 4-point functions in interacting scalar field theory, Regularization and Renormalization, Renormalization group equation and beta function, Anomalous dimension, Renormalization of composite operators.

- **Renormalization group flow**
  Solution of Callan-Symanzik equation, Classification of fixed points, Multiple couplings and linearized RG-flow in the neighborhood of a fixed point, Various types of asymptotic behavior of QFT, Wilson-Fisher fixed point and introduction to -expansion in large-N vector model.

- **Non-Abelian gauge theory**
  Non-Abelian gauge theory, Path-Integral quantization of non-abelian gauge theories, BRST symmetry, One loop beta function of non-Abelian gauge theory and asymptotic freedom, Introduction to Wilson loop and confinement.

- **Effective action and global symmetry breaking**
  1PI effective action and Coleman-Weinberg potential, Spontaneous global symmetry breaking using 1PI effective potential, Goldstone Boson.

- **Gauge symmetry breaking**
  Spontaneous breaking of gauge symmetry and Higgs mechanism.

- **Anomalies**
  Introduction to anomalies in QFT.

- **Finite temperature field theory**
  Introduction to finite temperature field theory, Coleman-Weinberg effective potential at finite temperature, Symmetry restoration at high temperature.

- **Miscellaneous topics**
  Non-Perturbative techniques in field theory. Solitons and Instantons in field theory.

Course Outcomes:

- Understanding of path integral formulation of quantum field theory.
- Understanding of non-abelian gauge theory and renormalization group.

References :

1. Peskin and Schroeder - An introduction quantum field theory
2. Ramond- Field theory - A modern primer

3. Matthew Schwartz - Quantum field theory and the standard model
4. Weinberg- The quantum theory of fields, Vol-1 and Vol-2.
5. Sidney Coleman - Aspects of symmetry

07-PHYS04-205-E: High Energy Physics (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in-

Course Details:

A selection of topics from the following list.

- **Introduction**
  Broad preview and overview, a bit of discussion of history and current status, basic ingredients of modern theories, colliders and detectors, LHC and main detectors

- **Symmetries and Lie Groups**
  Quantum numbers, conservation laws, discrete and continuous symmetries, Lie groups and algebras, SU(n) and SO(n) groups and representations, Young Tableau, hadron spectroscopy, eight-fold way, quark model

- **S-Matrix, Cross section and Decay rates**
  General discussion, relativistic kinematics, phase space, basic formulas for 2 → 2 scattering and decays into 2 or 3 particles, Feynman rules

- **Gauge Theories and Spontaneous symmetry breaking**
  Construction of gauge theories, discrete symmetry breaking, breaking of global and local continuous symmetries, Goldstone and Higgs phenomena

- **Electromagnetic Interactions**
  Quantum Electrodynamics, Simple processes like Moller Scattering, Bhabha Scattering, Compton scattering, pair annihilation

- **Weak Interaction**
  Fermi theory, V-A theory, C, P and CP violation, muon decay, pion, kaon and B/D-mesons decay, neutrino-electron, neutrino-muon, and neutrino-quark scattering, IVB theory, problems

- **Strong Interaction**
  Deep-inelastic scattering and structure of hadrons, Bjorken scaling, Quark-parton model, sum rules, scaling violation, splitting functions, DGLAP equation, e −e + → hadrons, basic 2 → 2 processes involving quarks and gluons, glimpse of helicity methods

- **Standard Model**
  Motivation for SUc(3) ⊗ SUL(2) ⊗ UY (1) symmetry and its breaking, construction of the action, masses of vector bosons and fermions, CKM matrix and CP violation

- **Basic processes in the Standard Model**
  W/Z boson decays, heavy quark production, neutral-current processes, basic Higgs boson production and decays

- **Beyond Standard Model Scenarios**
  Neutrino oscillations and neutrino mass, standard model shortcomings, effective field theories, anomalous interactions, GUTs, supersymmetry, large extra dimension, etc

Course Outcomes:

- Understanding of symmetries, scattering cross-section calculation and spontaneous symmetry breaking.
- Concept building of Standard model of particle physics, Higgs mass generation to carry out further research.

References :

1. F. Halzen and A. D. Martin - Quarks and Leptons
2. T-P Cheng and L-F li - Gauge Theory of Elementary Particle Physics
3. V. D. Barger and R. J. N. Phillips - Collider Physics
4. V. Barger, D. Marfatia, and K. Whisnant - The Physics of Neutrinos

07-PHYS04-206-E: Introduction to Quantum Information (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

A selection of topics from the following list.

- **Quantum Mechanics Formalism**
  Postulates, density matrix, generalized measurements, qubits, no-cloning theorem
- **Composite Systems**
  Entangled states, partial trace, Schmidt decomposition, purification
- **Quantum Entanglement**
  Detection and quantification of entanglement in bipartite and multipartite systems, monotones, majorization
- **Quantum Operations**
  quantum channels, Kraus representation, quantum noise, master equations, tomography
- **Quantum Nonlocality**
  EPR paradox, Bell inequality, CHSH inequality, Tsirelson bound, PR box, steering, quantum games
- **Quantum Communication**
  superdense coding, teleportation, entanglement swapping, secret sharing
- **Quantum Cryptography**
  One-time pad, BB84, B92, Ekert protocols
- **Quantum Algorithms**
  Universal quantum gates, Deutsch algorithm, Deutsch-Jozsa algorithms, Quantum Fourier transform

Course Outcomes:

- Introduction to the basic formulation of quantum information.
- Concept building in advanced topics of quantum information to carry out future research.

References :

1. M. A. Nielsen and I. L. Chuang - Quantum Computation and Quantum Information
2. J. Preskill - Lecture notes on Quantum Information Theory, Online at Caltech Website
3. M. M. Wilde - Quantum Information Theory
4. A. Peres - Quantum Theory: Concepts and Methods

07-PHYS04-207-E: Non-Linear dynamics and Chaos (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

- **Introduction**
- **One- and two-dimensional systems**
  Fixed points, bifurcation, limit cycles; phase plane analysis; Topological analysis
- **Interacting systems**
  Predator-Prey model/Lotka-Volterra system
- **Specific systems**
  (one or more of the following)
  Enzyme Kinetics (Michaelis-Menten equation)
  Neuron dynamics (Hodgkin-Huxley and FitzHugh-Nagumo models)
  Kinematic waves (Belousov-Zabotinski reaction, traffic flow, Singular perturbation/shocks)
  Travelling waves (Fisher-Kolmogorov problem, kdV equation)
  noisy problems (Edwards-Wilkinson/KPZ problem of surface growth)
- **Chaos**
  Lyapunov exponent, Lorentz equation, Logistic map, fractals
- **Turbulence**
  Elementary introduction to Kolmogorov scaling.

Course Outcomes:

- Introduction to the basic formulation of non-linear dynamics.
- Concept building in advanced topics of non-linear dynamics and chaos to carry out future research.

References :

1. S. Strogatz: Nonlinear dynamics and Chaos
2. J. Murray: Mathematical Biology I, II
3. J. K. Bhattacharjee -Staticial Physics

07-PHYS04-208-E: - 07-PHYS04-213-E:: Special Topics (45 Lectures Hrs)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

These are special courses as per research requirements, may even be research level topics not covered in other courses or topics of current interest.

Course Outcomes:

- Learning and understanding of special advanced topics in any field of physics.
- Concept building and training to carry out research towards the direction of special topic.

07-PHYS04-214-PR: Project (core)

Coordinators: Prof. Tapobrata Som
tsom@iopb.res.in

Course Details:

Each student has to do a project (equivalent to 2 courses) and defend it at the end of the semester.

Course Outcomes:

- Concept building and alignment to carry out research in a particular direction of theoretical/experimental physics.
- Hand to hand training to solve journal papers within a limited time scale.
- Training of writing project report and seminar presentation.
- Understanding of research topic via regular discussion with a project mentor.