Post M Sc (Physics) Course Structure†

1st Trimester (Aug-Nov)	2nd Trimester (Dec-March)	3rd Trimester (April-July)
Research Methodology* (6) **Computational and Numerical Methods * (6)** **Core/Basic Courses Group A* (6)** **Core/Basic Courses Group B* (2 courses x 4)** **Total = 26 Credits**	**Elective #** **(Any 2 courses x 6)** **Project-I* (8)** **Total = 20 Credits**	**Elective #** **(Any 1 course x 6)** **Project –II* (8)** **Total = 14 Credits**
Total = 60 Credits		

†The courses offered in different Trimesters may be adjusted to suit the availability of resources and instructors.

* indicates courses are mandatory.

# indicates courses to be opted for. List of possible courses offered are appended.

- **Course Credits:**
  Course credits are calculated by considering approximately 25 hours of time spent on the given course per week = 1 Credit. Credit assignments are indicated in brackets in the above table.

- **Grade:**
  Grade obtained in each course will be based on performance in home assignments, tutorials and examinations. Pass marks in each subject is 50%. Oral General Comprehensive Examination (OGCE) will be conducted at the end of the 3rd Trimester.

Post Msc (Physics) Syllabus

Compulsory Courses

1. Research Methodology

- **Basic concepts of research:**
  Meaning and importance of Research – Types of Research – Selection and formulation of Research Problem – Research Design

- **Types and methods of research:**
  Classification of research, basic and applied research – similarities and differences, interdisciplinary research, case study, field study, survey of research fields, and methods of research as applied to basic and applied sciences – a few examples.

- **Data Collection and Presentation:**
  Objectives and classification of data, data organization, presentation and interpretation – general concepts and methods, use of computers and related software for data collection, analysis and interpretation.

- **Ethics in Research:**
  General ideas on presentation of scientific research, dissemination of research findings - different methods such as publishing reports, patents and patent rules, presentation of work in conferences, ethics and norms to be followed in presentation of research findings, plagiarism and its consequences, how to avoid plagiarism in scientific research – a few case study.

- **Scientific Report Writing:**
  Basic motivation for writing scientific report, content of a research report – a few case study, methods of preparing research reports, use of computers in preparing reports, quantification of quality of research disseminated through journals or patents.

- **Experimental Methods in Physics:**
  Low temperature techniques and measurements, High vacuum production techniques, handling and related measurements, Radiation detection techniques and measurements, electronics, measurements and data acquisition techniques as applied to experiments, a few selected topics.

- **Attending seminars, colloquia and interaction with the scientists.**

2. Computational and Numerical Methods

- **C programming language:** Overview and basic concepts, data types, flow control, functions, pointers, arrays, structure, inputs / outputs, makefile, libraries, parallelization, concepts of object-orientation.

- **Numerical methods:** Introduction and sources of computational errors**,** solution of non-linear equations (Root finding), solution of system of linear equations, numerical interpolation, numerical differentiation and integration, solution of differential equations, solution of partial differential equations.

- **Data analysis:** Classification of errors, error propagation, basics of Monte Carlo techniques, data interpretation using Bayesian approach.

3. Projects I and II

Research projects during the 2nd and 3rd Trimesters are carried out by the students under the guidance of supervisors, who propose project work based on his / her research areas of expertise. It is generally expected that during or after completion of the projects I and II, the student will get enough experience to identify the research problem for his / her Ph D work.

Core / Basic Courses Group A

1. Quantum Field Theory-I (QFT-I)

Elements of classical field theory, Euler-Lagrange equations, symmetries and Noether's theorem, Lorentz group and its representations, identifying scalar, fermion and vector representations, canonical quantization of scalar fields, path integral quantization of scalar fields, Dirac field, plane wave expansion, quantization, interactions involving scalar and Dirac fields.

2. Basic Experiments

The course is intended for imparting hands-on experience in the laboratories and the related support facilities. The students perform a few experiments in different research laboratories.

Core/Basic Courses Group B

1. Advanced Quantum Mechanics

Basics of Quantum Mechanics (Review focusing on basic concepts), geometric phases, familiarization with geometric quantization, adiabatic Theorem and Berry's Phase, electron in a magnetic field, gauge transformations, Landau levels, path integral approach to Quantum Mechanics, time dependent perturbation theory, theory of scattering, Lorentz Group, Klein-Gordon, Weyl and Dirac Equations, Linear vector spaces (finite and infinite dimensional), linear operators (bounded and unbounded), adjoint, self-adjoint and unitary operators, self-adjoint extension of linear operators, quantization in topologically multiply connected spaces including Bohm-Aharonov effect, particle statistics, the first fundamental group of the configuration space, Braid statistics and quantization of anyonic systems with application to the quantum Hall effect, singular potentials and renormalization with application to lower dimensional nano-systems, anomalies in quantum mechanics, non-equilibrium systems and quantum quenches, composite system, quantum entanglement, density operator, entanglement entropy, quantum computation and quantum information.

2. Advanced Statistical Mechanics

Review of thermodynamics with some emphasis on Gibbs-Duhem relation, Euler relation, Legendre transformations, brief introduction to various ensembles, some applications, quantum statistical mechanics: Bose and Fermi statistics, properties of Bose and Fermi gases at low temperatures, Bose condensation, phase transitions and critical phenomena, including

Landau-Ginzburg theory, scaling and critical exponents, correlation functions, susceptibilities, non-equilibrium statistical mechanics.

3. Mathematical Methods

- Group Theory: General Introduction, Discrete groups and their representations, Lie groups, Young tableaux
- Algebric structures: Algebra of propositions, Example of different structures: Vector space, Field, Ring
- Topology: Metric spaces, Open sets, and continuous functions, Topological spaces, Topological groups.

4. Classical Electrodynamics

Greens function and boundary value problems; 2-dimension boundary value problem with complex analysis, multipole expansion using Greens function, Maxwell's equations and general properties, electromagnetic waves and radiation, need for the special theory of relativity, Lagrangian formulation, relativistic treatment of radiation, vector multipole expansion, static and dynamical Screening in Plasma Physics, collisions between charged particles and energy loss, Magnetohydrodynamics.

Elective Courses

1. Quantum Field Theory-II (QFT-II)

Decay rate and cross-section, calculations involving scalar and Dirac fields, parity, time reversal, charge conjugation, vector fields and gauge symmetries, QED, simple processes in QED, divergences, dimensional regularisation, renormalisation, renormalized perturbation theory, non-abelian gauge theories, standard model Lagrangian.

3. Finite Temperature Field theory

- Quantum Statistical Mechanics: Brief review and need for Thermal Field Theory

- Imaginary Time (Matsubara) Formalism: Connection to imaginary time and Matsubara formalism; Matsubara formalism (Operatorial and Path Integral method); S-matrix, Wick's theorem, Diagrammatic techniques and Feynman rules, Green's function and Propagator, (Anti)Periodicity of the Green's function, Discrete frequencies and their Sums; Extension to non-zero chemical potential.

- Some General Structures in Thermal Environment: Vector and Fermion self-energies and Propagators; Quasiparticle spectra (collective excitations) in Scalar and Gauge Theories; Correlation functions and Spectral functions; Fluctuation-Dissipation theorem, conserved density fluctuations and correlation functions.

- Partition Function and Thermodynamics: Free field theory, interaction (in scalar and gauge theory) and diagrammatic techniques, next to leading order correction in Scalar and Gauge theories.

- Simple Applications of Bare Perturbation Theory: One loop diagrams in Scalar and Gauge theories; Cutting rules and their application to self-energy; Physical interpretation of discontinuities and production of particles; Infrared problems; Dynamical Screening; Damping Rate and Transport Coefficients.

- Improved Perturbation Theory: Problem in bare perturbation theory; Resummation and improved perturbation theory and its application to scalar and gauge theories.

4. Conformal Field Theory

- Introduction: Some basics in Statistical Physics, Ising model and scaling, Mean Field Theory, Real-Space Renormalization Group.
- Conformal Invariance: Introduction to Conformal Invariance, The Free Boson Theory, Conformal Field Theory & Operator Product Expansion, Conformal Invariance, Energy-momentum Tensor and Ward Identities.

- Algebras & Representations: Virasoro Algebra & the Hilbert Space of Conformal Field Theory, Introduction to Minimal Models, Null States & Correlation Functions, Monodromy, Ane Lie Algebras or Current Algebras.

- Some Applications: Partition Functions, A Route to Anti de-Sitter (AdS)/Conformal Field Theory (CFT) correspondence, Conformal Field Theory Techniques in Kondo Problem.

5. Special Topics in String Theory

- Introduction to Holography: Emergence of Gravity, Weinberg-Witten no-go theorem, Black Holes and Black Hole Thermodynamics, The Holographic Principle.

- A Specific Example of Holography: The AdS/CFT Correspondence, The Conjecture with a Bit of String Theory, The Many Avatars of AdS, A Brief Introduction to Conformal Field Theory, Into the Duality Toolbox: Calculating Observables.

- Insights into Many Body Systems: Transport Properties & Hydrodynamics, Condensed-Matter-Inspired Systems, Real-time Dynamics: Physics Out-of-equilibrium.

- Towards Quantum Gravity: Black Hole Information Paradox, Issues with Quantum Gravity.

6. Physics and Astrophysics of Supernovae and Compact Stars

- Supernovae: Introduction to stellar evolution: Hydrogen burning, pp chain and CNO cycle, Helium burning and synthesis of heavier elements and end of fusion chain: formation of iron group elements, Gravitational core collapse, Equation of state, Neutrinos, Shock formation, supernova explosions and birth of compact stars, SN1987, Type I Supernovae, standard candle.

- White Dwarfs: Degenerate pressure of electrons, polytropic equation of state, hydrostatic stability and Lane-Emden equation and structures of white dwarfs, Chandrasekhar mass.

- Neutron Stars: Discovery of neutrons and Landau's prediction of neutron stars in 1932, measurement of masses and radii of neutron stars, Pulsars and Magnetars, neutron star cooling and superfluidity.

- Dense Matter in Neutron Star: Composition of neutron stars, novel phases of dense matter, Hyperon, Bose condensate, quark matter and EoS, Non-relativistic and relativistic models of dense matter, Tolmann-Oppenheimer-Volkoff equation and masses and radii of neutron stars, Quark stars versus neutron stars.

7. General Relativity and Cosmology

Review of Special Relativity, Tensor Analysis, Equivalence Principle, General Covariance, Newtonian Limit, Covariant differential and Riemann tensor, Einstein-Hilbert action and Einstein equations, Schwarzschild solution, Classical tests of General Theory of Relativity, Interior solution and Kerr's solution, Collapse into black hole, Friedman-Robertson-Walker cosmology.

8. Advanced Condensed Matter Physics

Strongly interacting electron systems like Mott insulators, Superconductivity and Superfluidity: BCS theory, introduction to high Tc superconductors, unconventional pairing symmetries for superconductors, superfluidity in Bose-Hubbard model, Gross-Pitaveskii Equation, BCS-BEC crossover in attractive Hubbard model for fermions, Scattering with impurities, Anderson Localisation and Many body Localization, Drude Theory, Electrons as quantum gas, Density of states, properties of electron gas, Metal-Semiconductor contacts, Ohmic contacts, Two dimensional electron gas, scattering mechanism, Transport at low dimension, Coulomb blocked, conductance quantization, Quantum Hall effect, edge state transport, quantum electron optics, fractional quantum Hall effect, Optical properties of semiconductor, join density of states, Kondo impurity problem, Kondo lattice physics and heavy fermions, introduction to topological phases: graphene, topological insulators, Weyl semimetals, Second Quantization, Green's functions, Wick's theorem, Dyson equation, Linear response theory.

9. Advanced Plasma Physics

- Kinetic theory of plasmas: statistical equations for a coulomb plasma, BBGKY hierarchy, Vlasov equation, equilibrium solutions, electrostatic dispersion relations, Landau damping, Vlasov theory of waves in magnetized plasmas.

- Nonlinear phenomena in plasmas: Lagrange methods in plasma dynamics. Kortweg de Vries and Nonlinear Schrodinger equations, modulational instability, solitons, shocks, double layers and sheath structures, BGK modes, ponderomotive force.

- Magnetohydrodynamics: Derivation of MHD equations, pinch effect, pinch devices, concepts of toroidal confinement: tokamak.Grad-Shafranov equation, Rayleigh-Taylor, interchange, kink and sausage instabilities. Stabilizing MHD instabilities.

- Transport phenomena in plasmas: Basic ideas on transport processes, plasma resistivity, diffusion (classical and anamolous), ambipolar diffusion, energy transport. Fokker-Planck equation.

10. Advanced High Energy and Astroparticle Physics

Astroparticle Physics I:
Evolution of the Universe: Large scale isotropy and homogeneity of the Universe; Age of the Universe; Thermal radiation content of the Universe – the Cosmic Microwave Background Radiation (CMBR); the cosmic thermal neutrino background; Abundances of light elements, elementary introduction to Gravity waves, Gravitational wave detectors – LIGO and detection by “chirps”, Fundamental particle interactions in Early Universe, Very Early Universe and Phase Transitions, Standard Model of Particle Physics, Discrete symmetries, Breaking of discrete symmetries and domain wall problem, Symmetry restoration at high temperature, Brief introduction to Supersymmetry, Simple introduction to theories of extra dimension.

Astroparticle Physics II:
Baryonic and Dark Matter (DM); matter-antimatter asymmetry; anisotropies of the CMBR and the (large-scale) structure of the Universe; accelerated expansion of the Universe – the Dark Energy, Standard Model of Cosmology, The Big-Bang scenario – Friedmann-Robertson-Walker (FRW) cosmology; the Standard model of Particle Physics and the thermal history of the Universe – equilibrium thermodynamics in the early universe; Origin of the CMBR; Dark Matter, astronomical and cosmological evidences for Dark Matter; various possible candidates of DM – WIMPs, axions, primordial black holes; the phenomenology and methods of direct detection of WIMP dark matter candidates; indirect detection of dark matter – (high energy) gamma rays, neutrinos, antiprotons, positrons, etc., from dark matter annihilation; various currently operating direct- and indirect detection dark matter search experiments, Neutrinos and Neutrino Oscillation, Flavour eigen states and mass eigenstates and their mixings, CKM mixing matrix and a few selected topics, Neutrino Sources: Natural; Solar neutrinos, Atmospheric neutrinos, Supernova neutrinos, Ultra High Energy (UHE) neutrinos from extra-galactic sources and man-made neutrinos, CP violation in neutrino sector, Neutrinoless double Beta Decay and Leptogenesis.

Astroparticle Physics III: Experimental Aspects
What constitutes Astroparticle Physics? basic ideas, current experimental status, recent results and upcoming experiments in various areas of Astroparticle Physics including Dark Matter, Dark Energy, High Energy Cosmic messengers, Gravitational Waves, Proton Decay, properties of neutrinos, neutrino experiments, Reines & Cowan discovery experiment; upcoming INO, DUNE, Hyper- Kamiokande & JUNO experiments – experimental methods and the basic physics and technology of various kinds of neutrino detectors used in these experiments, basic experimental and detector aspects of some of the major ongoing and upcoming dark matter search experiments.

11. Advanced tools for High Energy Physics and related detectors

Basic ideas and concepts, Python Programming: Basic concepts, Input/output, Exception, Idiomatic usage, Object Oriented Programming, Introspection, Important Libraries, ROOT and its usage, Basic concepts, Root Files and Input/Output, Math Libraries, Histograms, Graphs, Trees, Statistical Analysis, GEANT4 and its usage, Structure of Geant4 C++ Library, Modelling Detector Geometry, Simulation of Passage of Particle through detector material and study of Detector performance.

12. Advanced Nuclear Physics I (Nuclear Structure and advanced nuclear radiation detectors & techniques)

Binding energy and liquid drop model, Nuclear Shell Model: Introduction: basic concepts, Configuration mixing – model space and interaction, Applications and issues in various mass regions, Recent developments and future directions, Collective modes in nuclei: Introduction: basic concepts, Vibrational spectra, Deformation in nuclei: shapes and rotation, Nuclear Physics at the extremes of stability, Nuclear radiation Detectors, Techniques of nuclear radiation detection.

13. Advanced Nuclear Physics II (Nuclear Reactions)

Introduction & Classification of Nuclear Reactions, Kinematics, Energetics (Non Relativistic), Two Body, Three Body Scattering, Elastic, Inelastic Reactions, Direct Reactions-Transfer, Knockout, Breakup, Compound Reactions-Fusion, Evaporation, Fission, Low energy nuclear reactions, Nuclear Astrophysics (Direct & Indirect Methods)

14. Advanced Condensed Matter Physics

Strongly interacting electron systems like Mott insulators, Superconductivity and Superfluidity: BCS theory, introduction to high Tc superconductors, unconventional pairing symmetries for superconductors, superfluidity in Bose-Hubbard model, Gross-Pitaveskii Equation, BCS-BEC crossover in attractive Hubbard model for fermions, Scattering with impurities, Anderson Localisation and Many body Localization, Drude Theory, Electrons as quantum gas, Density of states, properties of electron gas, Metal-Semiconductor contacts, Ohmic contacts, Two dimensional electron gas, scattering mechanism, Transport at low dimension, Coulomb blocked, conductance quantization, Quantum Hall effect, edge state transport, quantum electron optics, fractional quantum Hall effect, Optical properties of semiconductor, join density of states.

15. Materials Science / Nanoscience / Physics of Surfaces and Interfaces

- Physical properties of surface using scanning force microscopy – Atomic Force Microscopy, Frictional Force Microscopy, Magnetic force Microscopy, Atomic Force Acoustic Microscopy / Ultrasonic force microscopy, Near-field Scanning Optical Microscopy (NSOM), Scanning Tunnelling Microscopy, Conducting tip atomic force microscopy.

- Synchrotron radiation and its application in studying surface, interface and nanomaterials, Physics background of synchrotron radiation, different synchrotron components - Bending magnet, undulator, wiggler, RF cavity, characteristics and applications of synchrotron X-rays (GIXRD, GIRX, SAXS, EXAFS, …).

- Magnetism in nanomaterials, d0 magnetism, defect induced magnetism, magnetism arising from surfaces and interfaces, dilute magnetic wide band gap semiconductor, magnetism in carbon based materials, experimental and theoretical models.

- Electrochemical studies of nanomaterial based electrode (Energy storage and sensing devices), Enzymatic and non-enzymatic bio sensors to detect Glucose, uric acid, H2O2 etc., Photo-catalysis and hydrogen generation, Supercapacitors, Experimental techniques to study nanomaterials - Transmission electron microscopy, Scanning electron microscopy, Dynamic light scattering, Raman, IR, UV-Vis.

16. Some Topics on Detection and Measurement of Radiation

Interaction of particles with matter and neutron detectors, Detector basics and gaseous ionization detectors, MWPC, Recent advances in gaseous detectors, Device level simulation of particle detectors, Experimental data analysis using Bayesian approach.